Water temperature controls the growth of waterhyacinth and South American sponge plant

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ABSTRACT

We examined the effect of water temperature on the growth of two free-floating aquatic species in this study: waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] and sponge plant [*Limnobium laevigatum* (Humb. & Bonpl. Ex Willd.) Heine]. Waterhyacinth has been rated as the worst aquatic weed worldwide. A native of South and Central America, it is a recurring management issue in tropical and subtropical freshwater bodies in the United States. Sponge plant, native to southern Mexico, Central America, South America, and the Caribbean, was first detected in California in 2003. We studied the growth of these two species with two 6-wk growth studies (for each species), at water temperatures of 15, 20, 25, and 30 C. All temperatures were replicated in four tanks, for a total of 16 tanks. Waterhyacinth biomass was over 2,000 g dry weight (DW) m^{-2} for plants grown at 25 and 30 C by 42 d after start (DAS). Waterhyacinth density reached almost 800 rosettes m^{-2} at 42 DAS at 25 and 30 C. Waterhyacinth relative growth rate (RGR) reached 0.099 d^{-1}, for a doubling time of 7.0 d. Sponge plant biomass at42 DAS was 400 g DW m^{-2} at 25 and 30 C. Density was as high as 3,900 rosettes m^{-2} at 42 DAS grown at 25 C. Sponge plant RGR was 0.12 d^{-1} at 25 C, for a doubling time of 5.7 d. The invasive potential of sponge plant has been demonstrated in this study.

Key words: biomass, *Eichhornia crassipes*, environmental driver, *Limnobium laevigatum*, relative growth rate.

INTRODUCTION

Plants respond to a variety of environmental drivers that limit their growth through either a limiting requirement or a stressing extreme. These include factors such as light intensity and photoperiod, water availability, nutrient availability, carbon dioxide, oxygen, temperature, and a suitable place to establish (Bornette and Puijalon 2011, Madsen 2013). For aquatic plants, water availability is generally not a limiting factor. For a floating or emergent plant, the ready availability of unobstructed sunlight, unlimited access to carbon dioxide and oxygen, and access to plentiful water create some of the most productive plant communities on the planet (Westlake 1963). Temperature is often cited as a factor that limits plant growth at both the lower (Owens and Madsen 1995) or upper (Whiteman and Room 1991) extremes of the plant's physiological limits, but in between these limits temperature controls the rate of chemical and biochemical reactions (Carr et al. 1997). While due consideration must be given to nutrient availability, particularly nitrogen and phosphorus (Cary and Weerts 1983, Henry-Silva et al. 2008), temperature is a key factor in floating and emergent aquatic plants' initiation of sprouting, germination, and rate of growth (van der Heide et al. 2006, Miskella and Madsen 2019).

Waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] is an invasive free-floating herbaceous perennial plant native to South and Central America, though likely originating from the Amazonian basin (Penfound and Earle 1948). Widely distributed for the water garden trade, it is now infesting warm regions of North and South America, Africa, Europe, Asia, and Australia (Holm et al. 1969). It was introduced to the United States at the Cotton Centennial Exposition in New Orleans in 1884, to Florida in 1890, and California by 1920 (Penfound and Earle 1948). Plant growth results in dense mats from clonal reproduction, with rosettes near the mat edge forming many child plants on attached stolons. Self-thinning occurs as density increases, leading to fewer rosettes that are larger in size (Madsen 1993b). Dense mats of waterhyacinth cause significant economic losses and impact the ability to utilize water resources (Holm et al. 1969, Edwards and Musil 1975, Mullin et al. 2000, Villamagna and Murphy 2010). In addition, waterhyacinth infestations may cause significant environmental and ecological impacts to water quality, water quantity, and plant and animal communities (Villamagna and Murphy 2010, Getsinger et al. 2014). For decades, waterhyacinth has been considered the world's worst aquatic weed (Holm et al. 1977).

Sponge plant (also called South American spongeplant or West Indian spongeplant) [*Limnobium laevigatum* (Humb. & Bonpl. Ex Willd.) Heine] is a free-floating aquatic plant that reproduces both sexually and vegetatively (USDA APHIS 2013). Sponge plant was first observed in California in 2003, and by 2010 had spread to 12 counties, including into the Sacramento–San Joaquin River Delta (USDA APHIS 2013). A relatively recent invader to California, it is native to Mexico, Central America, South America, and the Caribbean (USDA APHIS 2013). In addition to California, it has been introduced to southern Africa and Japan, apparently through use in the aquarium and water garden trades

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(Kadono 2004, Howard et al. 2016). A weed risk assessment has evaluated sponge plant as a high risk for both potential impact and potential to establish and spread in the United States (USDA APHIS 2013). The State of California has placed it on the State Noxious Weed List, with orders for eradication.

Water temperature is a typical environmental parameter used for modeling the growth of aquatic plants (Carr et al. 1997, Bornette and Puijalon 2011). Data can be collected in natural settings, with abundance data collected across the growing season; data can also be obtained from collecting plants grown under controlled conditions for similar time periods but at differing temperatures (Mitchell and Tur 1975). Typically, a relative growth rate (RGR) is calculated using the biomass differential over the period of time, from which the doubling time can be calculated (Mitchell and Tur 1975, Sastroutomo et al. 1978). Our purpose in this study was to grow waterhyacinth and sponge plant under controlled temperature conditions to assess the effect of water temperature on the growth of these two plants.

MATERIALS AND METHODS

The experiments for both species used the same experiment design. The experiments were conducted in a greenhouse at the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA ARS) Aquatic Weed Research Facility in Davis, CA, at ambient air temperature. Waterhyacinth and sponge plant were collected from the Sacramento–San Joaquin River Delta near Stockton, CA. The natural light was supplemented with overtank lighting to establish a 14 : 10 light : dark photoperiod. Four rows of four fiberglass tanks (330 L each) were used, with each row controlled for water temperature (15, 20, 15 and 30 C). The water temperature in each row was controlled using a chiller/heater with temperature controller[1] to generally within ± 1 C. Each tank was subdivided into six cells of 0.1 m^2 using a polyvinyl chloride frame. Waterhyacinth initial planting was two rosettes (31.4 g dry weight [DW]) per cell and sponge plant initial planting was three rosettes (0.72 g DW) per cell. All experiments were carried out for 6 wk, with one quadrat per tank harvested every 7 d. At harvest, the number of rosettes was counted; the entire biomass was dried at 70 C for 48 hr, and then weighed. The experiments on each species was done twice, for two runs per species and four experiments total. This created eight replicates for each temperature and species. Before the studies, water in the tanks was amended with adequate nitrogen to produce 4 ppmw N in the water as nitrate, and nutrients and water were replenished as needed.

The weekly RGR was calculated from the change in biomass over time, using the following equation:

$$\mathrm{RGR} = \frac{(\ln W_2 - \ln W_1)}{(t_2 - t_1)} \quad [1]$$

where W_2 is the biomass at Time 2, W_1 is the biomass at Time 1, t_2 is the days after start at Time 2, and t_1 is the days after start at Time 1 (Radford 1967, Hutchings 1986). RGR was calculated only on the first 7 d of growth, before the plant growth was suppressed by crowding. Doubling time was calculated from RGR using this equation:

$$\mathrm{DT} = \frac{\ln 2}{\mathrm{RGR}} \quad [2]$$

where DT is doubling time (Mitchell and Tur 1975).

Statistical analysis of biomass and relative growth rate were calculated using Statistix 10.0.[2] For comparison between temperatures, biomass at the end of the study (42 d after start [DAS]) was analyzed using a one-way ANOVA, with means compared using a Bonferroni Significant Difference at $P = 0.05$. A simple linear regression of RGR versus water temperature was calculated using the same platform.

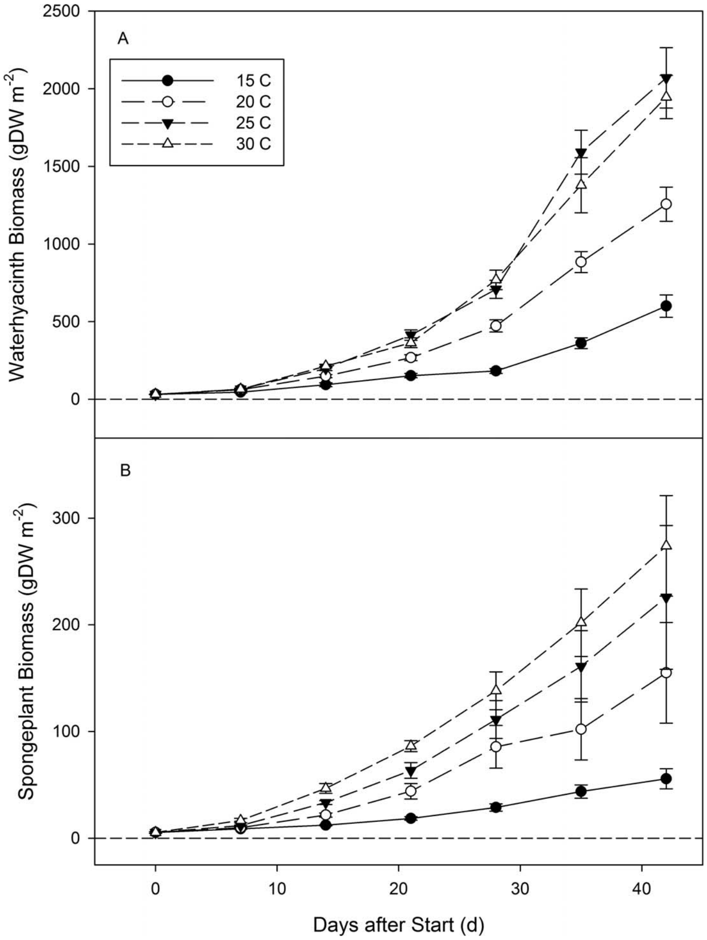

Figure 1. (A) Waterhyacinth biomass (g dry weight [DW] m^{-2}) versus days after start (DAS) grown in greenhouse tanks for 6 wk, an average of samples every week for two studies. (B) Sponge plant biomass (g DW m^{-2}) versus DAS grown in greenhouse tanks for 6 wk, an average of samples collected every week for two studies. Bars indicate ± 1 standard error of the mean. Plants grown at 15, 20, 25, and 30 C. Note the difference in the Y axis.

RESULTS AND DISCUSSION

Waterhyacinth biomass increases exponentially over time at all four temperatures, but the rate of increase is not the same for all temperatures (Figure 1A). The growth at 25 and 30 C is similar, while at 15 and 20 C growth is less than at the

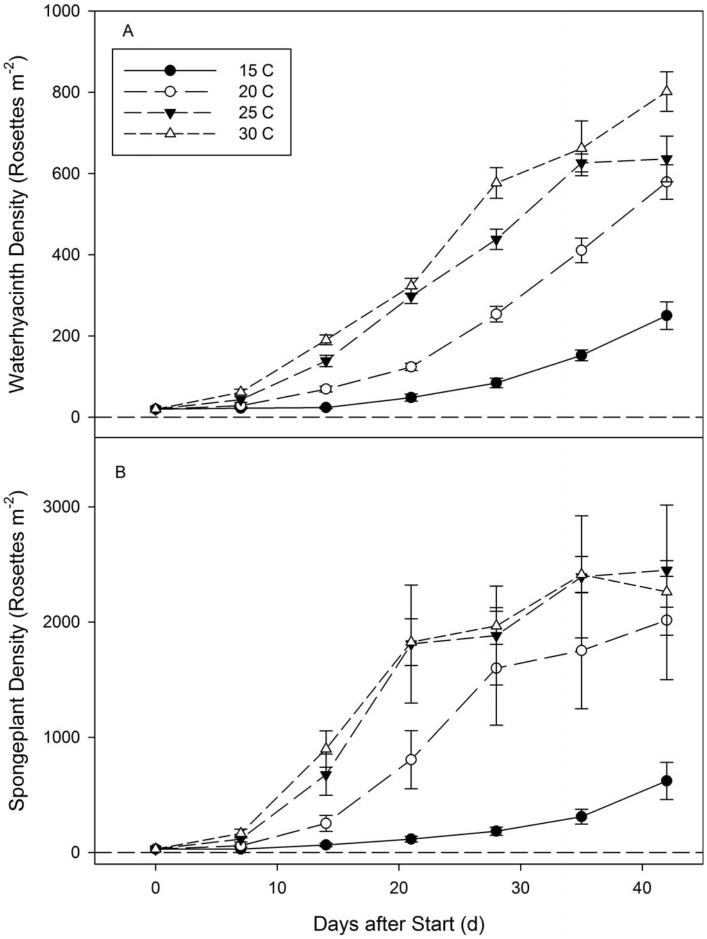

Figure 2. Density (rosettes m^{-2}) of plants grown for 6 wk in a temperature-controlled tank at water temperatures of 15, 20, 25, and 3 0C. (A) waterhyacinth, (B) sponge plant.

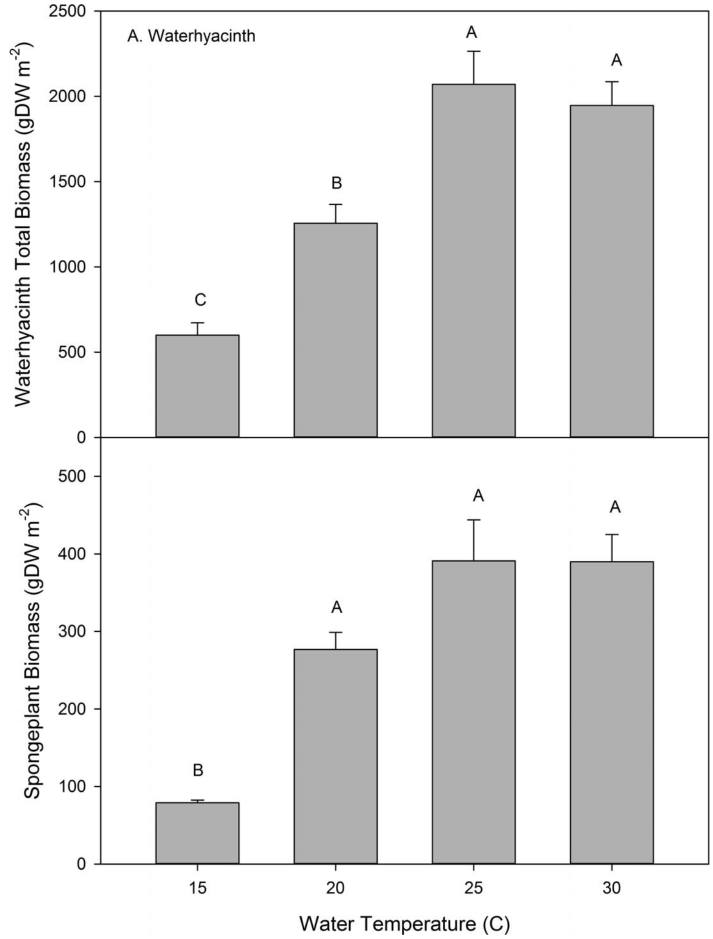

Figure 3. Biomass of plants grown for 42 d at 15, 20, 25, and 30 C in a greenhouse under controlled water temperature conditions. Means with a different letter are significantly different based on a Bonferroni Significant Difference at $P = 0.05$ on a one-way ANOVA. Bars are $\pm$ 1 standard error of the mean. (A) Waterhyacinth, (B) sponge plant.

other two temperatures by 42 DAS. Waterhyacinth does not grow or sprout below 15 C, but will grow at or above 15 C (Miskella and Madsen 2019). Waterhyacinth will grow most rapidly when densities are low, with growth slowing as plant densities increase. Plant growth then translates into an increase in the size of individual rosettes (Madsen 1993b). In this study, density increased for waterhyacinth grown at 25 and 30 C at a similar rate, but not for those plants grown at 15 or 20 C (Figure 2A). By 42 DAS, biomasses of waterhyacinth grown at 25 and 30 C are not statistically different from each other, but they are significantly greater than biomass at 20 C, and plants grown at 20 C have higher biomass than those grown at 15 C (Figure 3A). Water temperature has a significant effect on both biomass and density of waterhyacinth plants.

Waterhyacinth relative growth rate is also significantly affected by water temperature. A simple linear regression of RGR versus water temperature yields this equation:

$$RGR = 0.043 + 0.0020 \times T \qquad [3]$$

where RGR is relative growth rate and T is temperature (Figure 4A). This regression is statistically significant ($P = 0.0075$), but the R^2 is low ($R^2 = 0.0371$). High variability in growth and biomass data is not uncommon (Madsen 1993a). The RGR at 15 C was 0.068 (DT = 10.2); it was 0.087 (DT = 7.9) at 20 C, 0.099 (DT = 7.0) at 25 C, and 0.098 (DT = 7.1) at 30 C. These growth rates are consistent with those reported for field measurements. For instance, Sale et al. (1985) report an RGR of 0.089 to 0.093 and a DT of 7.8 for plants grown in outdoor tanks in Griffith, Australia. Wilson et al. (2005) report that the RGR of field-grown plants tends to be somewhat below the values found in this study. That these values may represent an overestimate of what might be observed in field-grown plants is not unlikely given that temperature is maintained for these plants, adequate nutrients are constantly supplied, and light availability is unimpeded.

Very little has been published previously on the growth and temperature requirements of sponge plant. The growth of sponge plant over 6 wk was similar at 20, 25 and 30 C but not at 15 C (Figure 1B). While waterhyacinth reached a biomass of over 2,000 g DW m^{-2} in 6 wk (Figures 1A and 3A), the maximum biomass of sponge plant was less than 400 g DW m^{-2} (Figures 1B and 3B). Over time, the densities of sponge plants grown at 25 and 30 C were similar, but lower

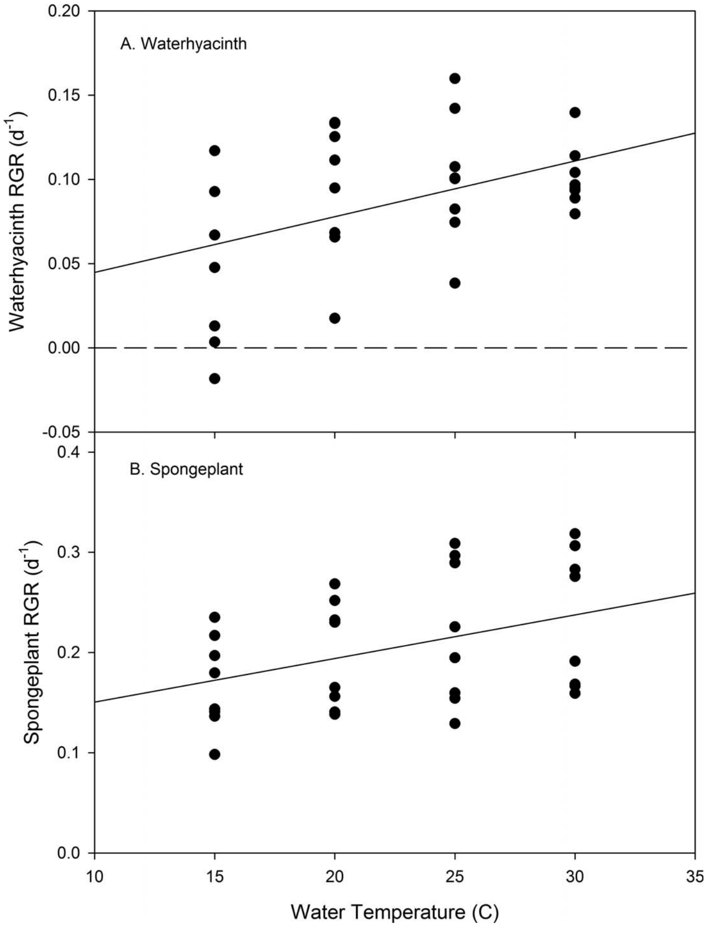

Figure 4. Regression of relative growth rate (RGR) of (A) waterhyacinth and (B) sponge plant after 7 d of growth versus water temperature (C) under controlled water temperature conditions of 15, 20, 25, and 30 C. Note the difference in the Y axis.

densities were observed for plants grown at 15 and 20 C (Figure 2B). Biomass in sponge plants after 42 DAS was similar when grown at 20, 25, and 30 C, but significantly lower for plants grown at 15 C (Figure 3B).

The growth rate of sponge plant, however, was greater than that observed for waterhyacinth. A simple linear regression of RGR versus water temperature resulted in the following equation:

$$RGR = 0.043 + 0.0029 \times T \quad [4]$$

where T is water temperature (Figure 4B). The regression is significant ($P = 0.0056$), but the R^2 is low ($R^2 = 0.0475$). At 15 C, the RGR is 0.076 (DT = 9.1); at 20 C, RGR = 0.11 (DT = 6.2); at 25 C, RGR = 0.12 (DT = 5.8); and at 30 C, RGR = 0.12 (DT = 5.7). The doubling time is substantially less than that of waterhyacinth, and is comparable to giant salvinia (*Salvinia molesta* Mitchell) (RGR, 0.11 to 0.16; DT, 6.2 to 5.3; Sale et al. 1985). While sponge plant has not been widely studied, the growth rate is certainly comparable to some of the worst aquatic weeds. If the potential growth and spread of sponge plant could equal giant salvinia, then sponge plant has the potential to be a significant threat to water resources in the United States.

This study makes important contributions to other efforts within the Delta Region Areawide Aquatic Weed Project, and more broadly within aquatic plant management. These data for waterhyacinth and sponge plant have already been incorporated into the bioeconomic growth models used to evaluated the project outcomes (Jetter et al., this volume) and could be utilized in other plant growth models. Growth rate data is also one component of weed risk assessment protocols (Kriticos and Brunei 2016, Lozano and Brundu 2018). This study impacts management of floating plants in the Delta, as well. In the past, the initiation of management was decided by a calendar date, by which time the aquatic plants in a given year may already be actively growing, or not yet started. Either extreme will waste management resources and increase costs. Using water temperature data, managers can predict when plants will start actively growing, and management should commence. Likewise, if given scientific documentation, regulatory agencies may agree to management seasons that reflect the environmental and biological reality rather than a time framework based on the calendar.

SOURCES OF MATERIALS

[1]UTCH-5 1 HP Titanium chiller/heater with controller, Universal Marine Industries, 2790 Sunnyside Road, Anmore, BC V3H 4W9, Canada.

[2]Statistix 10.0, Analytical Software, 2105 Miller Landing Road, Tallahassee, FL 32312.

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