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NOTES

Effects of salinity and pH on growth of giant salvinia (*Salvinia molesta* Mitchell)

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INTRODUCTION

Giant salvinia (*Salvinia molesta* Mitchell) is a floating aquatic fern native to southeastern Brazil. The species is considered invasive and is currently found worldwide in subtropical, tropical, and temperate regions. It has been reported in more than 20 countries including the United States, where it was most likely introduced as an aquarium or water garden species (Room et al. 1981). Giant salvinia has invaded several freshwater aquatic systems in southern, southwestern, and gulf coastal states of the United States, where it has exhibited persistent and sometimes explosive growth (USGS 2004). An aggressive aquatic species under ideal conditions, giant salvinia can completely cover water surfaces and form mats up to 1 m thick (Thomas and Room 1986). Dense mats of giant salvinia can impede transportation, irrigation, hydroelectric production, flood and mosquito control, destroy habitats, degrade water quality, and hinder rice cultivation and fishing (Holm et al. 1977, Mitchell 1979). Despite its invasive characteristics, several environmental factors appear to limit the range, distribution, and survival of giant salvinia within the United States, including temperature, salinity, pH, and nutrient availability (Cary and Weerts 1984, McFarland et al. 2004, Owens et al. 2004, 2005).

Temperature is probably the greatest factor limiting giant salvinia survival and growth. In the United States, giant salvinia has a distinct northern boundary corresponding to low (below freezing) winter temperature, and does not persist in locations where ice forms for extended periods (Harley and Mitchell 1981, Whiteman and Room 1991, Owens et al. 2004).

Oliver (1993) found that giant salvinia has a low tolerance for salinity and cannot colonize or survive marine or brackish waters. In Cameron Parish, LA, good control of giant salvinia has been attained by pumping high-salinity waters into infested canals. The resultant short-term increase in salinity (to approximately 20 parts per thousand [ppt]) decreased giant salvinia populations in less than 4 wk (USGS 2007). An 18-foot storm surge from Hurricane Rita (2005) carried saltwater into Cameron Parish, LA, increasing salinities that resulted in elimination of all floating freshwater vegetation (D. Sanders, pers. comm.). Additionally, storm surge after Hurricane Katrina (2005) and subsequent increases in marsh water salinities are thought to have caused declines of giant salvinia previously found west of the Pascagoula River delta, MS (MS Department of Marine Resources 2006, Madsen et al. 2007). Problematic growth of giant salvinia may therefore be limited in systems exhibiting brackish to saline conditions, or that are prone to periods of saltwater intrusion.

Research has shown that pH also affects giant salvinia survival and growth (Owens et al. 2005, Owens and Smart 2010). Explosive growth is associated with low pH (7.0 or less units) and dissolved oxygen, where nutrients may become more available to floating plants such as giant salvinia. Because giant salvinia obtains nutrients via the modified third leaf that resembles roots, nutrient availability in the water column is essential for maximum growth. At higher pH (over 7.0 units), giant salvinia may survive but growth is limited because of reduced nutrient availability (Wetzel 1983, Riemer 1984, Owens et al. 2005, Owens and Smart 2010). Cary and Weerts (1984) found that greatest dry weights were obtained from giant salvinia plants grown in nutrient solution at a pH of 6.0 versus plants grown at a pH of 7.0 or greater.

The objectives of this study were to document the combined effects of pH and salinity on giant salvinia growth. This knowledge is useful for predicting distributional limits of giant salvinia, as well as evaluating the potential for new infestations to reach problematic proportions.

MATERIALS AND METHODS

This study was conducted at the Lewisville Aquatic Ecosystem Research Facility (LAERF) located in Lewisville, TX. Fourteen treatments included two distinct pH levels at seven salinities, with six replicates of each treatment. In August 2007, 0.24 L of LAERF pond sediment was added to 84 19-L containers to ensure that adequate trace nutrients were available to sustain growth of giant salvinia. Smart et al. (1995) found that LAERF pond sediments were fine textured, generally consisting of equal parts clay, silt, and sand. Containers were filled with alum-treated water from Lake Lewisville. Each container was amended with 20 ml of

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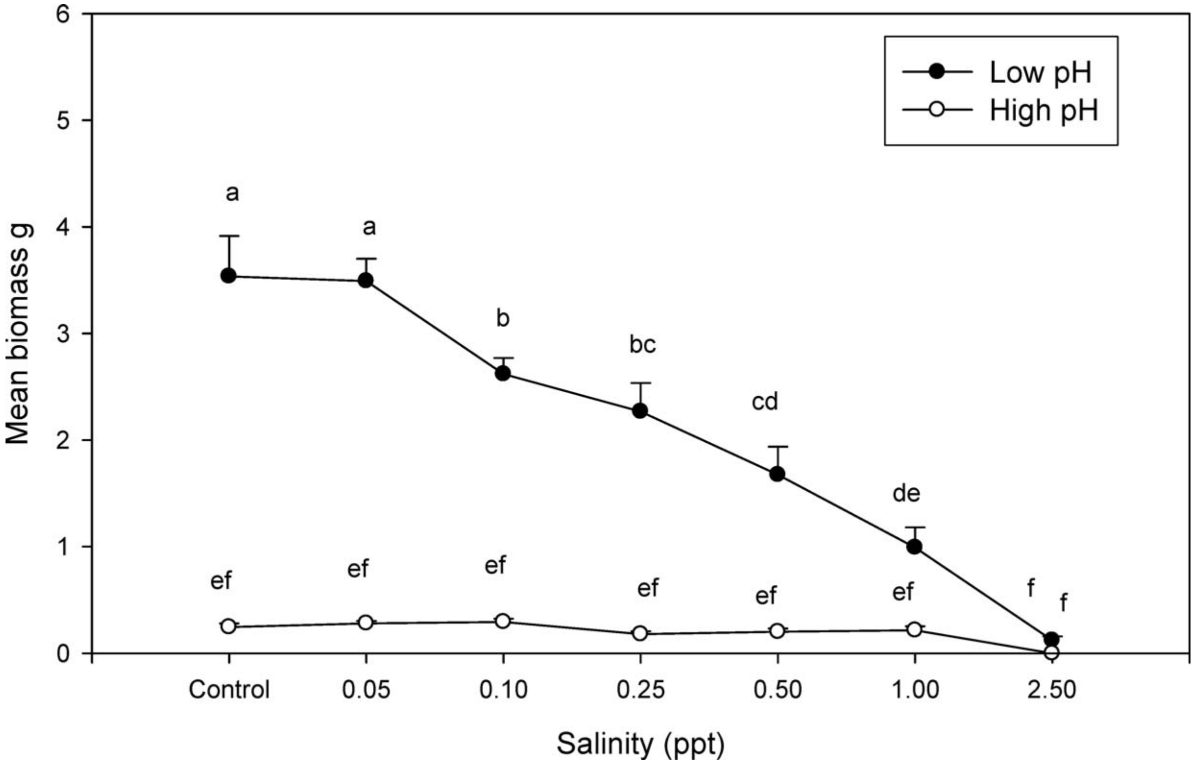

Figure 1. Significant two-way ANOVA interaction ($P < 0.0000$, $F = 25.038$) for giant salvinia biomass (mean biomass g) between the two parameters of pH and salinity. Main effects for pH ($P < 0.0000$, $F = 446.5286$) and salinity ($P < 0.0000$, $F = 32.15$). The letters a to f indicate significant differences for low-pH and high-pH line graphs.

a 26.5 g L^{-1} NH_4NO_3 (2 mg L^{-1} N) and 8.26 g L^{-1} Na_2PO_4-H_2O (0.2 mg L^{-1} P) solution to provide nitrogen and phosphorus for the duration of the study.

Water from Lake Lewisville used in the study typically exhibits high pH (8.5+) and this level represented high pH treatments. Low pH (7.0 and less) was maintained by adding 0.8 L (30 g) of nonbuffered Canadian peat moss (Premier Horticulture, Quebec, Canada) to appropriate containers. The pH was measured weekly using Waterproof pH Testr 10 (Eutech, Ind, Vermont Hill, IL). Salinity treatments (measured as specific conductance in µmho) were amended with NaCl and $NaHCO_3$ to achieve the following concentrations: Control (400 µmho, 20 mg Na L^{-1} [LAERF pond water]), 0.05 ppt (600 µmho, 50 mg Na L^{-1}), 0.1 ppt (800 µmho, 100 mg Na L^{-1}), 0.25 ppt (1,350 µmho, 250 mg Na L^{-1}), 0.5 ppt (2,400 µmho, 500 mg Na L^{-1}), 1.0 ppt (4,350 µmho, 1,000 mg Na L^{-1}), and 2.5 ppt (10,000 µmho, 2,500 mg Na L^{-1}). Twelve containers per salinity treatment (six low and six high pH) were used. After amendments, one giant salvinia plant with five leaf pairs was added to each container. Each plant was green, robust, and undamaged by herbivory. Six salvinia plants were collected and dried for initial biomass weights (average 0.04 g).

Algal growth was controlled using 100 µl of Aquashade (Applied Biochemist, Germantown, WI) and floating styrofoam plates to limit light penetration of water column. Plates were removed as giant salvinia grew to minimize interference with spread. Measurements of pH and conductivity (to monitor salinity) were made during the first and third weeks of the study, and the surface area of the container covered by giant salvinia (percent cover) was estimated and recorded weekly. Plants were collected from each container after 3 wk of growth, dried to a constant weight at 55 C using a Blue M forced-air oven (General Signal, Atlanta, GA), and weighed. Statistical differences between treatment dry weights were calculated using a two-way ANOVA. Significant differences between means were determined using Tukey's at $P = 0.05$ level of significance. Statistics were performed using Statistica 7.1 (StatSoft, Inc., Tulsa, OK).

RESULTS AND DISCUSSION

Significant interaction effects ($P < 0.0000$, $F = 25.038$), as well as the main effects of pH ($P < 0.0000$, $F = 446.5286$) and salinity ($P < 0.0000$, $F = 32.15$), were identified for giant salvinia biomass production (Figure 1). Figure 1 clearly shows that plants grown under low pH conditions (less than 7.0) produced greater biomass than the high-pH treatments, agreeing with findings by Owens et al. (2005) when evaluating the effects of pH alone and Owens and Smart (2010). Plants were also affected by increasing salinity (Figure 1).

Owens et al. (2005) and Owens and Smart (2010) reported that giant salvinia covered the surface of low-pH (7.0 or less, average 6.4 ± SE 0.14) tanks within 4 wk; however, this did not occur in the high-pH (8.0+, average 8.2 ± SE 0.16) tanks. In the current study, initial starting surface coverage (one five-leaf-pair plant) for all treatments was approximately

5%. After 1 wk of culture, all low-pH (7.0 or less) treatments except for the highest conductivity (2.5 ppt) averaged approximately 15 to 20% coverage. By weeks 2 and 3, the low-pH treatments except for the 1.0 ppt and 2.5 ppt salinities averaged between 60 and 90% surface coverage. By week 3 the 1.0 ppt salinity treatment had approximately 40% surface coverage, whereas plants in the highest salinity treatment (2.5 ppt) under low pH conditions never covered more than 5% of the container surface. High pH treatments except for the highest salinity (2.5 ppt) grew to cover approximately 10 to 15% surface area by week 2 with a slight increase by week 3. The highest salinity treatment at high pH did not exhibit growth and plants were dead by week 3.

Increased growth at lower pH is due to the availability of nutrients under those conditions. Because giant salvinia is a free-floating plant, nutrients must be obtained from the water column via the modified third leaf, which resembles roots. Increased growth at lower pH may be attributable to the uptake availability of micronutrients such as manganese and iron, which exhibit pH-dependent solubility (Wetzel 1983, Riemer 1984). Therefore, either or both of these nutrients may limit growth under higher-pH conditions. Without these micronutrients, important processes such as photosynthesis, chlorophyll synthesis, enzymatic activity, etc. may be affected (Raven et al. 1992). Poor growth of giant salvinia at higher pH in our study likely reflected these limitations.

Salinity can affect plant growth and survival by increasing osmotic potential and accumulation of ions in plant tissue (Levitt 1972, Yeo 1983, Wainwright 1984, Flowers 1985, Munns 1993, Howard and Mendelssohn 1999). Studies have shown that giant salvinia has low tolerance for saline systems and cannot survive in marine or brackish water (Oliver 1993). Storrs and Julien (1996) found that infestations of giant salvinia can survive at approximately 2,000 μS cm^{-1} but conductivities by around 4,800 μS cm^{-1} (equal μmho) damaged plant tissue and reduced plant growth rate about 25% (Divakaran et al. 1980). This study found an approximate threefold decrease in plant biomass production around 4,350 μmho when grown under low-pH conditions, indicating that under otherwise sufficient growing conditions, increasing salinity negatively affects giant salvinia growth. This same effect was not observed under high-pH conditions, where growth was limited by other factors. However, as salinity increased even under optimum (low) pH conditions, giant salvinia produced significantly less plant biomass. It should be noted that under low-pH conditions, small amounts of giant salvinia survived even when grown at 2.5 ppt salinity, whereas in high pH, no giant salvinia survived to week 3 at the higher salinity level.

Giant salvinia has been in the United States for several years and is now a major detrimental factor in many lakes (e.g., Lake Bistineau, LA) and wetland systems (e.g., Caddo Lake, TX/LA) where it is not limited by temperature. This research reveals the importance of pH and salinity on the growth potential of giant salvinia and provides information that could be used to identify areas (low pH, low salinity) where giant salvinia could potentially become a problem.

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