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# Evaluation of foliar herbicide and surfactant combinations for control of giant salvinia at three application timings

CHRISTOPHER R. MUDGE, ALEXANDER J. PERRET, AND JONATHAN R. WINSLOW*

## ABSTRACT

The invasive aquatic fern, giant salvinia (*Salvinia molesta* Mitchell) continues to spread throughout Louisiana, Texas, and the Gulf Coast Region. Most infestations in Louisiana are chemically managed throughout the growing season with a combination of the aquatic herbicides glyphosate and diquat plus two adjuvants (nonionic surfactant with buffering agents and a nonionic organosilicone surfactant). Heavy reliance on one spray mixture is of concern to natural resource managers because of the possibility of developing herbicide resistance. In addition, it is unknown whether combinations of other herbicides and adjuvants or surfactants can provide improved efficacy at certain times of the year (i.e., seasonal differences) compared with the primary treatment used operationally. Therefore, three mesocosm trials were conducted in the spring, summer, and fall to evaluate the efficacy of various combinations of glyphosate, carfentrazone-ethyl (hereafter, called *carfentrazone*), diquat, endothall, flumioxazin, and adjuvants on giant salvinia. All treatments involving glyphosate + carfentrazone or flumioxazin, as well as endothall + flumioxazin, resulted in giant salvinia injury 1 d after treatment. Glyphosate alone required 4 d to produce injury symptoms. All treatments, regardless of application time, were efficacious against giant salvinia 7 wk after treatment and reduced plant dry weight by 65 to 99% compared with the nontreated control. In general, fall herbicide treatments were less efficacious than the spring or summer treatments, and a great amount of regrowth also occurred following this application. The substitution of carfentrazone or flumioxazin for diquat into the glyphosate spray mixture, as well as other surfactants or adjuvants, provided similar control to the herbicide mixture used operationally in Louisiana. Based on these data, the new mixtures evaluated in the spring and summer can be viable alternatives to manage salvinia during the growing season. Further research is needed to evaluate other mixes for the fall when plant growth is decreasing.

*Key words*: adjuvant, carfentrazone-ethyl, chemical control, diquat, endothall, flumioxazin, glyphosate, *Salvinia molesta*, surfactant, tank mix.

## INTRODUCTION

The free-floating, mat-forming aquatic fern giant salvinia (*Salvinia molesta* Mitchell) has been problematic in water bodies throughout the southeastern United States, Puerto Rico, and Hawaii for more than 15 yr (Forno and Harley 1979, Johnson et al. 2010). It is estimated that under optimal growth conditions, plants can double in coverage every 36 to 53 h (Cary and Weerts 1983, Johnson et al. 2010) and can form surface mats up to 1 m thick (Thomas and Room 1986). Dense infestations disrupt transportation, hinder water uses, affect desirable native plant communities, and increase mosquito-breeding habitat in ponds, lakes, rivers, and bayous, especially in Louisiana and Texas (Jacono 1999, Jacono and Pitman 2001, Nelson et. al 2001). The Louisiana Department of Wildlife and Fisheries (LDWF) spent approximately $3,415,000 on giant salvinia control measures in 2013 (A. Perret, pers. comm.). These expenditures included aquatic herbicides, herbicide application, and giant salvinia weevil (*Cyrtobagous salviniae* Calder and Sands) rearing and release efforts. During the same year, the U.S. Army Corps of Engineers, Fort Worth District, spent approximately $300,000 to manage approximately 300 acres on two Corps reservoirs in Texas (A. Gray, pers. comm.).

In 2013, giant salvinia covered an estimated 45,300 acres of Louisiana public waters and most of the populations were treated with a combination of the aquatic herbicides glyphosate and diquat, with two adjuvants (nonionic surfactant with buffering agents [NISBA] and a nonionic organosilicone surfactant [NIOS]) (Mudge et al. 2014). This herbicide mixture is the primary foliar treatment in Louisiana and Texas and has been used as the primary treatment operationally in Louisiana for the past 3 yr. This spray mixture is used during the growing season (1 April through 31 October). During the winter, and in specific situations, foliar applications consist of diquat and one surfactant (Mudge et al. 2014). Aquatic herbicides have typically been applied as foliar applications to giant salvinia with moderate to good success, but contact with all frond surfaces is difficult to achieve (Mudge et al. 2012). Consequently, surface-matted giant salvinia often requires multiple herbicide applications to ensure that underlying plants receive treatment (Nelson et al. 2007).

Although the current four-way mix of herbicides and surfactants has been used operationally by multiple agen-

*First 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. Second and third authors: Aquatic Plant Control Coordinator and Inland Fisheries Biologists, Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA 70898. Corresponding author's E-mail: Christopher.R.Mudge@usace.army.mil. Received for publication July 30, 2014 and in revised form August 6, 2015.

cies, there is limited literature to suggest this is the optimal treatment mix. To date, the only published literature describing the efficacy of glyphosate + diquat + surfactants, to our knowledge, was a giant salvinia mesocosm trial, which demonstrated that this mixture provided similar control to foliar and subsurface penoxsulam and fluridone treatments (Mudge et al. 2012). It is unknown whether other combinations of herbicides and surfactants can be substituted or rotated to achieve similar or increased control. In addition, it is unknown whether this current mixture of herbicides and surfactants is being used at the most-appropriate time of the year. Glyphosate provides better cattail (*Typha* spp.) control in the late summer or fall (Comes and Kelley 1989, Messersmith et al. 1992), whereas most other aquatic herbicides are more effective when applied early in the growing season when plants are immature and actively growing. Because giant salvinia lacks underground storage organs (i.e., roots, rhizomes, stolons), herbicide application timing should not be as crucial for optimum efficacy for this type of plant as compared with perennial emergent species that are actively transporting carbohydrates to belowground storage organs in the fall. Physiological weaknesses, including herbicide application before winter dormancy, have been used to control target plants by disrupting the normal source-to-sink translocation in the fall (Luu and Getsinger 1990).

The contact herbicides carfentrazone-ethyl (hereafter, called *carfentrazone*), endothall, and flumioxazin are efficacious against a variety of invasive floating, emergent, and submersed plants (Langeland et al. 2009). Endothall is primarily used as a subsurface treatment to control nuisance, submersed aquatic plants (Skogerboe and Getsinger 2002, Skogerboe et al. 2006). Both carfentrazone and flumioxazin are effective as foliar treatments when applied to single layers of giant salvinia (Glomski and Getsinger 2006, Richardson et al. 2008), but regrowth often occurs when these products are applied alone to multiple plant layers. Previous research demonstrated that the combination of endothall and flumioxazin was injurious to the nontarget, submersed aquatic plants coontail (*Ceratophyllum demersum* L.), to two pondweeds (*Potamogeton* spp.), and to two biotypes of American eelgrass (*Vallisneria americana* Michx.) (Mudge 2013). Their activity against giant salvinia as a foliar combination treatment is unknown. Protoporphyrinogen oxidase–inhibiting herbicides (i.e., carfentrazone and flumioxazin) have been used in combination with glyphosate to control weeds in nursery, landscape, and agriculture settings for several years (Culpepper et al. 2004, 2005, Williams and Miller 2007, Wehtje et al. 2010). Recent research by Glomski et al. (2014) demonstrated that glyphosate plus low to moderate rates of carfentrazone or flumioxazin provided good to excellent control of crested floatingheart [*Nymphoides cristata* (Roxb.) Kuntze] at 6 WAT. It is unknown whether these products can be used as rotation partners for diquat when applied in combination with glyphosate or in combination with each other to effectively control giant salvinia.

The current herbicide mix used by LDWF for giant salvinia control incorporates the use of two different surfactants, a NISBA and a NIOS. In combination, they are thought to deliver the herbicide to the leaf surface despite the layer of trichomes that act as a barrier. In recent years, methylated seed oil–organosilicone surfactant blends have become more widely used with aquatic herbicides. It is speculated that this type of surfactant may produce results similar to the two surfactants that are currently used by LDWF for giant salvinia control. Reduction to only one surfactant in the giant salvinia mix would alleviate spraying complications stemming from the incompatibility of multiple adjuvants in the same tank. This has been an issue for LDWF when applying the four-way mix from vessels equipped with metered spray systems (A. Perret, pers. comm.).

Although herbicide resistance in aquatic areas has been limited to hydrilla (*Hydrilla verticillata* L. f. Royle) and landoltia duckweed [*Landoltia punctata* (G. Mey.) D.H. Les & D.J. Crawford] (Koschnick et al. 2006, Michel et al. 2004), heavy reliance on one herbicide or one spray mixture may be problematic if giant salvinia were to develop resistance to glyphosate or diquat in the future. Research and demonstration efforts are necessary to develop alternative treatments that are efficacious against this floating nuisance. Therefore, the objectives of this research were to 1) determine whether glyphosate in combination with other contact herbicides or adjuvants or surfactants can provide giant salvinia control similar to the standard foliar treatment of glyphosate, diquat, and two surfactants; and 2) determine whether time of year (i.e., fall, spring, or summer) influences the efficacy of giant salvinia control.

## MATERIALS AND METHODS

Three outdoor mesocosm trials were conducted at the Louisiana State University (LSU) AgCenter Aquaculture Research Facility (Baton Rouge, LA) to evaluate the efficacy of herbicide combination treatments against mature giant salvinia at various times of the year. The trials were initiated and treated in October 2013, May 2014, and August 2014, and will be referred to as the *fall*, *spring*, and *summer* trials, respectively. Giant salvinia used in this research was collected from cultures maintained at LSU Aquaculture facility. Equal amounts of fresh plant material, enough to cover approximately 75% of the water surface, were placed inside 76-L plastic containers (49.5-cm diam by 58.4-cm tall). The containers were filled with well water (fall and spring trials) or a 50 : 50 mixture of well and pond water (summer trial), which was amended with Miracle-Gro[1] (36–6–6 N–P–K; 41.6 mg $L^{-1}$; fall and spring trials) or Osmocote[2] (19–6–12; 116.7 mg $L^{-1}$; summer trial) fertilizers initially and 4 wk after herbicide treatment. Water level was maintained weekly at 60 L. The plastic containers were placed inside larger plastic tanks (1,136 L) partially filled with water to help maintain a consistent water temperature. Culture techniques were adapted from previous giant salvinia research (Nelson et al. 2001, 2007; Mudge et al. 2012).

Plants were allowed to acclimate to container conditions for 2 wk before herbicide application. At the time of herbicide treatment, the mature plants had reached approximately 95 to 100% coverage, with mean ± SD dry weights of 18.7 ± 0.7, 23.0 ± 1.3, and 29.0 ± 0.8 g for the

Table 1. Effect of foliar herbicide treatments on Giant Salvinia 7 wk after fall, spring, and summer applications

| Herbicide Treatment | Rate,[1] g ai ha$^{-1}$ | Mean Dry wt, g (Mean ± SD) | | |
|---|---|---|---|---|
| | | Fall 2013 | Spring 2014 | Summer 2014 |
| G[2] + MVO | 4205.2 + 0.25% v/v | 0.12 ± 0.10 c[3] | 0.39 ± 0.21 b | 1.05 ± 0.65 b |
| G + D + NISBA + NIOS | 3364.1 + 560.1 + 0.25% v/v + 0.094% v/v | 5.10 ± 3.43 bc | 0.15 ± 0.09 b | 1.20 ± 0.54 b |
| G + D + SBA | 3364.1 + 560.1 + 0.25% v/v | 8.30 ± 2.73 bc | — | — |
| G + D + MVO | 3364.1 + 560.1 + 0.25% v/v | 6.73 ± 1.80 bc | 0.20 ± 0.08 b | 1.87 ± 1.13 b |
| G + F + MVO | 3364.1 + 71.5 + 0.25% v/v | 0.00 ± 0.00 c | 0.30 ± 0.13 b | 0.16 ± 0.14 b |
| G + F + MVO | 3364.1 + 143.0 + 0.25% v/v | 0.03 ± 0.02 c | 0.08 ± 0.04 b | 0.05 ± 0.04 b |
| G + C + MVO | 3364.1 + 33.3 + 0.25% v/v | — | 0.43 ± 0.28 b | 1.99 ± 0.94 b |
| G + C + MVO | 3364.1 + 66.6 + 0.25% v/v | — | 0.49 ± 0.12 b | 0.58 ± 0.18 b |
| E + F + MVO | 592.9 + 143.0 + 0.25% v/v | 10.49 ± 4.37 b | 0.48 ± 0.15 b | 0.44 ± 0.44 b |
| Control | 0 | 29.7 ± 0.2 a | 28.54 ± 3.46 a | 40.96 ± 2.42 a |

[1]Glyphosate and endothall applied as g ae ha$^{-1}$.
[2]Abbreviations: C, carfentrazone; D, diquat; E, endothall (dipotassium salt); F, flumioxazin; G, glyphosate; MVO, modified vegetable oil; NIOS, nonionic organosilicone surfactant; NISBA, nonionic surfactant and buffering agent; SBA, spray binder adjuvant.
[3]Means within a column followed by the same letter are not significantly different according to Student-Newman-Keuls method at $P \leq 0.05$; $n = 4$.

spring, summer and fall trials, respectively. The air temperatures at herbicide application for the spring, summer, and fall trials were 25, 33, and 16 C, respectively. Most of the herbicide treatments were repeated at all three application timings (i.e., spring, summer, and fall). Herbicides evaluated included carfentrazone,[3] diquat,[4] endothall,[5] flumioxazin,[6] and glyphosate,[7] as well as various adjuvants[8–11] (Table 1). A nontreated control was also used to compare plant growth in the absence of herbicide. Treatments were randomly assigned and replicated four times. Herbicide treatments were applied to the foliage of giant salvinia using a forced-air $CO_2$-powered sprayer at an equivalent of 935 L ha$^{-1}$ diluent delivered through a single TeeJet[12] 80-0067 nozzle at 20 psi. Plant injury and regrowth were recorded daily for the first 2 wk and weekly thereafter to determine whether and when plant recovery occurred for all trials. Plant injury was not recorded until 10% injury was achieved; this was chosen as a conservative value and near the threshold at which a resource manager may detect adverse effects on plant growth. At 7 wk after treatment (WAT), all viable giant salvinia biomass was harvested, dried to a constant weight (55 C for 1 wk), and recorded as dry-weight biomass. Data were subjected to ANOVA, and means separated using the Student-Newman-Keuls (SNK) method ($P = 0.05$) for the fall trial. Data from the spring and summer trials did not meet normality assumptions and thus were transformed using a base-10 log transformation. Nontransformed data are presented.

## RESULTS AND DISCUSSION

With the exception of glyphosate + modified vegetable oil (MVO), all herbicide treatments across all three trials resulted in giant salvinia injury (chlorosis and necrosis) 1 d after treatment (DAT) (data not shown). Glyphosate alone resulted in necrosis at 4 DAT, which is slightly faster than anticipated. Typically, glyphosate inhibits plant growth soon after application followed by injury symptoms 4 to 7 DAT (WSSA 2014). The addition of the contact herbicides carfentrazone, diquat, or flumioxazin to glyphosate enhanced injury symptoms and decreased the number of days until injury was visible. Plants treated with glyphosate + carfentrazone, diquat, or flumioxazin began to lose buoyancy, and open water was noticeable as early as 2 WAT. The combination of endothall + flumioxazin provided the most-intense and rapid injury symptoms of all treatments, and most of the injury occurred in the upper portion of the plant for the first 2 WAT. The injury symptoms escalated thereafter, and plants began to lose integrity for the spring- and summer-treated plants; however, fall plants required a longer period (approximately 4 wk), and regrowth occurred largely during this period. Endothall and flumioxazin are contact herbicides that rapidly produce injury symptoms in the first few hours after application. Field (C. Mudge, pers. observ.) and greenhouse trials (Richardson et al. 2008) demonstrated that flumioxazin has activity against giant salvinia as both subsurface and foliar treatments, but regrowth often occurs when applied alone.

Single herbicide and combination treatments, regardless of application time, provided control of giant salvinia at 7 WAT (Table 1). The herbicide treatments reduced plant dry weights by 65 to 99, 98 to 99, and 96 to 99% compared with the nontreated control for the fall, spring, and summer trials, respectively. Although there were minimal differences among herbicide treatments, giant salvinia treated in the fall of 2013 was less responsive to the herbicides than it was in the spring or summer application timings. Plant regrowth was noted in the fall trial at 4 to 6 WAT, especially for plants treated with the combination of contact herbicides endothall + flumioxazin. Four of the seven herbicide treatments, including glyphosate + diquat + NISBA + NIOS, glyphosate + diquat + spray binder adjuvant (SBA), glyphosate + diquat + MVO, and endothall + flumioxazin + MVO, applied in the fall provided 65 to 83% control. This decreased control could be attributed to the time of year. Typically, glyphosate efficacy increases later in the growing season and into the fall when applied to perennial weeds (Ivany 1981, Comes and Kelley 1989). Similarly, endothall was more efficacious against curlyleaf pondweed (*Potamogeton crispus* L.) biomass and also inhibited turion production when applied to plants growing in cooler waters (15 and 20 C) (Netherland et al. 2000). Systemic herbicides are translocated with sugars and carbohydrates to the root system for winter storage and will likely result in greater perennial weed control than when applied during the spring and summer months (Altland 2003). Although giant salvinia is commonly referred to as a perennial species (Global Invasive Species Database 2010), it does not allocate carbohydrates to underground appendages during the fall for winter storage, which is common for large rhizomatous, rooted, emergent plants. As a result, giant salvinia does not have a transport mechanism to move herbicides with carbohydrate storage, and this suggests that it would respond differently to herbicides during the fall. Giant salvinia initially expands throughout an aquatic system in the primary growth or colonizing stage, progresses through the secondary growth stage, and finally reaches maximum capacity in a single mat-forming layer, otherwise known as the *tertiary growth stage* (Oliver 1993). This continuous expansion is the result of rapid reproduction. Under ideal conditions, the plant has a tendency to completely cover large areas regardless of season.

Glyphosate + MVO and glyphosate + flumioxazin + MVO were highly active in the fall compared with the other herbicide treatments (including those with glyphosate). There were no differences among herbicide treatments in the spring and summer trials. Previous research demonstrated that the tank mix of glyphosate + diquat + NISBA + NIOS mix was initially highly efficacious against giant salvinia, but plants recovered by 3 WAT and displayed no injury symptoms by 11 WAT (Mudge et al. 2012). On the contrary, plant regrowth or healthy plants were observed in only a few of the tanks in the current spring and summer trials.

These data provide evidence that the contact herbicides carfentrazone and flumioxazin may be suitable tank-mix partners for glyphosate to control giant salvinia. In addition, the treatment of glyphosate + diquat + NISBA + NIOS is as effective as the other treatments evaluated and provides evidence that field use of these products is warranted. These data also support current use patterns of herbicide combination treatments for spring and summer use. Although the fall treatments were generally less effective than the spring and summer treatments, most of the herbicide and surfactant combinations still provided good to excellent control. Recent management efforts have focused on applying multiple herbicides and surfactants in a tank mix to control giant salvinia; however, glyphosate + one surfactant were very effective, especially during the fall trial. Although glyphosate alone was highly efficacious against giant salvinia during the three treatment timings, the development of injury symptoms was slower than those treatments containing a contact herbicide. The additional 3 d is minimal but may be necessary for aquatic applicators that rely on next-day rapid injury (i.e., visual markers) to determine where to continue spraying on consecutive days (Mudge and Netherland 2014, Mudge and Netherland 2015). The addition of carfentrazone or flumioxazin to the slow-acting acetolactate synthase–inhibiting herbicides bispyribac, imazamox, and penoxsulam, increased the speed of injury (Mudge and Netherland 2014, 2015).

The slow growth rate of plants in the fall, which is attributed to the shorter day length and cooler water and air temperatures, is likely the cause of decreased herbicide efficacy. On the contrary, rapid growth of healthy plants resulted in improved control during the spring and summer trials. Although plant control was hindered in the fall, an efficacious treatment, if timed correctly, can be advantageous. At the conclusion of the growing season through the winter months, the plant stand will decrease from multiple layers to one or two plants thick. Herbicide treatments have an opportunity to be successful if the application reaches all plants before the winter freezes. Therefore, a different management strategy or alternative herbicide combinations may be required during the end of the growing season through the early winter to provide optimal control. The results of the fall experiment provided evidence that the conventional or often-used glyphosate + diquat + surfactants may not be suitable at this time of the year. In addition, resistance management requires using alternative chemicals or control methods instead of relying on one herbicide mixture year-round.

Additional research is necessary to determine whether other single herbicide or combination treatments may provide better control during the fall or whether fall treatment should be eliminated altogether because of reduced efficacy resulting from seasonal effects. With regard to the various surfactants evaluated in these three trials, no differences were noted among the MVO, NISBA, NIOS, and SBA adjuvants and surfactants. Future research will investigate winter treatments for efficacy as well as evaluate other adjuvant–surfactant combinations to determine whether the most-optimal tank mix is being used during the spring and summer.

## SOURCES OF MATERIALS

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

[2]Osmocote, The Scotts Company, P.O. Box 606, Marysville, OH 43040.

[3]Stingray, SePRO Corporation, 11550 N. Meridian St., Suite 600, Carmel, IN 46032.

[4]Tribune herbicide, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 24719.

[5]Aquathol K, United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406.

[6]Clipper herbicide, Valent USA Corporation, P.O. Box 8025, Walnut Creek, CA 94596.

[7]Roundup Custom, Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167.

[8]Inergy, Winfield Solutions, LLC, P.O. Box 64589, St. Paul, MN 55164.

[9]Aqua-King Plus adjuvant, Winfield Solutions, LLC, P.O. Box 64589, St. Paul, MN 55164.

[10]Thoroughbred adjuvant, Winfield Solutions, LLC, P.O. Box 64589, St. Paul, MN 55164.

[11]TopFilm, Biosorb, Inc. 5988 Mid Rivers Mall Dr., St. Charles, MO 63304.

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

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## LITERATURE CITED


Altland JE. 2003. Postemergence herbicides, the basics. Digger 47(7):44–49.

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.

Comes RD, Kelley AD. 1989. Control of common cattail with postemergence herbicides. J. Aquat. Plant Manage. 27:20–23.

Culpepper AS, Carlson DS, York AC. 2005. Pre-plant control of cutleaf eveningprimrose (*Oenothera laciniata* Hill) and wild radish (*Raphanus raphanistrum* L.) in conservation tillage cotton (*Gossypium hirsutum* L.). J. Cotton Sci. 9:223–228.

Culpepper AS, Flanders JT, York AC, Webster TM. 2004. Tropical spiderwort (*Commelina benghalensis*) control in glyphosate-resistant cotton. Weed Technol. 18:432–436.

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

Global Invasive Species Database. 2010. Salvinia molesta. http://www.issg.org/database/species/ecology.asp?fr=1&si=569. Accessed March 12, 2015.

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

Glomski LM, Willey LN, Netherland MD. 2014. The efficacy of protox inhibiting herbicides alone and in combination with glyphosate to control crested floating heart. J. Aquat. Plant Manage. 52:90–92.

Ivany JA. 1981. Quackgrass (*Agropyron repens*) control with fall-applied glyphosate and other herbicides. Weed Sci. 29:382–386.

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

Jacono C, Pitman B. 2001. *Salvinia molesta*: Around the world in 70 years. ANS Dig. (4)2:13–16.

Johnson S, Sanders D, Eisenberg L, Whitehead K. 2010. Fighting the blob: efforts to control giant salvinia. La. Agric. 5(1)3:6–9.

Koschnick TJ, Haller WT, Glasgow L. 2006. Documentation of landoltia (*Landoltia punctata*) resistance to diquat. Weed Sci. 54:615–619.

Langeland K, Netherland M, Haller W. 2009. Efficacy of Herbicide Active Ingredients Against Aquatic Weeds. University of Florida, Institute of Food and Agricultural Sciences. http://edis.ifas.ufl.edu/ag262. Accessed March 12, 2015.

Luu KT, Getsinger KD. 1990. Seasonal biomass and carbohydrate allocation in waterhyacinth. J. Aquat. Plant Manage. 28:3–10.

Messersmith CG, Christianson KM, Thorsness KB, 1992. Influence of glyphosate rate, application date and spray volume on cattail control. N. D. Farm Res. 49(5):27–28.

Michel A, Scheffler BE, Arias RS, Duke SO, Netherland MD, Dayan FE. 2004. Somatic mutation-mediated evolution of herbicide resistance in the invasive plant hydrilla. Mol. Ecol. 13: 3229–3237.

Mudge CR. 2013. Impact of aquatic herbicide combinations on non-target submersed plants. J. Aquat. Plant Manage. 51:39–44.

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

Mudge CR, Netherland MD. 2014. Response of invasive floating plants and non-target emergent plants to foliar applications of imazamox and penoxsulam. J. Aquat. Plant Manage. 52:1–7.

Mudge CR, Netherland MD. 2015. Response of water hyacinth and non-target emergent plants to foliar applications of bispyribac-sodium alone and combination treatments. J. Aquat. Plant Manage. 53:7–13.

Mudge CR, Perret AJ, Winslow JR. 2014. Evaluation of new herbicide combinations for managing giant salvinia in Louisiana. Proc. Aquat. Plant Manage. Soc. 54:34.

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, Skogerboe JD, Owens CS, Madsen JD. 2000. Influence of water temperature on the efficacy of diquat and endothall versus curlyleaf pondweed. J. Aquat. Plant Manage. 38: 25–32.

Oliver JD. 1993. A review of the biology of giant salvinia (*Salvinia molesta* Mitchell). J. Aquat. Plant Manage. 31:227–231.

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. 46:144–158.

Skogerboe JG, Getsinger KD. 2002. Endothall species selectivity evaluation: northern latitude aquatic plant community. J. Aquat. Plant Manage. 40:1–5.

Skogerboe JG, Getsinger KD, Glomski LM. 2006. Efficacy of diquat on submersed plants treated under simulated flowing water. J. Aquat. Plant Manage. 44:122–125.

Thomas PA, Room PM. 1986. Taxonomy and control of *Salvinia molesta*. Nature 320(17):581–584.

Wehtje G, Gilliam CH, Marble SC. 2010. Postemergence weed control with glyphosate plus flumioxazin combinations. Weed Technol. 24:356–360.

Williams BJ, Miller DK. 2007. Cool-season weed response to flumioxazin. https://www.crops.org/publications/cm/abstracts/6/1/2007-0509-02-RS?search-result=1. Crop Management doi: 10.1094/CM-2007-0509-02-RS. Accessed March 12, 2015.

[WSSA] Weed Science Society of America. 2014. Herbicide Handbook. 10th ed. Weed Science Society of America, Lawrence, KS. 513 p.