J. Aquat. Plant Manage. 56: 107–112

Evaluation of 12 foliar applied non-aquatic herbicides for efficacy against giant salvinia (*Salvinia molesta*)

BRADLEY T. SARTAIN AND CHRISTOPHER R. MUDGE*

ABSTRACT

Registered aquatic herbicides are frequently used for managing the invasive aquatic fern giant salvinia (*Salvinia molesta* D.S. Mitchell). Unfortunately, there is a limited number of efficacious and economically feasible products available for large-scale management. Therefore, outdoor mesocosm trials were conducted to evaluate nonaquatic registered herbicides for efficacy against giant salvinia. In the first trial, metsulfuron and sulfometuron were the most effective. Both treatments caused plants to become necrotic, lose buoyancy, and desiccate as early as 2 wk after treatment (WAT) and 100% plant mortality was documented by 8 WAT. In addition, clomazone, halosulfuron, and bensulfuron provided 69, 76, and 77% control, respectively. Herbicide treatments that provided $\geq$ 30% control in Trial 1 (with the exception of clomazone) were re-evaluated in Trial 2 at additional rates. All herbicide treatments in Trial 2 significantly reduced giant salvinia biomass compared with the nontreated reference. In addition, all three rates of metsulfuron and sulfometuron provided 98 to 99% control. Although sulfometuron and metsulfuron did not provide 100% giant salvinia control in Trial 2 at 12 WAT, no new frond growth was observed and harvested material consisted of small rhizome fragments that had little to no viability. The results of these studies conclude that giant salvinia is sensitive to low use rates of metsulfuron (21 g ai ha^{-1}) and sulfometuron (158 g ai ha^{-1}) and regrowth of treated plant material is minimal.

Key words: Louisiana, management, mesocosm, metsulfuron, sulfometuron, Texas.

INTRODUCTION

Giant salvinia (*Salvinia molesta* D.S. Mitchell) is a free-floating aquatic fern that originates from Brazil (Jacono 1999, Jacono and Pitman 2001, McFarland et al. 2004). Over the past 80 yr, giant salvinia has spread outside of its native range in South America (Oliver 1993, Jacono and Pitman 2001) to Africa (Mitchell and Tur 1975, Cilliers 1991), India (Cook 1976), Sri Lanka (Room 1990), Southeast Asia (Baki et al. 1990), Australia (Forno and Harley 1979), and the United States (Johnson 1995). The first reported documentation of giant salvinia established in the United States occurred in 1995 in South Carolina (Johnson 1995). Since 1995, it has been found in an additional 11 states including Alabama, Arizona, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, North Carolina, Texas, and Virginia (Thayer et al. 2018).

Giant salvinia exhibits very rapid growth, with plant biomass doubling under greenhouse conditions in only 2.2 d (Cary and Weerts 1983). Conversely, field observations have shown the amount of time for a twofold increase in plant biomass to range from 1 to 8 d (Finlayson 1984, Room 1986). In addition, it forms dense mats made of multiple plant layers that have been documented up to 1 m thick (McFarland et al. 2004). Dense plant growth impedes navigation, irrigation, and recreational use of infested water bodies (Pimentel et al. 1999), leading to not only environmental impacts, but economic impacts and public health concerns (McFarland et al. 2004). These negative impacts have led to situations where giant salvinia needs to be intensively managed to limit its growth and spread to surrounding water bodies.

Small-scale research and large-scale field operations have shown that aquatic herbicides are capable of managing giant salvinia infestations in the United States (McFarland et al. 2004). Currently, 14 active ingredients are registered by the U.S. Environmental Protection Agency (USEPA) for use in or around aquatic sites; however, only 10 have activity on giant salvinia (Table 1) (Nelson et al. 2001, Glomski et al. 2003, Glomski and Getsinger 2006, Mudge and Harms 2012, Mudge et al. 2012, 2013, Glomski and Mudge 2013, Mudge 2016). To date, glyphosate and diquat applications are the most effective for giant salvinia control (Mudge et al. 2016), but other herbicides including carfentrazone-ethyl, flumioxazin, bispyribac-sodium, penoxsulam, and topramezone have demonstrated varying levels of control when applied alone or in combination with other chemistries (Glomski and Getsinger 2006, Mudge and Harms 2012, Mudge et al. 2012, Glomski and Mudge 2013, Mudge 2016, Mudge et al. 2016).

A combination of glyphosate (3.4 kg ae ha^{-1}), diquat (0.5 kg ai ha^{-1}), and two surfactants has been used almost exclusively for giant salvinia control by the Louisiana Department of Wildlife and Fisheries (Mudge et al. 2016) as well as other federal and state agencies in Louisiana and Texas. Despite this combination being effective against giant salvinia, the continuous use of one herbicide or one

First author: Graduate Research Assistant, Louisiana State University School of Plant Environmental and Soil Sciences, Baton Rouge, LA 70803. Second author: Research Biologist, U.S. Army Engineer Research and Development Center, Louisiana State University School of Plant Environmental and Soil Sciences, Baton Rouge, LA 70803. Corresponding author's E-mail: Christopher.R.Mudge@usace.army.mil. Received for publication March 5, 2018 and in revised form April 9, 2018.

Table 1. Registered aquatic herbicides that are efficacious on giant salvinia.

Herbicide	Mode of Action[1]	Application Method
Bispyribac-sodium	ALS inhibitor	Foliar/subsurface
Carfentrazone-ethyl	PPO inhibitor	Foliar/subsurface
Copper	Not classified	Foliar/subsurface
Diquat	Photosystem I inhibitor	Foliar/subsurface
Endothall	Not classified	Foliar/subsurface
Flumioxazin	PPO inhibitor	Foliar/subsurface
Fluridone	Carotenoid biosynthesis inhibitor	Subsurface
Glyphosate	EPSP synthase inhibitor	Foliar
Penoxsulam	ALS inhibitor	Foliar/subsurface
Topramezone	Carotenoid biosynthesis inhibitor	Foliar

[1]Abbreviations: ALS = acetolactate synthase, PPO = protoporphyrinogen oxidase, EPSP = enolpyruvyl shikimate-3-phosphate.

Table 2. Herbicide rates (g ai ha^{-1}) applied to the foliage of giant salvinia and the number of weeks until plants documented ≥ 25% visual injury in herbicide screening Trial 1.

Herbicide Treatments	Rate[1] g ai ha^{-1}	≥ 25% Visual Injury WAT
Bensulfuron	70	2
Clomazone	1,393	2
Flumiclorac	60	1
Glufosinate	882	1
Halosulfuron	290	2
Metsulfuron	42	2
Florpyrauxifen-benzyl	117	N/A
Rimsulfuron	35	N/A
Saflufenacil	150	1
Sethoxydim	526	N/A
Sulfometuron	315	2
Trifloxysulfuron	21	3

[1]Abbreviations: WAT = weeks after treatment, N/A = not applicable; indicates that plant injury never exceeded 25%.

spray mixture will be detrimental if giant salvinia were to develop resistance to either herbicide in the future (Mudge et al. 2016). Although herbicide resistance in aquatic weed management has been limited to fluridone-resistant hydrilla (*Hydrilla verticillata* L.f. Royle) (Michel et al. 2004) and diquat-resistant landoltia duckweed [*Landoltia punctata* (G. Meyer) D.H. Les and D.J. Crawford] (Koschnick et al. 2006), over 250 herbicide-resistant plant species have been documented globally at a rate of 11 new cases per year (Heap 2014, Heap 2017). Best management practices that promote the rotation of herbicides are encouraged to decrease the chances of establishing resistant plant populations. As a result of the overuse of two active ingredients and a limited number of efficacious aquatic herbicides, it is important to evaluate other potential chemistries (i.e., herbicides with different modes of action) and/or nonaquatic herbicides.

Herbicide screenings for giant salvinia have been limited because it is considered a regional weed compared with more widespread invasive aquatic species such as hydrilla and Eurasian watermilfoil (*Myriophyllum spicatum* L.). Regional weed problems represent a small market for the herbicide industry and essentially it is not economically beneficial to develop new chemistries for a regional weed species. Products including bispyribac, carfentrazone, flumioxazin, imazamox, penoxsulam, and topramezone were screened, developed, and registered for aquatic use after fluridone-resistant hydrilla was discovered in the late 1990s (Haller 2011, Haller and Gettys 2017). Therefore, the objectives of this research were to 1) evaluate the efficacy of 12 non-aquatic herbicides against giant salvinia and 2) further evaluate products that provided > 30% control at additional rates.

MATERIALS AND METHODS

Two outdoor mesocosm trials were conducted and repeated at the Louisiana State University (LSU) Aquaculture Research Facility in Baton Rouge, LA in 2016 (July and September) and 2017 (May and August). In Trial 1, the efficacy of 12 herbicides not registered for aquatic use was evaluated against giant salvinia. In Trial 2, herbicides that provided at least a 30% reduction of giant salvinia biomass in trial 1 (excluding clomazone) were re-evaluated at additional rates. Giant salvinia used in this research was collected from cultures maintained at LSU Aquaculture.

In both trials, plants were cultured in 76-L plastic containers (49.5 cm diam by 58.4 cm height) filled with 60 L of pond water (pH 8.5). Before planting, pond water was amended with sphagnum peat moss (14 g) to lower the pH to < 7.0. Equal amounts of fresh plant material, enough to cover approximately 85% of the water surface, were placed in each 76-L container. In addition, 2.1 g of Miracle-Gro®[1] water-soluble lawn food (24–8–16) was applied to each container at planting and every 2 wk throughout both trials to encourage plant growth. Plants were allowed to acclimate to container conditions for 2 wk before herbicide application. At herbicide application, plants had reached ca. 100% coverage, with mean dry weights of 33.76 ± 1.59 and 28.72 ± 2.03 g for trials 1 and 2, respectively. Culture and planting techniques were adapted from previous giant salvinia research (Nelson et al. 2007, Mudge et al. 2012, Mudge et al. 2016).

Herbicides evaluated during trials 1 and 2 included acetolactate synthesis inhibitors (ALS): bensulfuron,[2] halosulfuron,[3] metsulfuron,[4] rimsulfuron,[5] sulfometuron,[6] trifloxysulfuron;[7] protoporphyrinogen oxidase inhibitors (PPO): saflufenacil[8] and flumiclorac;[9] carotenoid biosynthesis inhibitor: clomazone;[10] glutamine synthesis inhibitor: glufosinate;[11] synthetic auxin: florpyrauxifen-benzyl[12] (4-amino-3-chloro-6-[4-chloro-2-fluoro-3-methoxyphenyl]-5-fluoro-pyridine-2-benzyl-ester); and acetyl CoA carboxylase inhibitor: sethoxydim[13] (Tables 2 and 3).

All herbicides were applied at maximum application rates on the basis of the USEPA Section 3 label in their respective use sites (i.e., row crops, horticulture, turf, right-of-way, etc.) for trial 1 and additional rates in Trial 2. Each treatment included a modified vegetable oil and nonionic organosilicone surfactant blend[14] at 0.25% v/v. A nontreated reference was also included. A completely randomized design was utilized, with four replicates per treatment. Herbicide treatments were applied to the foliage of giant salvinia using a CO_2-powered sprayer at an equivalent of 935 L ha^{-1} diluent delivered through a single TeeJet®[15] 80-0067 nozzle at 20 psi. All viable plant biomass was harvested

Table 3. Herbicide rates (g ai ha^{-1}) applied to the foliage of giant salvinia and the number of weeks until plants documented $\geq$ 25% visual injury in herbicide screening Trial 2.

Herbicide Treatments	Rate g ai ha^{-1}	> 25% Visual Injury WAT[1]
Bensulfuron	70	3
	140	3
Halosulfuron	289	3
	578	2
Metsulfuron	21	3
	42	3
	84	2
Saflufenacil	300	1
Sulfometuron	158	3
	315	2
	630	2
Trifloxysulfuron	42	3

[1]Abbreviation: WAT = weeks after treatment.

12 wk after treatment (WAT), dried to a constant weight (65 C), and recorded as grams of dry weight biomass. Dry weight data from each trial were subjected to an analysis of variance using Proc Glimmix procedure in SAS® version 9.4 (2017) statistical software with trial replicates as a random effect. Means were separated using Fishers Protected LSD test ($P \leq 0.05$).

RESULTS AND DISCUSSION

The nonaquatic herbicides evaluated as foliar applications against giant salvinia provided a variety of injury symptoms. In trial 1, injury to giant salvinia from saflufenacil, flumiclorac, and glufosinate resulted in chlorosis and necrosis to giant salvinia less than 1 WAT. Despite saflufenacil and flumiclorac having the same mode of action (PPO inhibitors), saflufenacil resulted in faster injury symptoms than flumiclorac. Although rapid plant injury was documented with the aforementioned products, plant recovery was evident 2 WAT, and all three herbicide treatments failed to provide > 35% control 12 WAT (Figure 1).

Clomazone-treated plants exhibited bleaching and chlorosis < 2 WAT, with peak visual injury observed 5 WAT. Halosulfuron and bensulfuron treatments exhibited chlorosis of existing fronds and growth reduction of newly formed fronds 2 WAT; plants were necrotic by 4 WAT. Unfortunately, plant recovery was documented $\leq$ 6 WAT and was very noticeable by the conclusion of the 12-wk study in clomazone, halosulfuron, and bensulfuron treatments, which resulted in 69, 76, and 77% control, respectively. Florpyrauxifen-benzyl caused short-term and minimal visible injury ($\leq$ 10%), with newly formed fronds appearing slightly stunted 3 WAT; however, no injury symptoms were visible at 5 WAT. Sethoxydim and rimsulfuron treatments did not produce any visible injury symptoms and dry weight biomass was not significantly different from reference treatments at the conclusion of trial 1. Metsulfuron and sulfometuron were the most effective treatments and provided 100% control of giant salvinia at the end of the 12-wk study (Figure 1). Both treatments caused plants to become necrotic, lose buoyancy,

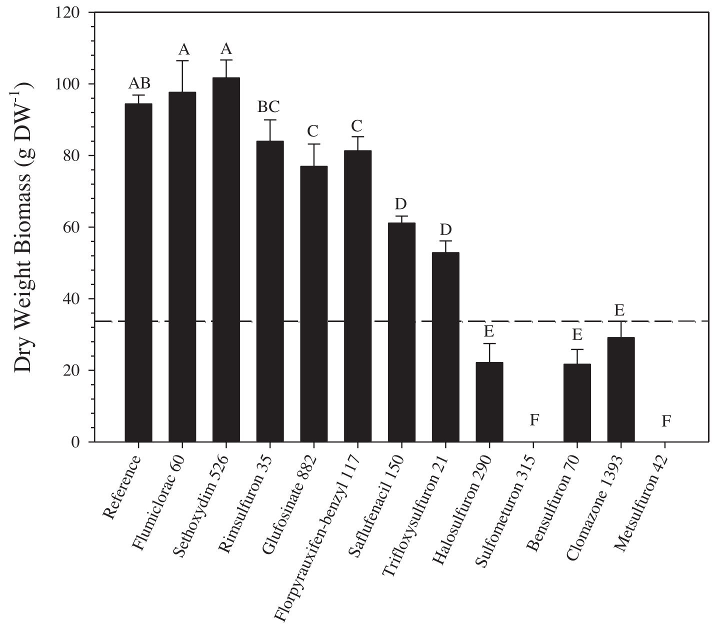

Figure 1. Dry weight biomass (mean ± SE) response of giant salvinia 12 wk after treatment with foliar-applied nonaquatic herbicides in Trial 1. Bars sharing the same letter are not significantly different according to Fisher's Protected LSD test; $P \leq 0.05$; $n = 8$. Horizontal dashed line represents pretreatment biomass. Numbers following the treatment represent g ai ha^{-1}.

and desiccate as early as 2 WAT. At 6 WAT, $\geq$ 85% of the plant material fell below the water surface and deteriorated, and by 7 WAT only a few small chlorotic and necrotic fronds remained at the water surface. By 8 WAT, 100% plant mortality was documented for both treatments.

Because of the level of control provided by bensulfuron, halosulfuron, metsulfuron, saflufenacil, sulfometuron, and trifloxysulfuron, these products were further evaluated in trial 2 at additional rates. All herbicide treatments in trial 2 reduced giant salvinia biomass 53 to 99%, in comparison with the nontreated reference 12 WAT (Figure 2). The 2× rate of saflufenacil (300 g ai ha^{-1}) in trial 2 provided better control (89%) compared with trial 1 (31%, 150 g ai ha^{-1}); however, plant recovery was observed 3 WAT. The 2× rate of trifloxysulfuron in trial 2 provided 53% control, which was modestly higher than the 44% control observed in trial 1. There were no differences in plant response between plants treated with the 1× or 2× rate of bensulfuron or halosulfuron in trial 2, with each providing 92 to 96% control, respectively. All three rates of metsulfuron and sulfometuron provided 98 to 99% control.

Saflufenacil (trial 1 and 2) and flumiclorac (trial 1) performed similarly to the contact herbicides flumioxazin and carfentrazone, which are also PPO-inhibiting herbicides currently registered for aquatic use by the USEPA (Netherland 2014). Flumioxazin and carfentrazone are efficacious when applied to the foliage of giant salvinia (Glomski and Getsinger 2006, Richardson et al. 2008); however, regrowth frequently occurs, especially when multiple plant layers are present (Mudge et al. 2016). These previous findings (Mudge et al. 2016) are similar to observations documented in the

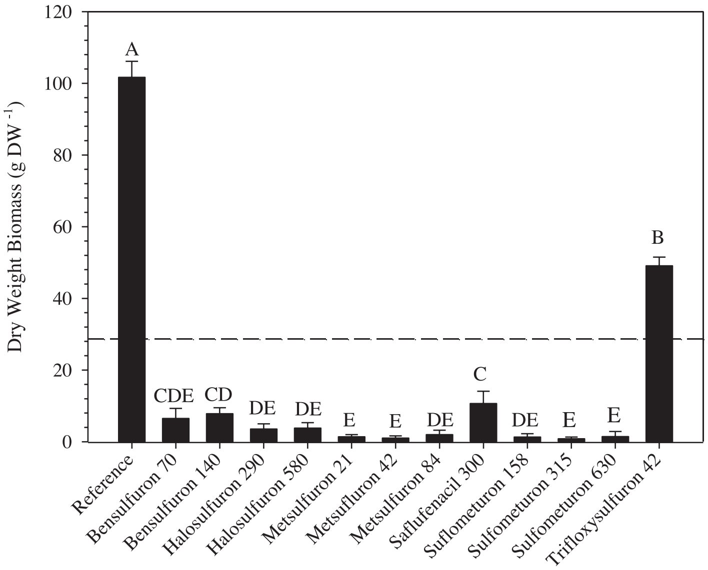

Figure 2. Dry weight biomass (mean ± SE) response of giant salvinia 12 wk after treatment with foliar-applied nonaquatic herbicides in Trial 2. Bars sharing the same letter are not significantly different according to Fisher's Protected LSD test; $P \leq 0.05$; $n = 8$. Horizontal dashed line represents pretreatment biomass. Numbers following the treatment represent herbicide rates in g ai ha^{-1}.

current studies with saflufenacil- and flumiclorac-treated plants, documenting recovery ≤ 3 WAT.

Clomazone, halosulfuron, and bensulfuron are currently registered by the USEPA and labeled for use in several row crops for control of broadleaf weeds, sedges, and grass species (Shaner 2014). Giant salvinia exposed to bensulfuron and halosulfuron documented typical ALS herbicide symptomology. Fronds that developed after herbicide application appeared crinkled, stunted, and chlorotic, whereas older fronds gradually became necrotic, lost buoyancy, and deteriorated. These injury symptoms are similar to the registered aquatic herbicide penoxsulam, which is also an ALS inhibitor that is efficacious against giant salvinia as a foliar or subsurface application (Mudge et al. 2012). Bensulfuron has previously been documented as efficacious against fern species. Toxicity tests of bensulfuron against the aquatic ferns *Salvinia natans* (L.) All., *Azolla japonica* Franch. & Sav., and *Marsilea quadrifolia* (L.) indicated an estimated dose to kill 50% of the test population of less than 1/20th the recommended application rate (51 to 75 g ai ha^{-1}) for bensulfuron in Japanese rice paddy fields (Aida et al. 2004). Although clomazone efficacy was observed in trial 1, it was excluded from trial 2 because of potential volatility issues and off-site injury of sensitive plants (Mervosh et al. 1995) that may decrease the probability of achieving an aquatic label for giant salvinia control.

It is evident from the results of these screenings that sulfometuron and metsulfuron are highly efficacious against giant salvinia. Both treatments provided noticeable visual injury symptoms ≤ 2 WAT and 98 to 100% plant control as early as 8 WAT across all the rates evaluated. Although sulfometuron and metsulfuron did not provide 100% giant salvinia control in trial 2, no new fronds were observed and harvested material consisted of small rhizome fragments that had limited viability.

Sulfometuron is registered for use in conifer and hardwood sites for the control of annual and perennial broadleaf and grass species, and late fall/early winter applications in unimproved turf sites (Shaner 2014). Sulfometuron activity on nonaquatic fern species has been previously documented. Horsley (1988) reported 100% control of hay-scented fern [*Dennstaedtia punctilobula* (Michx.) Moore] and New York fern [*Thelypteris noveboracensis* (L.) Nieuwl.] 2 yr after applications of sulfometuron at 102, 204, and 408 g ai ha^{-1}. In addition, sulfometuron and tank mixes of sulfometuron + glyphosate have been successfully implemented to reduce hay-scented fern densities in forested areas of the northeastern United States (Fei et al. 2010).

Metsulfuron is registered for control of broadleaf weeds in grain crops, pasture grass species (Shaner 2014), turf grass, and brush control (Bayer 2017a). In addition, metsulfuron can be applied under the authority of a Federal Insecticide, Fungicide, and Rodenticide Act Special Local Need (SLN) 24(c) label to control Old World climbing fern [*Ligodium microphyllum* (Cav.) R. Br; OWCF] and for use in lake restoration projects in dewatered zones of lakes in Florida (Bayer 2017b, 2017c). The efficacy of metsulfuron on OWCF subsequently led to the testing of metsulfuron on giant salvinia in the current herbicide screening trials. Langeland and Link (2006) documented 100% control of OWCF with foliar applications of metsulfuron at 40 and 80 g ai ha^{-1}, which is comparable with the results of trials 1 and 2 in the current research.

Nontarget injury to native aquatic plants is also a major concern when managing infestations of invasive weeds. Hutchinson and Langeland (2008) documented several broadleaf wetland plants sensitive to applications of metsulfuron; however, sand cord grass (*Spartina bakeri* Merr.), soft rush (*Juncus effusus* L.), swamp lily (*Crinum americanum* L.), and buttonbush (*Cephalanthus occidentalis* L.) were more tolerant to applications ≤ 42 g ai ha^{-1}. Chiconela et al. (2004) reported no significant effects on torpedograss (*Panicum repens* L.), knotgrass (*Paspalum distichum* L.), paragrass [*Urochloa mutica* (Forssk) T.Q. Nguyen], or softstem bulrush [*Schoenoplectus tabernaemontani* (C.C. Gmel.) Palla] at metsulfuron rates ≤ 70 g ai ha^{-1}, but pickerelweed (*Pontederia cordata* L.) and arrowhead (*Sagittaria lancifolia* L.) were negatively affected. It should be noted that the majority of giant salvinia infestations in Louisiana and Texas are vast monotypic mats that have negatively affected infested water bodies for nearly 2 decades (A. Perret, personal comm. 2017). Thus, any negative impacts of metsulfuron applications to co-occurring native aquatic plant species would likely be minimal when targeting giant salvinia.

This research provides the first documentation of metsulfuron and sulfometuron efficacy on giant salvinia, and that giant salvinia is sensitive to low use rates of metsulfuron (21 g ai ha^{-1}) and sulfometuron (158 g ai ha^{-1}), with minimal regrowth of treated plant material. Sulfometuron is classified as general-use herbicide with an acute and chronic toxicity of low to very low for rats (oral 50% lethal dose [LD_{50}] > 5,000 mg kg^{-1} body weight) and a 96-h 50% lethal concentrationl (LC_{50}) > 12.5 mg L^{-1} in bluegill (*Lepomis macrochirus*) and rainbow trout (*Oncorhychus mykiss*) (Shaner 2014). Hydrolysis and photolysis are two degradation pathways of sulfometuron in aquatic environments. Harvey et al. (1985) reported sulfometuron to readily hydrolyze at pH 5.0 (half-life ~ 2 wk) compared with pH 7 and pH 9, where it remained stable throughout the 30-d test period. Harvey et al. (1985) also reported the photolytic half-life of sulfometuron to be in the order of 1 to 3 d.

The acute and chronic toxicity of metsulfuron is also classified as low to very low for rats (LD_{50} > 5,000 mg kg^{-1}) and bluegill sunfish (96-h LC_{50} > 150 mg L^{-1}) (Bayer 2015). Although metsulfuron has low toxicity to aquatic fauna, its persistence in aquatic habitats could be a concern. Common degradation pathways in sulfonylurea herbicides include chemical hydrolysis and microbial degradation (Beyer et al. 1988), with degradation decreasing under alkaline conditions. Typically, in an aquatic habitat, pH is generally at or slightly above neutral (pH 7). Sarmah et al. (2000) reported metsulfuron hydrolysis to be most rapid below pH 6.2 (half-life 9.6 d) and above pH 10.2 (half-life 11.2 d); however, it remained relatively stable at pH 7 to 9. Thompson et al. (1992) reported metsulfuron at 10 μg L^{-1} to have an estimated DT_{50} (time required for 50% of the pesticide concentration to dissipate) of 29 d in natural waters (pH 6.7 to 7.3), which is more rapid than the 33-d hydrolytic half-life reported by Beyer et. al. (1988) at pH 5 (25 C). This suggests that other mechanisms may be affecting metsulfuron dissipation in natural waters (Thompson et. al. 1992). Sulfometuron is highly susceptible to photolysis, with a DT_{50} of 3 d (Harvey et al. 1985), and considering the structural similarities of metsulfuron and sulfometuron, it is reasonable to expect similar photolytic degradation between the two products (Thompson et al. 1992), although this degradation mechanism has been previously reported as insignificant in the environmental dissipation of metsulfuron (Beyer et al. 1988).

The lower toxicity to nontarget aquatic organisms, its efficacy on giant salvinia, and the SLN label already available in Florida make metsulfuron a more suitable potential candidate for registration as an aquatic herbicide or SLN label in Louisiana and Texas, where giant salvinia infestations are spreading annually. The SLN label in Florida for controlling OWCF allows applications in/on freshwater marshes (sloughs, wet prairies, and sawgrass marshes), floodplains, swamps, and Everglades tree islands (Bayer 2017b). This landscape is similar to giant salvinia-infested areas of Louisiana and Texas. Future research should examine efficacy toward additional nontarget vegetation and its persistence in natural waters. In addition, alternative application techniques such as in-water injection treatments and lower use rates ≤ 21 g ai ha^{-1} should be examined.

SOURCES OF MATERIALS

[1]Miracle-Gro® Lawn Fertilizer, The Scotts Company, P.O. Box 606, Marysville, OH 43040.

[2]Londax®, RiceCo LLC, 5100 Poplar Ave., Suite 2458, Memphis, TN 3817.

[3]Halomax™, Aceto Agricultural Chemicals Corporation, 4 Tri Harbor Ct., Port Washington, NY 11050.

[4]Cimarron® Max part A, E.I. du Pont de Nemours and Company, 1007 Market St., Wilmington, DE 19898.

[5]TranXit®, E.I. du Pont de Nemours and Company, 1007 Market St., Wilmington, DE 19898.

[6]Oust® XP, E.I. du Pont de Nemours and Company, 1007 Market St., Wilmington, DE 19898.

[7]Envoke®, Syngenta Crop Protection LLC, P.O. Box 18300, Greensboro, NC 27419-8300.

[8]Sharpen®, BASF Corporation, 26 Davis Dr., Research Triangle Park, NC 27709.

[9]Resource®, Valent U.S.A. Corporation, P.O. Box 8025, Walnut Creek, CA 94596-8025.

[10]Command® 3ME, FMC Corporation, Agriculture Products Group, Philadelphia, PA 19103.

[11]Liberty®, Bayer CropScience LP, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.

[12]Procellacor™ EC, SePro Corporation, 11550 N. Meridian St., Suite 600, Carmel, IN 46032.

[13]Poast®, BASF Corporation, 26 Davis Dr,, Research Triangle Park, NC 27709.

[14]Turbulence™, Winfield Solutions LLC, P.O. Box 64589, St. Paul, MN 55164.

[15]TeeJet®, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60187.

ACKNOWLEDGEMENTS

This research was funded by the Aquatic Plant Management Society, LSU AgCenter Vice President for Agriculture Assistantship, and the Louisiana Ag Consultants Ray and Dorothy Young Endowed Assistantship. The authors also thank Dr. Ronald Strahan and Matt Foster for providing herbicides used for screening, the U.S. Army Engineer Research and Development Center for project support, and Nick Firmin and Trista Gallivan for their assistance conducting these trials. Permission was granted by the Chief of Engineers to publish this information. Citation of trade names does not constitute endorsement or approval of such commercial products.

LITERATURE CITED

Aida M, Itoh K, Ikeda H, Harada N, Ishii Y, Usui K. 2004. Susceptibilities of some aquatic ferns to paddy herbicide bensulfuron methyl. Weed Bio. Manage. 4:127–135.

Baki BB, Lim GS, Sastroutmo SS, Yusof O, Ridzuan IM, Juilien MH. 1990 Biological control of *Salvinia molesta* Mitchell with *Cyrtobagous salviniae* Calder and Sands: Malaysian experience. Proc. Eur. Weed Res. Soc. Int. Symp. Aquat. Weeds 8, 23 pp.

Bayer 2015. Escort® XP herbicide safety data sheet. Bayer CropScience. Research Triangle Park, NC. http://www.cdms.net/ldat/mpCFM001.pdf. Accessed October 10, 2017.

Bayer. 2017a. Bayer Escort® XP herbicide label. Bayer Environmental Science, Bayer CropScience LP. Research Triangle Park, NC. http://www.cdms.net/ldat/ldCFM000.pdf. Accessed February 23, 2018.

Bayer. 2017b. Bayer Escort® XP herbicide label. Bayer Environmental Science, Bayer CropScience LP. Research Triangle Park, NC. http://www.cdms.net/ldat/idCFM006.pdf. Accessed October 10, 2017.

Bayer. 2017c. Bayer Escort® XP herbicide label. Bayer Environmental Science, Bayer CropScience LP. Research Triangle Park, NC. http://www.cdms.net/ldat/idCFM005.pdf. Accessed October 10, 2017.

Beyer EM, Duffy MJ, Hay JV, Schlueter DD. 1988. Sulfonylurea herbicides, Volume 3, Chapter 3. In: P. C. Kearney and D. D. Kaufman (*eds*.). Herbicides: Chemistry, degradation, and mode of action. Dekker, New York.

Cary PR, Weerts PGJ. 1983. Growth of *Salvinia molesta* as affected by water temperature and nutrition. I. Effects of nitrogen level and nitrogen compounds. Aquat. Bot. 16:163–172.

Chiconela T, Koschnick TJ, Haller WT. 2004. Selectivity of metsulfuron-methyl to six common littoral species in Florida. J. Aquat. Plant Manage. 42:115–116.

Cilliers CJ. 1991. Biological control of water fern, *Salvinia molesta* (Salviniaceae), in South Africa. Agric. Ecosyst. Environ. 37:219–24.

Cook CDK. 1976. Salvinia in Kerala, S. India and its control, pp 241–243. In: C. K. Varshney and J. Rzoska (*eds.*). Aquatic weeds in South East Asia. Junk Publ., The Hague, Netherlands.

Fei S, Gould P, Kaeser M, Steiner K. 2010. Distribution and dynamics of the invasive native hay-scented fern. Weed Sci. 58:408–412.

Finlayson CM. 1984. Growth rates of *Salvinia molesta* in Lake Moondarra, Mount Isa, Australia. Aquat. Bot. 18:257–262.

Forno IW, Harley KLS. 1979. The occurrence of *Salvinia molesta* in Brazil. Aquat. Bot. 6:185–187.

Glomski LM, Getsinger KD. 2006. Carfentrazone-ethyl for control of giant salvinia. J. Aquat. Plant Manage. 44:136–138.

Glomski LM, Mudge CR. 2013. Effect of subsurface and foliar applications of bispyribac-sodium on water hyacinth, water lettuce, and giant salvinia. J. Aquat. Plant Manage. 51:62–65.

Glomski LM, Nelson LS, Skogerboe JG. 2003. Clearigate® treatments for control of giant salvinia. J. Aquat. Plant Manage. 41:127–129.

Haller WT. 2011. New herbicides for activity against hydrilla and non-target plants, pp 4–5. In: D. C. Schmitz (*ed.*). Invasive plant management research and outreach newsletter. September 2011 3(1). Florida Fish and Wildlife Conservation Commission.

Haller WT, Gettys LA. 2017. Screening and development of new aquatic herbicides pp 15–16. Proceedings of the 41st Annual FAPMS Conference,. Florida Aquatic Plant Management Society. Lake Buena Vista, FL. [Abstract]

Harvey J, Dulka JJ, Anderson JJ. 1985. Properties of sulfometuron methyl affecting its environmental fate: Aqueous hydrolysis and photolysis, mobility and adsorption on soils and bioaccumulation potential. J. Agric. Food Chem. 33:590–596.

Heap I. 2014. Herbicide resistant weeds. In: D. Pimentel and R. Peshin (*eds.*). Integrated pest management. Springer, Dordrecht.

Heap I. 2017. International survey of herbicide resistant weeds. http://www.weedscience.org. Accessed October10, 2017.

Horsley SB. 1988. Control of understory vegetation in Allegheny hardwood stands with Oust®. N. Am. J. Appl. Forestry 5:261–262.

Hutchinson JT, Langeland KA. 2008. Response of selected non-target native Florida wetland species to metsulfuron-methyl. J. Aquat. Plant Manage. 46:72–76.

Jacono C. 1999. *Salvinia molesta* (D.S. Mitchell) invades the United States. Aquatics 21(1):4–9.

Jacono C, Pittman B. 2001. *Salivinia molesta*: Around the world in 70 years. Aquat. Nuisance Species Digest 4:13–16.

Johnson D. 1995. Giant salvinia found in South Carolina. Aquatics 17(4):22.

Koschnick TJ, Haller WT, Glasgow L. 2006. Documentation of Landoltia (*Landoltia punctate*) resistance to diquat. Weed Sci. 54:615–616.

Langeland KA, Link ML. 2006. Evaluation of metsulfuron-methyl for selective control of *Lygodium microphyllum* growing in association with *Panicum hemitomon* and *Cladium jamaicense*. Fla. Sci. 69:149–156.

McFarland DG, Nelson LS, Grodowitz MJ, Smart RM, Owens CS. 2004. *Salvinia molesta* D.S. Mitchell (Giant Salvinia) in the United States: A review of species ecology and approaches to management. U.S. Army Engineer Research and Development Center, Environmental Laboratory. ERDC/EL SR-04-2.

Mervosh TL, Sims GK, Stoller EW. 1995. Clomazone fate in soil as affected by microbial activity, temperature, and soil moisture. J. Agric. Food Chem. 43:537–543.

Michel A, Arias RS, Scheffler BE, Duke SO, Netherland M, Dayan FE. 2004. Somatic mutation-mediated evolution of herbicide resistance in the non-indigenous invasive plant hydrilla (*Hydrilla verticillata*). Mol. Ecol. 12:3229–3237.

Mitchell DS, Tur NM. 1975. The rate of growth of *Salvinia molesta* (*S. auriculata* Auct.) in laboratory and natural conditions. J. Appl. Ecol. 12:213–225.

Mudge CR. 2016. Evaluation of topramezone and benzobicyclon for activity on giant salvinia. APCRP Technical Notes Collection. ERDC/TN APCRP-CC-21. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Mudge CR, Harms NE. 2012. Development of an integrated pest management approach for controlling giant salvinia using herbicides and insects. APCRP Bulletin. ERDC APCRP-A-12-1. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Mudge CR, Harms NE, Nachtrieb JG. 2013. Interactions of herbicides, surfactants, and the giant salvinia weevil (*Cyrtobagous salviniae*) for control of giant salvinia (*Salvinia molesta*). J. Aquat. Plant Manage. 51:77–83.

Mudge CR, Heilman MA, Theel HJ, Getsinger KD. 2012. Efficacy of subsurface and foliar penoxsulam and fluridone applications on giant salvinia. J. Aquat. Plant Manage. 50:116–124.

Mudge CR, Perret AJ, Winslow JR. 2016. Evaluation of foliar herbicide and surfactant combinations for control of giant salvinia at three application timings. J. Aquat. Plant Manage. 54:32–36.

Nelson LS, Glomski LM, Gladwin DN. 2007. Effect of glyphosate rate and spray volume on control of giant salvinia. J. Aquat. Plant Manage. 45:58–61.

Nelson LS, Skogerboe JG, Getsinger KD. 2001. Herbicide evaluation against giant salvinia. J. Aquat. Plant Manage. 39:48–53.

Netherland MD. 2014. Chemical control of aquatic weeds, pp. 65–78. In: L. A. Gettys, W. T. Haller, and M. Bellaud (*eds.*). Biology and control of aquatic plants: A best management practices handbook. 3rd ed. Aquatic Ecosystem Restoration Foundation, Marietta, GA.

Oliver JD. 1993. A review of the biology of giant salvinia (*Salvinia molesta* Mitchell). J. Aquat. Plant Manage. 31:227–331.

Pimentel D, Lach L, Zuniga R, Morrison D. 1999. Environment and economic costs associated with non-indigenous species in the United States. College of Agriculture and Life Sciences, Cornell University, Ithaca, New York.

Richardson RJ, Roten RL, West AM, True SL, Gardner AP. 2008. Response of selected aquatic invasive weeds to flumioxazin and carfentrazone-ethyl. J. Aquat. Plant Manage. 46:154–158.

Room PM. 1986. *Salvinia molesta*—A floating weed and its biological control, pp. 164–186. In: R. L. Kitching, (*ed.*). The ecology of exotic animals and plants. John Wiley, Brisbane, Queensland, Australia.

Room PM. 1990. Ecology of a simple plant-herbivore system: Biological control of salvinia. Trends Ecol. Evol. 5:74–79.

Sarmah AK, Kookana RS, Duffy MJ, Alston AM, Harch BD. 2000. Hydrolysis of triasulfuron, metsulfuron-methyl, and chlorsulfuron in alkaline soil and aqueous solutions. Pest. Manag. Sci. 56:463-–71.

SAS® software version 9.4. 2017. SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC.

Shaner DL (*ed.*). 2014. Herbicide handbook. 10th ed. Weed Science Society of America, Lawrence, KS. 311 & 425 pp.

Thayer DD, Pfingsten IA, Jacono CC, Richerson MM, Howard V. 2018, *Salvinia molesta* Mitchell: U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, https://nas.er.usgs.gov/queries/factsheet. aspx? SpeciesID=298. Revision Date: March 15, 2016, Peer Review Date: March 18, 2016, Accessed January 2, 2018.

Thompson DG, MacDonald LM; Staznik B. 1992. Persistence of hexazinone and metsulfuron-methyl in a mixed-wood/boreal forest lake. J. Agric. Food Chem. 40(8):1444–1449.