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Early season population dynamics of salvinia weevil on giant salvinia in central Louisiana

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ABSTRACT

A single salvinia weevil (Brazil ecotype) (*Cyrtobagous salviniae* Calder and Sands) release was conducted on giant salvinia (*Salvinia molesta* D.S. Mitchell) infestations on Lake Iatt, LA, United States, during 2015. The site was not monitored postweevil release and it was assumed that yearly water level drawdowns and winter freezing temperatures most likely inhibited salvinia weevil establishment. In February 2017, lake managers surveying for giant salvinia were surprised to discover salvinia weevils present lake wide. Large-scale monitoring efforts were initiated to document the occurrence of an established and self-sustaining salvinia weevil population. Adult and larval salvinia weevil density, plant nitrogen content, and water temperature were monitored every 2 wk during February through July 2017. The detection of larval weevils in February was used to estimate the previous timing of adult salvinia weevil mating and oviposition and it was determined that these reproductive activities occurred at a previously undocumented low temperature range fluctuating between 14.5 and 17 C. Adult and larval densities had a distinct inverse relationship during the early warm season. Adult densities steadily decreased as larval densities increased, indicative of overwintered adults mating and dying soon after. Adult and larval densities stabilized at subequal densities as water temperatures warmed, and continual mating, oviposition, and adult emergence produced stable densities of both adult and larval salvinia weevils in May and June. These monitoring efforts provided a rare field demonstration of the population dynamics of a lake-wide established and self-sustaining salvinia weevil population.

Key words: biological control, Brazil ecotype, *Cyrtobagous salviniae*, low temperature reproduction, *Salvinia molesta*, thermal limits.

INTRODUCTION

Giant salvinia (*Salvinia molesta* D.S. Mitchell) is a free-floating aquatic fern native to southeastern Brazil (Forno and Harley 1979, Forno 1983) that has been present within the United States since 1995 (Johnson 1995). Currently, there are giant salvinia infestations in multiple waterbodies in 13 states, Puerto Rico, and the Virgin Islands of the United States (U.S. Geological Survey 2018). The negative effects of giant salvinia infestations have been well-documented and include the formation of dense mats which clog waterways and impact recreational activities, irrigation, drainage, flood mitigation, hydroelectric production, and mosquito control, alter water quality, and displace native vegetation (Tipping 2004).

Biological control of giant salvinia, utilizing salvinia weevils (*Cyrtobagous salviniae* Calder and Sands), has been successful at managing giant salvinia in at least 13 countries worldwide (Julien and Griffiths 1998). Both adults and larvae impact the growth of salvinia, but the destruction of vascular tissue and subsequent impact to nutrient flow through larval tunneling in the rhizome is the most detrimental to the plant (Thomas and Room 1986, Julien et al. 1987). Adults feed on leaves and submerged "roots" (modified third leaf), but prefer the nitrogen-rich buds of salvinia (Room and Thomas 1986, Julien et al. 1987).

Biological control efforts were initiated within the United States in 1999 (Tipping and Center 2003), yet success remains low and inconsistent in temperate regions (Julien et al. 2009, Sullivan and Postle 2010, Mukherjee et al. 2014). Low success is primarily attributed to unsuccessful salvinia weevil overwintering due to mortality at freezing temperatures (Mukherjee et al. 2014). Overwintering difficulties within the United States have led to a review of original, landmark salvinia weevil literature as well as a broad range of recent experiments to determine the cold tolerance and behavior of salvinia weevils at low temperatures and in temperate regions (Hennecke and Postle 2006, Sullivan and Postle 2010, Allen et al. 2014, Mukherjee et al. 2014, Obeysekara et al. 2015, Mukherjee et al. 2017, Russell 2017).

A large majority of recent research has been conducted in controlled laboratory settings to determine the lower thermal limits of the salvinia weevil. Due to the difficulty of locating established and sustained salvinia weevils (Brazil ecotype), far fewer studies of salvinia weevil population dynamics have been conducted in field settings. Tipping and Center (2005) reported on the abundance of adult Florida ecotype salvinia weevils subsisting naturally on common salvinia (*S. minima* Baker) in Florida, and Mukherjee et al. (2017) described the population dynamics of egg, larvae, and adult salvinia weevil (Brazil ecotype) in southeast Texas during a 15-mo period. Additionally, Sullivan and Postle (2010) monitored egg, larvae, and pupae (Brazil ecotype) presence at multiple overwintered populations of salvinia weevils over a 3-mo period in Australia. Of the three studies

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listed, only one (Mukherjee et al. 2017) evaluated Brazil ecotype weevils within the United States.

In February 2017, lake managers surveying for giant salvinia were surprised to discover salvinia weevils present lake-wide in Lake Iatt, Louisiana (31°35′01.7″N, 92°39′13.3″W). This population was the result of a single salvinia weevil release conducted in 2015 with no subsequent monitoring efforts. We capitalized on this opportunity and conducted a study to better understand the population dynamics of this insect in the southern United States. The objectives of this study were to describe the population dynamics of a naturally occurring salvinia weevil population and estimate timing of the initial oviposition by overwintering adults and its relationship to water temperature.

MATERIALS AND METHODS

Lake Iatt is located in central Louisiana (31°35′01.7″N 92°39′13.3″W) in the United States and is approximately 2,671 ha (6,600 ac) in size. The lake bottom is privately owned, and yearly water level drawdowns are initiated to aid private timber harvesting and to provide giant salvinia management via displacement or desiccation. During the months of June and July 2015, approximately 150,000 salvinia weevils reared by Red River Waterway Commission were released onto Lake Iatt by Louisiana Department of Wildlife and Fisheries. In February 2017, lake managers surveyed the lake and were surprised to discover salvinia weevils present lake wide. Large-scale monitoring efforts were initiated to document the occurrence of an established and self-sustaining salvinia weevil population.

Twenty sampling stations were identified throughout the heavily treed portions of Lake Iatt (Figure 1). Large, open-water areas were avoided due to the ease of giant salvinia mobility and unreliability of a stable plant presence. Samples were collected every 2 wk for a total of 20 wk, 15 February through 5 July 2017. Adult and larval salvinia weevil density, plant nitrogen content, and water temperature were monitored. A boat was driven in a random pattern within a 15-m radius or 707 m^2 area encircling each sampling station and giant salvinia was randomly collected to fill three 3.8-L (1 gal nominal size) plastic bags. Samples were returned to the lab, fresh weights were obtained, and each was placed into a Berlese funnel for 48 h for adult and larval weevil extraction into 70% ethanol for preservation. Berlese funnels were constructed of galvanized sheet metal (30.5-cm-diam) with an inside platform made of 0.64 cm (0.25 in nominal size) mesh poultry netting located 27 cm from the top. A light fixture with a single 60 W incandescent bulb was placed on top of the funnel and a mason jar (pint or quart capacity) filled with 70% ethanol was attached to the funnel below the platform. Adult and larval salvinia weevils per kg fresh weight of giant salvinia were quantified by sorting and identification using a dissecting microscope. Following weevil extraction, one sample per station was randomly chosen and placed into a paper bag and dried in a forced air oven at 55 C for 48 h. Dried floating fronds were separated from submersed fronds (i.e., roots) and floating

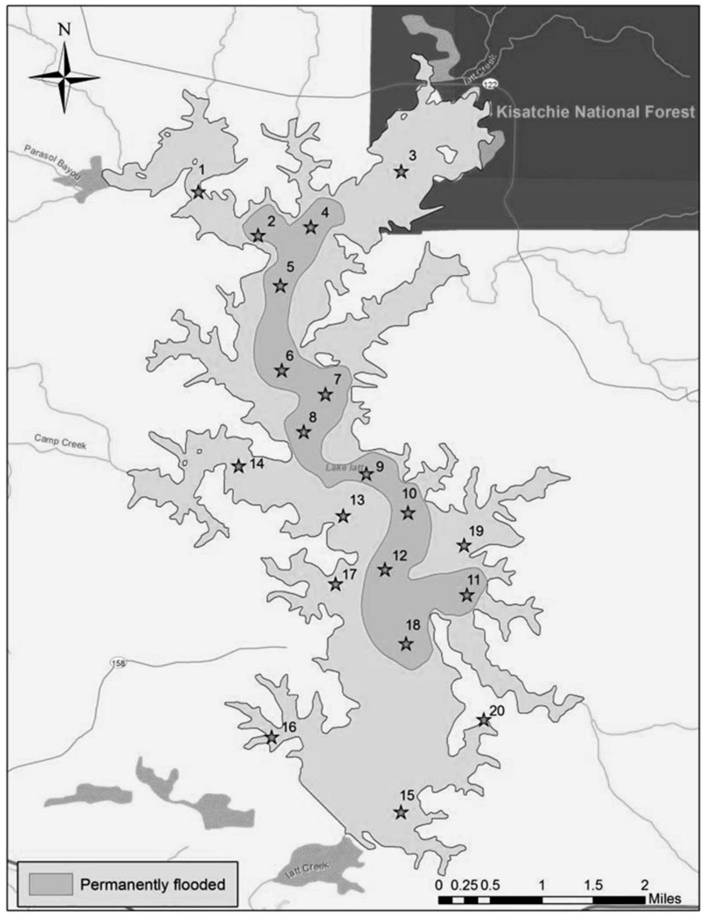

Figure 1. Lake Iatt, LA sampling stations.

fronds were mailed to the Pennsylvania State University Agricultural Analytical Services Laboratory and analyzed by combustion method using an Elementar Vario Max C/N Analyzer[1] to determine percent dry weight total nitrogen content. A water temperature logger (HOBO[2]) was placed at station 10 beneath the salvinia mat at a 5 cm depth and was programmed to continuously record hourly temperature readings. Timing of salvinia weevil life stage presence, with regard to temperature, was aligned to proceeding water temperatures (mean, minimum, and maximum water temperatures) from the 2 wk prior to weevil density sampling.

The water control/release structure on Lake Iatt was opened on 15 May 2017, beginning the yearly water level drawdown to decrease the giant salvinia infestation. By 7 June, two sampling stations were inaccessible and during the last two sampling events, 21 June and 5 July, eight and nine sampling stations were not accessible, respectively. Sampling was discontinued past 5 July due to loss of access to most sampling stations.

Statistical analyses

Data were analyzed using STATISTICA[3] version 12 software and included analysis of variance (ANOVA) and

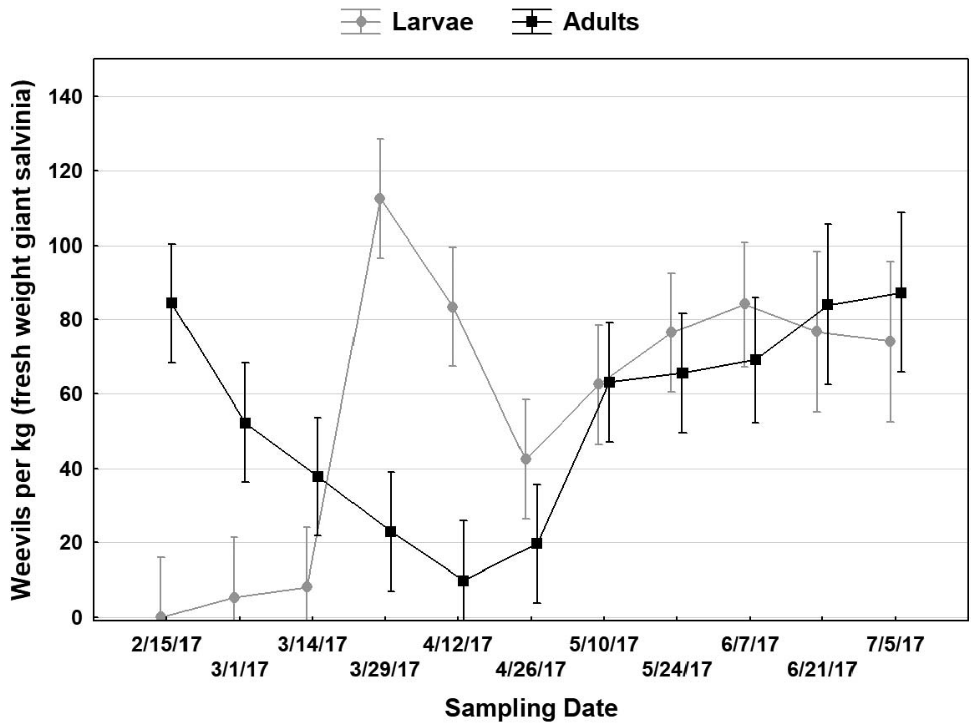

Figure 2. Mean adult and larval salvinia weevil densities (± 0.95 confidence interval).

Student-Newman-Keuls multiple comparison/range tests. A one-way ANOVA was performed to analyze changes in percent dry weight nitrogen content by sampling date. Statements of significance made throughout text refer to alpha level 0.05.

RESULTS AND DISCUSSION

Low larval densities were present in samples collected on 1 March (Figure 2). During the preceding 2-wk time period, the maximum and minimum water temperatures were 17 and 14.5 C, respectively (Figure 3). Sands et al. (1983) determined that the minimum water temperature for larval survival was 17 C under a constant temperature regime. However, our field data suggest that fluctuating temperatures of 14.5 to 17 C did not inhibit larval survival. In similar findings, larvae were detected by Sullivan and Postle (2010) at field sites at minimum water temperatures as low as 16 C.

Forno et al. (1983) documented negligible oviposition at constant temperatures of 21 C and 19 C and no successful egg hatch at less than 19 C. Several authors have suggested that oviposition and egg hatch might occur at lower temperatures if weevils have been acclimated to a natural, fluctuating, cold temperature regime (Hennecke and Postle 2006, Mukherjee et al. 2014, Obeysekara et al. 2015). Yet to our knowledge, none have documented this in field or laboratory studies. Based on the temperatures preceding larval detection at Lake Iatt, salvinia weevil mating, oviposition, and egg hatch occurred at temperatures fluctuating between 14.5 and 17 C.

Larvae reached peak density at Lake Iatt on 29 March (Figure 2), and although eggs were not counted during this study, it can be presumed that peak oviposition preceded the presence of peak larval density. During the 2-wk period preceding 29 March, maximum and minimum water temperatures were 24 and 18.5 C, respectively (Figure 3). Maximum temperatures were similar to those identified by Forno et al. (1983) as optimum for maximum salvinia weevil oviposition, constant water temperatures of 23 or 27 C. Yet the minimum temperatures were within the range of negligible egg laying as determined by Forno et al. (1983). Similar to the results for larval presence, this study suggests that in a natural, fluctuating temperature regime, temperatures below the low limit threshold are not detrimental to salvinia weevil reproduction.

At the beginning of the season, adult and larval densities experienced an inverse relationship in which adult weevil density decreased as larval density increased (Figure 2). This suggests that as overwintered adults mated, they soon after perished, as determined by a steady decline in adult density from 15 February through 12 April. This trend has been observed by the authors for many years during salvinia weevil rearing in open air cultures boxes and was documented in Lake B. A. Steinhagen in TX by Mukherjee et al (2017). Larval density sharply increased from 14 March to 29 March and then declined for a period of 4 wk as larvae developed into pupae and adults, resulting in increased adult density past 12 April (Figure 2). As warm temperatures stabilized, simultaneous mating, oviposition, and new adult emergence resulted in stable, subequal adult and larval densities from 10 May through 5 July, the end of sampling (Figure 2).

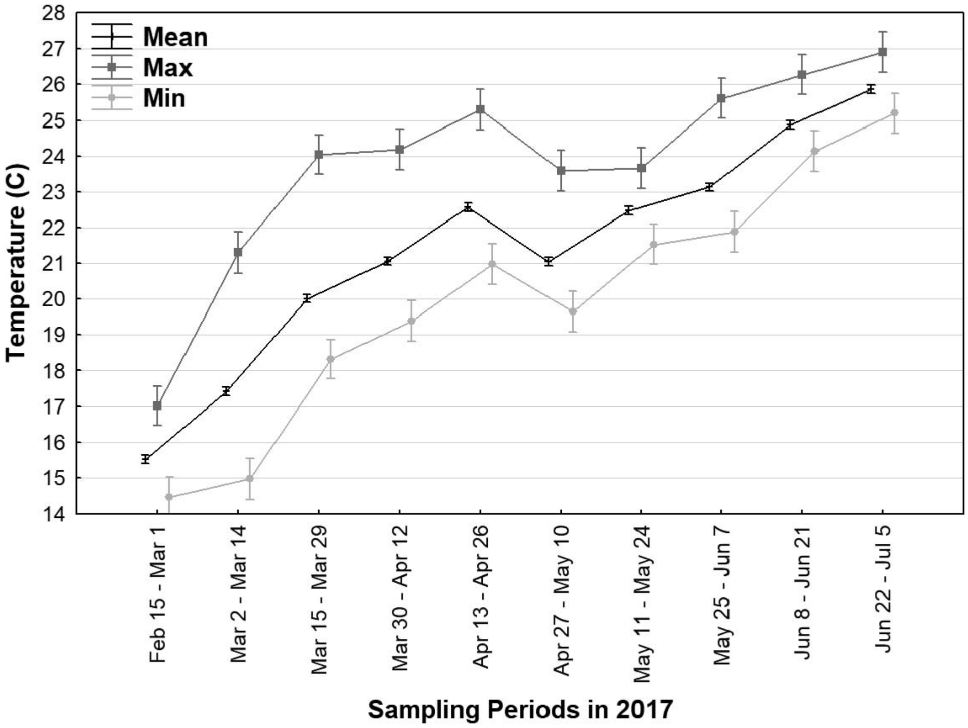

Figure 3. Maximum, mean, and minimum water temperature (C) (± standard error) collected at 5 cm depth beneath giant salvinia mat. Water temperature was grouped into 2-wk time periods equal to the time between each sampling date.

Many past studies have highlighted the importance of plant nitrogen content to herbivore growth rates, size, fecundity, productivity, and overall population size (McNeil and Southwood 1978, Brunsting and Heil 1985, Keesing 1993). Past studies have determined that increased nitrogen content of giant salvinia decreases larval development time (Sands et al. 1983), increases egg production (Sands et al. 1986), and increases weevil growth rate (Sands et al. 1983). Sands et al. (1986) identified 1.5% dry weight nitrogen content as the critical value necessary for salvinia weevil reproduction, but Room et al. (1989) determined that nitrogen values greater than 3% dry weight were optimum. In past studies conducted in Louisiana waterbodies, salvinia weevils were significantly reduced or did not successfully establish at sites with less than 1.5% plant nitrogen content (Nachtrieb 2019, Nachtrieb et al. 2019). During the current study at Lake Iatt, giant salvinia nitrogen content was stable and equal to or greater than the critical limit of 1.5% dry weight nitrogen for the entire 5-mo sampling period (Figure 4). Plant nitrogen content at Lake Iatt ranged from 1.50 to 1.94% dry weight and was sufficient to support sustained salvinia weevil establishment and population growth at Lake Iatt during this study.

This study demonstrates the potential for lower cold tolerance of acclimated salvinia weevils living in natural, fluctuating water temperatures as opposed to thermal limits determined during controlled laboratory studies at constant temperatures. During this study, larval presence was used to estimate the timing of adult salvinia weevil mating, oviposition, and egg hatch and it was determined that these reproductive activities occurred at a previously undocumented low temperature range fluctuating between 14.5 and 17 C.

Additionally, this study documented other population dynamics and trends of adult and larval salvinia weevils. Adult and larval densities had a distinct inverse relationship during the early warm season. Adult densities steadily decreased as larval densities increased, indicative of overwintered adults mating and dying soon after. As water temperatures warmed, continual mating, oviposition, and adult emergence produced stable and subequal densities of both adults and larvae. Overall, these monitoring efforts provided a rare field demonstration of the population dynamics of a lake-wide established and self-sustaining salvinia weevil population.

SOURCES OF MATERIALS

[1]Elementar Vario Max C/N Analyzer, Elementar, Germany.

[2]HOBO, Onset, 470 MacArthur Blvd., Bourne, MA 02532.

[3]STATISTICA version 12, formally of StatSoft, Inc., Tulsa, OK, currently owned by TIBCO Software Inc., 3307 Hillview Avenue, Palo Alto, CA 94304.

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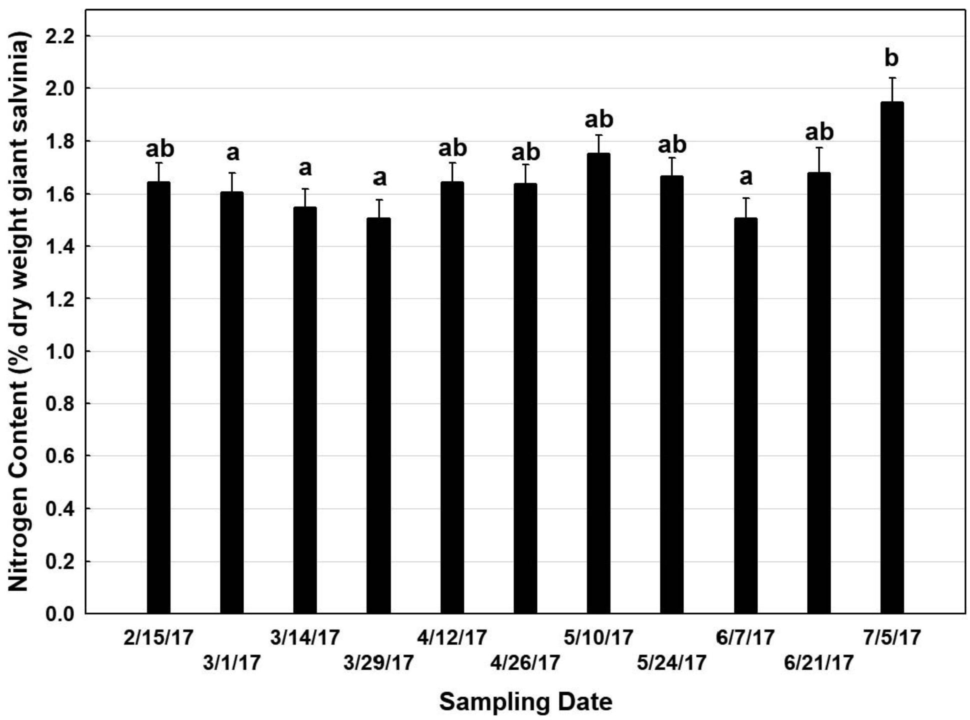

Figure 4. Mean plant nitrogen content ($\pm$ standard error) at each sampling date. Means with the same letter are not significantly different (Student-Newman-Keuls test, $\alpha = 0.05$). One-way ANOVA, sampling date: $P = 0.024$, F = 2.14.

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