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Integrated management of giant salvinia using herbicides and the salvinia weevil

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ABSTRACT

Despite the use of aquatic herbicides and release of the biological control agent salvinia weevil (*Cyrtobagous salviniae* Calder and Sands; Coleoptera: Curculionidae), giant salvinia (*Salvinia molesta* Mitchell) continues to hinder waterways in the Gulf Coast region of the United States. Outdoor mesocosm trials were conducted in April and August of 2016 to determine the compatibility of salvinia weevil and aquatic herbicides by testing efficacy of each alone or in combination. The results from the whole tank data confirmed that the most widely used herbicide treatment in Louisiana, glyphosate + diquat, is efficacious against giant salvinia when used alone, regardless of application timing at 6 wk after treatment. Penoxsulam and flumioxazin reduced plant biomass, but efficacy varied depending on the timing of the application in whole-tank data. All integrated treatments suppressed plant growth and provided similar control to herbicide-only treatments for the early season (April) application. The timing data for the late-season (August) herbicide application provided evidence that the mixture of glyphosate and diquat is less efficacious than penoxsulam or flumioxazin when used as an integrated pest management approach. Although weevils alone were effective against giant salvinia, this research suggests that incorporating herbicides and weevils into a giant salvinia management program is more beneficial than biological control alone, particularly in central and north Louisiana. Plant managers should consider treating giant salvinia with herbicides early in the growing season, either coupled with weevils or alone.

Key words: aquatic fern, diquat, flumioxazin, foliar application, glyphosate, integrated pest management, penoxsulam.

INTRODUCTION

Giant salvinia (*Salvinia molesta* Mitchell) is considered one of the world's worst weeds because of its high mobility, environmental stress tolerance (Tipping 2004), exponential growth rate, and difficulty to control (Nelson et al. 2001, Tipping 2004). These adaptations allow giant salvinia to rapidly invade aquatic environments (Tipping 2004). Greenhouse studies suggested that giant salvinia can double surface coverage in 36 (Johnson et al. 2010) to 53 h (Cary and Weerts 1983). This explosive growth rate enables giant salvinia to outcompete native vegetation for resources such as nutrients, light, and surface area (Mitchell and Tur 1975). Giant salvinia forms up to 1-m-thick mats (Thomas and Room 1986), which impede transportation, recreational activities, and irrigation for agronomic purposes, (Sullivan and Postle 2012, Thomas and Room 1986, Tipping 2004).

Integrated pest management (IPM) relies on combinations of common-sense practices that use current, comprehensive information on the life cycles of pests and their interaction with the environment to manage pest damage by the most economical means and with the least possible hazard to people, property, and the environment (USEPA 2014). The primary habitats of giant salvinia are slow-flowing streams and rivers, lakes, ponds, marshes, rice fields, and backwater swamps (Horner 2002). Aquatic herbicides are the most commonly used and efficacious treatment in Louisiana and Texas; however, there are limitations. Specifically, controlling giant salvinia infestations in bald cypress [*Taxodium distichum* (L.) Rich.] swamps by boat or aircraft is extremely difficult (Sartain and Mudge 2018) because watercraft are unable to maneuver through those areas where trees are growing in close proximity. Because of these challenges, cypress swamps serve as refuge for weeds, allowing giant salvinia to reinfest the waterbody. Timing of herbicide applications has not, to our knowledge, been studied in giant salvinia; however, winter applications have been suggested as an alternative period to control giant salvinia (Sartain and Mudge 2018). Releasing weevils into these swamps could benefit the management of giant salvinia, thus leading to an overall reduction of annual costs (i.e., chemical, fuel, labor, etc.) associated with herbicide treatments. Unfortunately, weevil survivability can be limited by environmental constraints, including, but not limited to, nutrient availability, water quality, length of time for insect establishment (Sullivan and Postle 2012), appropriate stocking densities (Room and Thomas 1985, Tipping and Center 2005), and unfavorable winter conditions, particularly in the northern range of giant salvinia (Tipping et al. 2008, Sullivan and Postle 2012, Mukherjee et al. 2014).

IPM using chemical and biological control is a relatively new concept for giant salvinia managers in Louisiana and Texas. Managers in Texas primarily use the aquatic herbicide glyphosate for the management of giant salvinia (T. Decker, pers. comm.), whereas, in Louisiana, managers use the mixture of glyphosate + diquat (Mudge et al. 2014,

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Mudge et al. 2016). By using a single herbicide or tank mix over an extended period, plant managers increase the risk of plants developing herbicide resistance to glyphosate or diquat.

Several factors can contribute to weeds developing herbicide resistance, including the long-term use of herbicides with the same modes of action (Anderson 2007). Despite the theory that asexually reproducing plants, such as hydrilla [*Hydrilla verticillata* (L.f.) Royle] are not capable of developing herbicide resistance (Powles and Holtum 1994), this species was the first aquatic plant with documented herbicide resistance in the United States (Michel et al. 2004). Similar to hydrilla, giant salvinia also reproduces asexually by vegetative propagation, creating major concerns of the potential of this weed to develop herbicide resistance (Netherland 2014). Because of that, researchers are focusing on IPM techniques using biological control programs and herbicides with alternate modes of action to combat giant salvinia (Mudge 2016).

The salvinia weevil is being used more frequently for biological control of giant salvinia; however, there is limited research on the interaction of aquatic herbicides and weevils. Previous research has addressed integrated control of water hyacinth [*Eichhornia crassipes* (Mart.) Solms] using water hyacinth weevils (*Neochetina* spp.) and aquatic herbicides (Harley 1990, Pellessier 1988). Interactions of weevils and the aquatic herbicides penoxsulam, flumioxazin (Mudge et al. 2013), and 2,4-D (Wahl et al. 2018) have been evaluated in short-term, small-scale mesocosms but need to be further tested at a larger scale for a prolonged period. Additionally, expeditious insect development is dependent on several factors, particularly temperature for second-generation development (Cilliers 1991, Sullivan and Postle 2012). Therefore, the objectives of this research were 1) to evaluate select herbicides and weevils for control of giant salvinia, and 2) to determine the optimum timing for herbicide applications to maximize control in an integrated program.

MATERIALS AND METHODS

Two studies were conducted at two different timings to evaluate the integrated control of giant salvinia by aquatic herbicides and salvinia weevils. The first study was conducted early in the growing season (April), followed by the second study later in the growing season (August) during 2016. Plants not infested with weevils were collected from a local waterbody in Lena, LA (31°30′36″N; 92°43′55.1994″W) in March 2016 and were the original food source for weevil colonies and used for both studies. Plants infested with weevils were collected from the weevil-rearing facility at the Red River Waterway Commission's Aquatic Plant Research Center in Lena, LA. Giant salvinia was cultured in 24 round tanks (2,160 L; 2.4 m diam by 45.7 cm depth) filled with a 1 : 1 ratio of rain water and local municipal water with an average pH of 5.6. Collected rain water was used to alleviate the high pH of the municipal water. Water was amended initially and every other week for the duration of the experiment with water-soluble fertilizer[1] (32–0–10 N–P–K) to provide 2 mg L^{-1} nitrogen in the water column (Glomski and Mudge 2013).

Table 1. Treatment and application rates of aquatic herbicides and salvinia weevil for integrated management of giant salvinia in a mesocosm setting.[1]

Treatment[2]	Rate (g ai ha^{-1})	% Herbicide Coverage[3]
Control	0	0
G + D + NIOS + NISBA[4]	3,364.1 + 560.1 + 0.25% v/v + 0.094% v/v	100
P + MVO	70.1 + 0.25% v/v	100
F + MVO	214.5 + 0.25% v/v	100
G + D + NIOS + NISBA + SW	G + D + 0.25% v/v + 0.094% v/v + 50 kg^{-1}	50[3]
P + MVO + SW	70.1 + 0.25% v/v + 50 kg^{-1}	50
F + MVO + SW	214.5 + 0.25% v/v + 50 kg^{-1}	50
CS	50 kg^{-1}	0

[1]Salvinia weevils were evenly distributed throughout the giant salvinia.
[2]Abbreviations: D, diquat (560.1 g ai ha^{-1}); F, flumioxazin (214.5 g ai ha^{-1}); G, glyphosate (3,364.1 g ae ha^{-1}); P, penoxsulam (70.1 g ai ha^{-1}); SW, salvinia weevils.
[3]Fifty percent of the giant salvinia was treated with herbicides in two separate, opposite quadrants for integrated treatments.
[4]All G + D treatments included a nonionic surfactant buffering agent blend (0.25% v/v) and a nonionic organosilicon surfactant (0.094% v/v), whereas a methylated vegetable oil (0.25% v/v) was included with all P and F treatments.

Of the 24 tanks, 3 control and 9 herbicide-alone tanks were infested with 10 kg of weevil-free, mature giant salvinia. Twelve tanks, three weevil and nine IPM, were infested with 5 kg of weevil-free giant salvinia and 5 kg of weevil-infested giant salvinia that was evenly distributed throughout the tanks. The infested plant material consisted of approximately 50 weevils kg^{-1} (both adults and larvae) of fresh weight biomass. The additional three tanks were used as a weevil-only treatment and received 10 kg of weevil-infested giant salvinia. After initial inoculation, all plant material was treated with *Bacillus thuringiensis* (Bt) for suppression of the giant salvinia stem borer moth (*Samea multiplicalis* Guenée [Lepidoptera: Pyralidae]) (Parys and Johnson 2013), which has no detrimental effects on weevils. The Bt treatment was repeated every other week for the duration of the experiment. All tanks were allowed 1 wk to acclimate before herbicide application.

In herbicide-only tanks, three different herbicide treatments were applied separately to each tank, achieving as close to 100% coverage as possible. The integrated tanks were divided into equal-sized quadrants (1 to 4) with opposite quadrants paired (i.e., one and three, two and four) and the herbicide treatments were randomly assigned to a quadrant pair before herbicide application. Two of the four quadrants were chemically treated, and each treated quadrant was separated by an adjacent, nontreated quadrant infested with weevils. This method allowed the integrated tanks to receive up to 50% herbicide coverage of the plant material, thus leaving the nontreated plants available for weevil foraging. Herbicides used in these studies included glyphosate,[2] diquat,[3] flumioxazin,[4] penoxsulam,[5] and adjuvants, including a nonionic surfactant and buffering agent blend,[6] a nonionic organosilicon surfactant,[7] and a methylated vegetable oil and organosilicon blend[8] (Table 1). Herbicide treatments were applied to the foliage of giant salvinia with a forced air CO_2-powered sprayer at an equivalent rate of 935 L ha^{-1} diluent delivered through a single TeeJet® 80-0067 nozzle[9] at 20 psi (138 kPa). A spray shield was placed over the nontreated quadrants to prevent herbicidal drift and cross-contamination to neighboring quadrants or tanks. The experimental design was completely randomized, and all treatments were replicated three times. A nontreated control was also included to monitor plant growth in the absence of herbicides and/or weevils.

Quantitative measurements included dry weight biomass and weevil density, which is based on the number of weevils per fresh weight biomass (CS kg^{-1}) (Forno 1987). Quantitative measurements were collected pretreatment and at 3, 6, 9, and 12 wk after treatment (WAT). At the appropriate time, two subsamples (0.0625 m^2 each) per paired quadrant (i.e., one and three, two and four) per tank were randomly collected to measure giant salvinia biomass (kg), then dried to a constant weight (g) with Berlese funnels (Boland and Room 1983) to assess weevil density. At the conclusion of the study (12 WAT), all remaining viable giant salvinia biomass in each tank was harvested to collect final dry weight and weevil density. This final harvest of the entire tank will be referred to as "whole-tank data."

Subsample data were subjected to a three-way ANOVA at $P \leq 0.05$ (Nelson et al. 2001). There were no significant differences in weevil densities between season ($P = 0.184$); therefore, data were pooled and a two-way ANOVA was performed. Plant dry weights and weevil densities were pooled and subjected to a two-way ANOVA because of no significant differences by season for subsamples ($P = 0.055$, $P = 0.093$, respectively). *Post hoc* tests (Fisher's Protected LSD test) were used for all pairwise comparisons at $P \leq 0.05$ for dry weights. Additionally, whole-tank data were subjected to two-way ANOVA, and Fisher's Protected LSD test was used for all pairwise comparisons at $P \leq 0.05$. Because there were no differences between seasons, data from weevil densities in whole-tank collections were pooled and subjected to a one-way ANOVA; however, differences were noted with regard to dry weight and not pooled.

RESULTS AND DISCUSSION

Aquatic plants, particularly giant salvinia, are composed of more than 90% water (Haller 2014). Dry weight compared with fresh weight biomass is a more reliable and consistent indicator of biomass reduction (Grodowitz et al. 2014); therefore, dry weight biomass is discussed hereafter (Cozad 2017). In the herbicide-only treatments, at 3 WAT, glyphosate + diquat and flumioxazin reduced plant biomass 56 to 67% compared with the control, and there was no significant reduction in biomass with penoxsulam. Although not as efficacious as herbicide-only treatments, integrated treatments reduced plant biomass 32 to 37% compared with the control at 3 WAT, whereas the weevil treatment alone failed to reduce biomass in comparison to the control. The lack of control at the early stages of the trial is not unexpected because of the small size, limited mobility, and insect developmental time needed for plant biomass reduction by this biological control agent. Furthermore, weevils at optimal temperatures require at least 6 wk to complete a second generation (Cilliers 1991, Sullivan and Postle 2012). The herbicide-only treatment of glyphosate + diquat provided 47% more biomass reduction compared with glyphosate + diquat integrated with weevils. Giant salvinia biomass exposed to penoxsulam and flumioxazin were equivalent to the respective integrated treatments at 3 WAT.

Table 2. Mean dry-weight biomass (g 0.125 m^{-1}) of giant salvinia in response to herbicides, salvinia weevils, and integrated treatments in mesocosm trials.[1]

Treatment	WAT[2] 0	3	6	9	12
			g 0.125 m^{-1}		
SW	16.7	24.9	31.8	32.2	32.8
G + D[3]	16.3	8.3	1.0	1.5	1.6
P	17.0	18.7	16.3	11.6	6.6
F	17.1	11.0	5.6	4.3	5.4
G + D + SW	20.1	15.6	19.7	19.4	16.2
P + SW	19.4	16.4	33.9	9.7	4.6
F + SW	19.1	16.9	40.0	6.1	5.5
SW	19.0	22.5	28.1	23.6	22.6
LSD (0.05)[4]			6.8		

[1]Ten kilograms of giant salvinia were introduced in 4.7-m^2 tanks 1 wk before pretreatment data collection and herbicide application.
[2]Abbreviations: C, control; D, diquat (560.1 g ai ha^{-1}); F, flumioxazin (214.5 g ai ha^{-1}); G, glyphosate (3,364.1 g ae ha^{-1}); P, penoxsulam (70.1 g ai ha^{-1}); SW, salvinia weevil; WAT, weeks after treatment.
[3]All G + D treatments included a nonionic surfactant buffering agent blend (0.25% v/v) and a nonionic organosilicon surfactant (0.094% v/v), whereas a methylated vegetable oil (0.25% v/v) was included with all P and F treatments.
[4]$n = 6$.

At 6 WAT, glyphosate + diquat, penoxsulam, and flumioxazin reduced giant salvinia biomass by 97, 46, and 82%, respectively (Table 2). The integrated treatment of glyphosate + diquat + weevil reduced biomass by 38% of the nontreated control; however, penoxsulam + weevils and flumioxazin + weevils biomass were equivalent to the nontreated control at 6 WAT. Glyphosate + diquat, and flumioxazin provided similar efficacy (> 81%) at 6 WAT compared with the control, whereas penoxsulam only provided 49% control. Biomass was significantly greater in the integrated treatments, and plants treated with glyphosate + diquat + weevils, penoxsulam + weevils, and flumioxazin + weevils had 95, 52, and 86% more biomass, respectively, than their respective herbicide-only counterparts at 6 WAT; however, significant biomass reductions were observed in all treatments at 9 WAT.

In the herbicide-only treatments, plants treated with glyphosate + diquat, penoxsulam, and flumioxazin had significantly less biomass by 95, 64, and 87%, respectively, compared with the control at 9 WAT (Table 2). In addition, all integrated treatments were efficacious; however, penoxsulam + weevils, and flumioxazin + weevils provided the best control, reducing plant biomass 70 to 81% of the nontreated control, whereas glyphosate + diquat + weevils provided 40% control. The severe reduction in plant biomass between 6 and 9 WAT for the integrated treatments can likely be attributed to the hatching of a second generation of weevils. Insects alone provided a biomass reduction of 27% of the nontreated control at 9 WAT. At 12 WAT, the herbicide-only treatments and integrated treatments involving penoxsulam + weevils, and flumioxazin + weevils provided ≥ 83% control (Table 2). Glyphosate + diquat + weevils and weevil-only treatments failed to provide sufficient efficacy, only reducing biomass by 51 and 31% of the nontreated control, respectively, at 12 WAT.

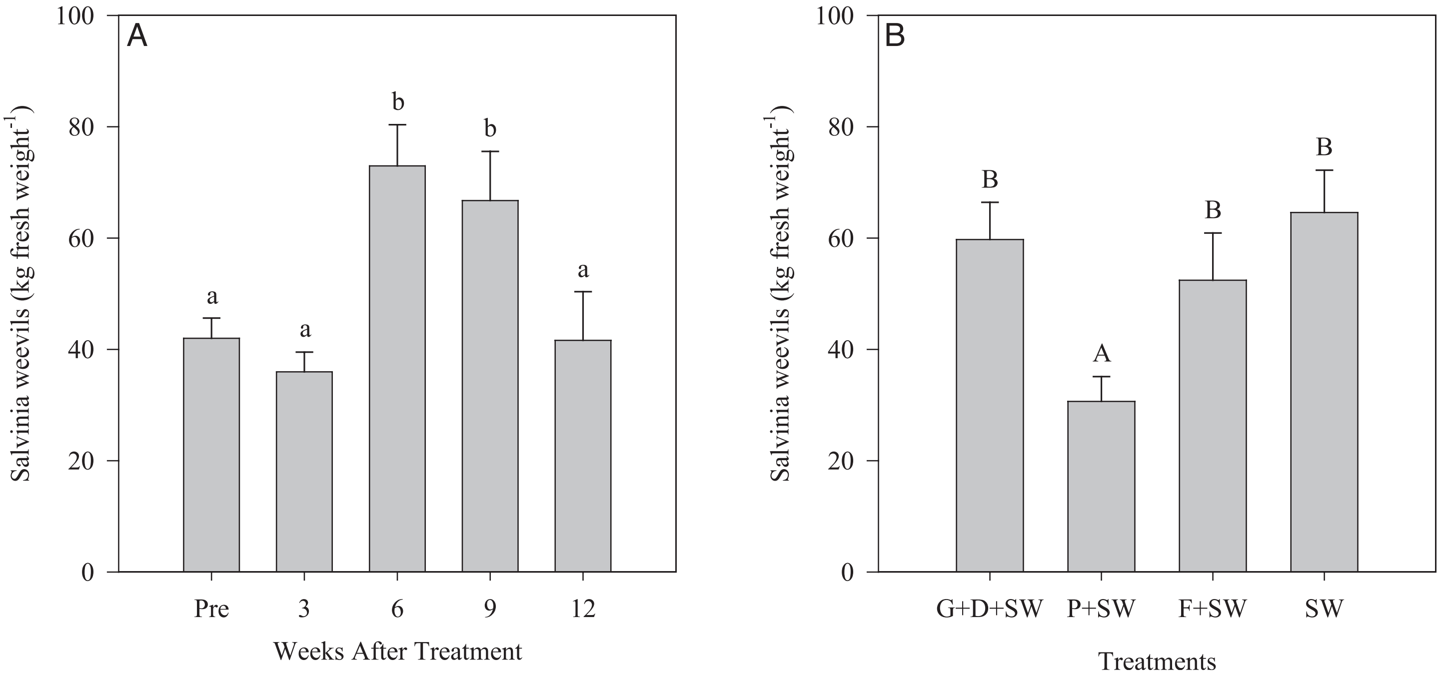

Figure 1. (A) Mean densities of salvinia weevils in mesocosm trials at pretreatment (Pre), 3, 6, 9, and 12 wk after treatment (WAT). (B) Weevil densities following herbicide applications to giant salvinia at 12 WAT. Means with different letters within a particular graph denote statistical differences according to Fisher's Protected LSD method at $P \leq 0.05$, $n = 6$. Abbreviations: G, glyphosate (3,364.1 g ae ha^{-1}); D, diquat (560.1 g ai ha^{-1}); SW, salvinia weevil; P, penoxsulam (70.1 g ai ha^{-1}); F, flumioxazin (214.5 g ai ha^{-1}). All glyphosate + diquat treatments included a nonionic surfactant buffering agent blend (0.25% v/v) and a nonionic organosilicon surfactant (0.094% v/v), whereas a methylated vegetable oil (0.25% v/v) was included with all penoxsulam and flumioxazin treatments.

Comparing a single treatment over the length of the study, the control plants increased in biomass by 47% at 6 WAT and remained similar through 12 WAT (Table 2). The glyphosate + diquat treatment decreased biomass by 50% at 3 WAT and by 90% by 12 WAT compared with pretreatment biomass. The penoxsulam treatment failed to reduce biomass until 12 WAT (61%) compared with all other subsamples, whereas the flumioxazin treatment significantly reduced biomass similarly (67%) as early as 6 WAT. These results are disparate when compared with previous research in which flumioxazin was applied to 100% of the plant material, and biomass was reduced by 98% of the nontreated control at 6 WAT (Mudge et al. 2013). The difference in efficacy between the experiments could be attributed to the amount of initial plant material at herbicide application, in which Mudge et al. (2013) inoculated 120 g of fresh-weight plant material, and the current study used 10 kg of fresh-weight plant material at inoculation.

The integrated treatment of glyphosate + diquat + weevils did not reduce giant salvinia dry-weight biomass throughout the experiment. Penoxsulam + weevil and flumioxazin + weevil treatments were not significantly different at 3 WAT compared with the pretreatment, and a significant increase in biomass occurred at 6 WAT by > 50%. Plant biomass was significantly reduced at 9 WAT by 71 and 85% for penoxsulam + weevils and flumioxazin + weevils, respectively. This delay in control is likely due to insect establishment and development of the second-generation immature insects, which is the most damaging developmental stage of the insect's life cycle. The plants exposed to the weevils treatment increased in biomass at 6 WAT by 32%, which was similar to the control, and 31% of plant material was reduced at 12 WAT compared with the control. Although this study was not conducted at optimal temperatures, the reduction in biomass between 6 and 9 wk can likely be attributed to the hatching of adults and the feeding by juvenile insects from the second generation.

Despite biomass not being reduced by the weevil treatment as originally anticipated within the 12-wk trial, a longer study may have yielded greater reductions in biomass if the third weevil generation was allowed to complete its life cycle. The weevil's life cycle must be considered when making management decisions, and longer exposure times may be needed to achieve acceptable efficacy in a mesocosm setting. In field settings, giant salvinia control by weevils has been reported to clear a 400-ha mat weighing 50,000 tons in fresh weight in as little as 15 mo in tropical climates; moreover, in subtropical zones, such as south Louisiana, success was reported between 1 to 5 yr (Julien et al. 2012, Tipping et al. 2005).

Densities of weevils are based on fresh weight of giant salvinia and are used to estimate populations in rearing facilities and in the field (Grodowitz et al. 2014, Nachtrieb 2014). When weevil densities were compared throughout the experiment, there were no differences at 3 WAT compared with pretreatment; however, there was a 100% increase in insect density at 6 WAT, regardless of herbicide application timing (Figure 1a). At 9 WAT, insect densities in all treatments were similar to that at 6 WAT but, by 12 WAT,

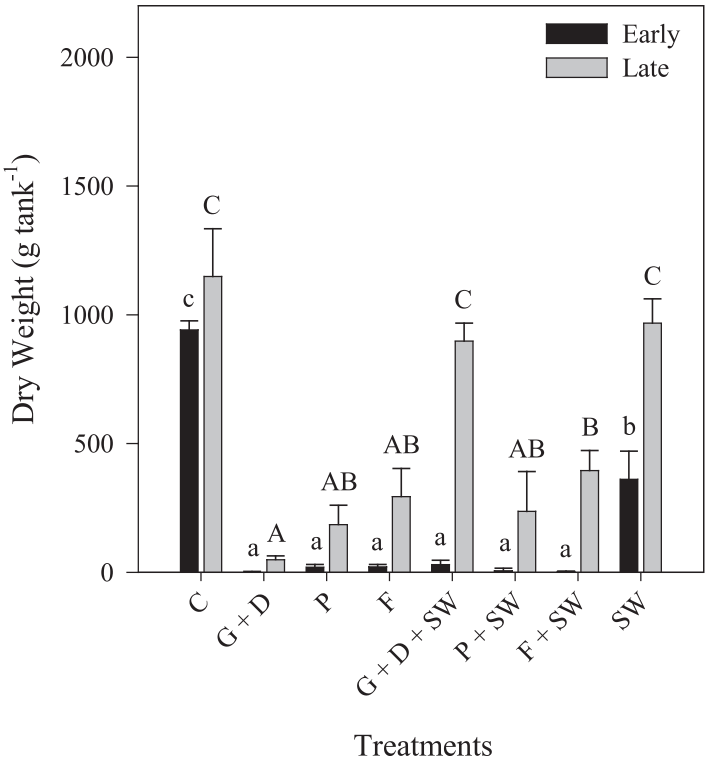

Figure 2. Giant salvinia dry weight biomass in response to herbicides, salvinia weevils, and integrated treatments. Data represent whole-tank biomass 12 wk after treatment. Means with the same letter within the early (April 7, 2016) or late (August 4, 2016) application timing trials are not significant according to Fisher's Protected LSD test at $P \leq 0.05$; $n = 3$. Abbreviations: C, control; G, glyphosate (3,364.1 g ae ha^{-1}); D, diquat (560.1 g ai ha^{-1}); SW, salvinia weevils; P, penoxsulam (70.1 g ai ha^{-1}); F, flumioxazin (214.5 g ai ha^{-1}). All glyphosate + diquat treatments included a nonionic surfactant buffering agent blend (0.25% v/v) and a nonionic organosilicon surfactant (0.094% v/v), whereas a methylated vegetable oil (0.25% v/v) was included with all penoxsulam and flumioxazin treatments.

decreased by 37% and were equal to pretreatment levels. Similar to previous IPM research (Mudge et al. 2013), these data exhibited an increase in insect density for the treatment with weevils alone at 6 WAT. These data from the present study, offer insight into the timing at which weevil densities peak, regardless of late or early season infestation. Although this study was not conducted at optimal temperatures, in which it takes 6 wk for one generation to develop (Cilliers 1991, Sullivan and Postle 2012), infested plant material at onset of the experiment contained all life stages of the insect, which supported biomass reduction by 6 WAT. Alternatively, when IPM treatments were compared across the length of the study, the density in the penoxsulam + weevil treatment was 48 to 62% lower than other treatments (Figure 1b). This indicates that this combination, although suitable, may not be the most viable option when using an IPM approach as the result of the low weevil densities at 12 WAT. Throughout the study, the weevil, flumioxazin + weevil, and glyphosate + diquat + weevil treatments negatively affected giant salvinia; therefore, they would all be viable management options.

Based on whole-tank data, treating giant salvinia early in the growing season is more efficacious than late-season herbicide applications and/or insect releases (Figure 2b). In the early trial (April 2016), all treatments containing herbicides (alone or in combination with weevils) had significantly less plant biomass than the weevil-only or control treatments. Conversely, all treatments, except glyphosate + diquat + weevils, were efficacious in the late trial (August 2016). These data suggest that glyphosate + diquat is efficacious at controlling giant salvinia during both early and late season applications, but when integrated with weevils, biomass is not significantly reduced.

By late season, giant salvinia forms more than one layer on the surface and, consequently, limits herbicide coverage. Although herbicides were applied at the same rate and plants received the same amount of acclimation in both trials, complete chemical coverage was not achieved on the second layer of plant material in the second trial. Despite no differences between early and late season in relation to insect densities at 6 and 9 WAT, weevil densities in the IPM treatments were highest during these sampling periods, possibly indicating the hatching of a second generation of insects. Longer studies may have observed a third generation and further biomass reductions or higher weevil densities. Natural resource managers typically monitor and reapply herbicides to areas when acceptable reductions are not met within ample timing. Peak weevil densities (6 and 9 WAT) in this study may offer insight for these herbicide reapplications. Based on these data, flumioxazin or penoxsulam would provide suitable alternatives to reapplying glyphosate + diquat late in the growing season to sites infested with high densities of weevils. Although complete control was not achieved, these treatments provided substantially better control than the mixture currently being used operationally in Louisiana.

Based on previous IPM research, penoxsulam + a nonionic and buffering-blend surfactant (identical mixture used in the current study) had the lowest weevil density compared with flumioxazin + the same surfactant 6 WAT (Mudge et al. 2013). In the Mudge et al. (2013) research, the significant decrease in weevil densities at 2 WAT in the penoxsulam treatment was unknown; however, the current data confirm the low weevil density in this treatment throughout the study. This study attempted to avoid direct toxicity to insects in the IPM treatments by spraying only 50% of plant material and leaving untreated plant material for foraging and harborage. Although the low insect densities could be resultant of flight, indirect toxicity, herbicidal activity in the water column, or lack and degradation of food source, these findings should be taken into consideration when natural resource managers are selecting alternate modes of action.

Previous research (Mudge et al. 2013) also provided evidence that flumioxazin and penoxsulam alone are relatively nontoxic (< 5% mortality) when directly applied to the weevil without a surfactant; however, mortality increased to 20 and 47%, respectively, with the addition of a surfactant. Because the insects are nocturnal (Schotz and Sands 1988) and adult weevils and can be found on or under fronds, within buds, or among the root-like modified leaves of giant salvinia plants (Johnson et al. 2010), direct applications of herbicides/surfactants are not likely to occur because the mixture will be applied during the daytime (Mudge et al 2013).

Although deliberately skipping entire sections of a waterbody or selectively applying herbicides in strips to provide habitat for weevils is not practical and resourceful, releasing biological control agents into backwater areas where the water is shallow and/or dense infestations of bald cypress or other trees limit or restrict boat access may be an alternative method for establishing a population and achieving control. IPM techniques could benefit stakeholders in the Gulf Coast region by reducing herbicide-control costs and the risk of herbicide resistance. These findings suggest that early season management of giant salvinia can provide better control throughout the growing season. Future studies should aim to optimize the use of herbicide applications considering the timing of weevil damage and the spatial and temporal distribution of plants and weevils in forested and open swamps. Lastly, using these methods as a foundation, researchers should experiment with other herbicides (i.e., bispyribac-sodium, fluridone, carfentrazone-ethyl, and topramezone) against giant salvinia to understand the interactions with weevils, along with cost estimates for aquatic weed management.

SOURCES OF MATERIALS

[1]Scotts Southern Turf Builder Lawn Fertilizer®, The Scotts Company, LLC. P.O. Box 606 Marysville, OH 43040.

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

[3]Tribune™, Herbicide, Syngenta Crop Protection, P.O. Box 18300 Greensboro, NC 24719.

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

[5]Galleon®, SePRO Corporation, 11550 North Meridian Street Suite 600 Carmel, IN 46032.

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

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

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

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

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