Aquatic Botany 136 (2017) 175–185

Contents lists available at ScienceDirect

Aquatic Botany

journal homepage: www.elsevier.com/locate/aquabot

Investigating the role of water and sediment chemistry from two reservoirs in regulating the growth potential of *Hydrilla verticillata* (L.f.) Royle and *Cabomba caroliniana* A. Gray

Brent J. Bellinger*, Stephen L. Davis[1]

Watershed Protection Department, City of Austin, 505 Barton Spring Rd., Austin, TX 78704, USA

ARTICLE INFO

Article history:
Received 22 April 2016
Received in revised form 13 October 2016
Accepted 15 October 2016
Available online 19 October 2016

Keywords:
Aquatic invasive species
Growth rates
Sediment texture
Mesocosm
Stoichiometry

ABSTRACT

Knowledge of aquatic system physicochemical characteristics can inform managers into growth potential of submerged plants. In a mesotrophic central Texas reservoir, Lake Austin, the exotic invasive *Hydrilla verticillata* (L.f.) Royle thrived for over a decade until management efforts achieved recent control. However, in the immediate downriver eutrophic reservoir, Lady Bird Lake, *H. verticillata* has been unsuccessful despite repeated introductions. Instead, the native plant *Cabomba caroliniana* A. Gray has recently colonized and spread. In this study we established mesocosms approximating each reservoir and tracked plant growth metrics to test the role of water chemistry and sediment chemistry and composition in inhibiting or supporting two internationally important species. Lake Austin had a significantly higher pH and lower nitrate concentrations in the water and sandy sediments compared to the eutrophic, silty reservoir. We observed higher growth rates and greater biomass of *H. verticillata* and *C. caroliniana* in the eutrophic reservoir treatments; the former species growth contrary to expectations. Between species, *H. verticillata* relative growth rates were nearly 4× higher, lengths 5–10× longer, and dry weights 2–5× greater than those for *C. caroliniana* within a given treatment. Concurrent with rapid growth rates in the eutrophic reservoir treatments, tissue phosphorus contents for both species increased. Our findings suggest that *H. verticillata* growth in the eutrophic reservoir has not been significantly impaired by the water and sediment attributes measured in this study. Conversely, our initial evidence corroborates the reduced growth potential of *C. caroliniana* in systems of relatively low nutrients and pH over 8.

1. Introduction

Submerged aquatic vegetation (SAV) is an important component of lentic and lotic aquatic systems, facilitating nutrient uptake and retention, settling of sediment particles, providing habitat for aquatic organisms, and attenuating wave energy (Thorp et al., 1997; Madsen et al., 2001). However, nuisance growth can negatively affect aquatic ecosystems in ways such as reducing native vegetation diversity and abundance, impacting recreational uses by fouling props or entangling swimmers, and damaging water control structures (Langeland, 1996; Crooks, 2002; Sousa, 2011). In such cases, aquatic plant management may be necessary to control nuisance growth in order to maintain desired ecosystem services.

Hydrilla verticillata (L.f.) Royle is native to Asia and India and has successfully colonized aquatic systems across the globe, often to the detriment of the native flora and physical properties of the system (Kennedy et al., 2009; Sousa, 2011). Annually, significant effort and resources are expended to control and reduce growth of *H. verticillata* using mechanical, chemical, biological, and physical methods in infested aquatic systems, notably in the sub-tropical southern United States (Langeland, 1996). *Cabomba caroliniana* is a native aquatic plant to the southern United States and northern South America and is generally not actively managed within its' native range (Wilson et al., 2007). However, primarily through the aquarium trade, *C. caroliniana* has been introduced across the northern United States, Canada, Europe, and Australia where it is recognized as an invasive exotic nuisance (Schneider and Jeter, 1982; Wilson et al., 2007; June-Wells et al., 2013; Bickel and Schooler, 2015). Control of *C. caroliniana* has been focused on biological and physical methods as chemical control agents have been less effective (Wilson et al., 2007; Schooler, 2009).

In central Texas, USA, *H. verticillata* has an established and sometimes prolific presence in the reservoirs and free-flowing rivers, negatively impacting recreational and flood control func-

* Corresponding author.
E-mail addresses: brent.bellinger@austintexas.gov, bjbellin@mtu.edu (B.J. Bellinger), sdavis@bseacd.org (S.L. Davis).
[1] Present address: Barton Springs/Edwards Aquifer Conservation District, 1124 Regal Row, Austin, TX, 78748, USA.

http://dx.doi.org/10.1016/j.aquabot.2016.10.005
0304-3770/

tions (*e.g.*, the Colorado River and reservoirs; Supplemental Fig. S1) (for a full Texas distribution map see: http://www.texasinvasives.org/observations/mapping.php?species=HYVE3&search=go; site accessed 7/2016). However, a conspicuous exception to *H. verticillata*'s spread across central Texas has been in a eutrophic reservoir in downtown Austin, TX (*i.e.*, Lady Bird Lake; Supplemental Fig. S1). Despite repeated inadvertent introductions from the contributing reservoir over a decade and a half period, *H. verticillata* has not yet become established (Gilroy, 2006; B. Bellinger, pers. obs.). Rather, SAV was typically sparse in the small flow-through reservoir until 2011 when *Cabomba caroliniana* A. Gray, colonized from a tributary source and quickly spread through the upper reach of the reservoir (Magnelia and De Jesus, 2008; Farooqi and De Jesus, 2012). An understanding of the physicochemical characteristics of each reservoir where the species have been differentially successful will further our understanding of the attributes of aquatic systems that contribute to plant spread, growth, and success.

The growth, species composition, and biomass of SAV are primarily influenced by existing plant community composition and biomass, basin morphology, phytoplankton shading, herbivore density, pH, and nutrient availability. When determining the susceptibility of a system to successful colonization by an aquatic plant (desired or not), sediment composition and chemistry and water chemistry are commonly evaluated (Koch, 2001; Bornette and Puijalon, 2011; Sousa, 2011; June-Wells et al., 2013; Matthews et al., 2013). *Hydrilla verticillata* has been shown adaptable to oligotrophic through eutrophic lentic and lotic temperate and tropical systems (Langeland, 1996; Sousa, 2011). However, *H. verticillata* has an apparent preference to sediment organic matter content. Growth has been shown to be negatively affected by dense inorganic sands or fine organic sediments (*i.e.*, bulk densities < 5% or > 20%, respectively) (Barko and Smart, 1986; Spencer et al., 1992; Sousa, 2011). While nutrient limitations to growth influencing competition are a potential with inorganic sediments, growth inhibition in organic matter-rich sediments may be related to phytotoxin concentrations (Barko and Smart, 1983; Koch et al., 1990; Sousa, 2011). For example, Wu et al. (2009) observed reductions in *H. verticillata* photosynthetic activity when sulfide was added to the root zone.

Conversely, *C. caroliniana* appears to inhabit a more restricted ecological niche. Preferential physicochemical conditions include protected inlets or channels that have soft, loose, silty, nutrient-rich sediments that are minimally impacted by wave energy or high currents due to a shallow root system and fragile stems (Wilson et al., 2007; Schooler et al., 2009; Bickel, 2012). *Cabomba caroliniana* was typically found in eutrophic systems but has recently been shown capable of spreading to oligotrophic waters (Wilson et al., 2007). Specific conductance has been correlated with *C. caroliniana* occurrence (June-Wells et al., 2013), but pH appears to be one of the most important determinants of success. Optimum growth occurs at a pH of 4–6 with senescence at a pH over 8. The rationale for the decline in condition at an elevated pH is a preference for CO_2 (Riemer, 1965; Schooler, 2009; Bickel, 2012; but see Matthews et al., 2013). Occurrence of *H. verticillata* has been positively correlated with pH, but a pH < 7 may not be detrimental through effective uptake of CO_2 and HCO_3^- (Sousa, 2011). Both species appear capable of utilizing water and sediment nutrients (Langeland, 1996; Wilson et al., 2007), though the latter have been shown more important to *H. verticillata* growth (Barko and Smart 1986; Sousa, 2011).

In this study we evaluated the sediment and water characteristics of two reservoirs that may have promoted or limited the growth of two potentially nuisance species in order to provide managers with more information when evaluating system vulnerability or resistance to colonization. We utilized mesocosms to approximate two central Texas reservoirs where *H. verticillata* and *C. caroliniana* have had individual success and cross-planted each species in order to track growth potential. By removing interspecific competitive influences on growth potential, we tested the hypotheses that: (1) physicochemical attributes of the sediments in the eutrophic Lady Bird Lake reservoir have heretofore prevented invasion by *H. verticillata*; and (2) an elevated pH coupled with less water and sediment nutrients in the mesotrophic Lake Austin reservoir would impair *C. caroliniana* growth and thus potential future spread.

2. Materials and methods

2.1. Study area

In central Texas, a series of reservoirs have been created along the Colorado River for flood control, water supply, and hydroelectric generation, and are increasingly used for recreational activities (Lower Colorado River Authority [LCRA], http://www.lcra.org/about/overview/Pages/default.aspx; site accessed 7/2016). Lake Austin (30°21′05.8″N, 97°48′22.4″W) and Lady Bird Lake (30°14′53.2″N, 97°43′05.0″W) are the last two reservoirs in the Highland Lake chain (Supplemental Fig. S1). Both reservoirs are maintained at a constant level and have historically functioned as run-of-the-river systems (*i.e.*, they do not provide storage).

Lake Austin is a 34 km long, 647 ha reservoir with an average depth of 3.5 m and maximum depth of 22.9 m. Based on the trophic state index (TSI; Carlson, 1977) classification, the Lake Austin reservoir has generally maintained mesotrophic-to-eutrophic conditions (TSI = 35–50; Porras and Richter, 2015; B. Bellinger, unpubl. data). In 1999, the invasive aquatic plant *H. verticillata* was first observed in Lake Austin (Gilroy, 2006). For over a decade the areal coverage of *H. verticillata* varied from approximately 3–240 ha until the end of 2013 when observable vegetative growth was virtually eliminated due to stocked triploid *Ctenopharyngodon idella* (Valenciennes) (Lesniak, 2015). Littoral sediments where *H. verticillata* was abundant have been observed as coarse, compact sands (Gilroy and Turner, 2010).

Lady Bird Lake is a 7 km long, 189 ha reservoir with an average depth of 4.3 m and maximum depth of 7.6 m (Gilroy, 2006; Magnelia and De Jesus, 2008). The Lady Bird Lake reservoir has a eutrophic TSI score (> 50) based on historic data (Porras and Richter, 2015; B. Bellinger, unpubl. data). Aquatic vegetation coverage in Lady Bird Lake had historically been minimal (< 5% coverage) until 2011 when *Cabomba caroliniana* A. Gray colonized the reservoir from a tributary source and subsequently spread across over 20% of the reservoir area (Magnelia and De Jesus, 2008; Farooqi and De Jesus, 2012; Lesniak, 2015). Sediments supporting *C. caroliniana* are soft, fine organic materials (B. Bellinger, pers. obs.).

2.2. Experimental design

2.2.1. Treatments

Our study was carried out in a greenhouse facility at the University of Texas at Austin Brackenridge Field Laboratory (BFL; 30°17′04.6″N, 97°46′41.8″W). The facility faces southwest and received unfiltered sunlight in the late morning through afternoon during the study period of August–October 2015. Greenhouse temperature (daytime 20–30 °C) was moderated by an evaporative cooler. We established four treatments with five replicates for each plant species for a total of forty experimental mesocosm units in 19 L plastic buckets. Replicate treatment containers were placed in a water-filled basin (4 m × 2 m × 0.3 m deep) to further regulate treatment water temperatures. Treatment combinations and abbreviations were: Lady Bird Lake water with Lady Bird Lake sediments (LBW/LBS); Lake Austin water with Lake Austin sediments (LAW/LAS); Lady Bird Lake water with Lake Austin sediments (LBW/LAS); and Lake Austin water with Lady Bird Lake sediments