Student Section

Featured Article: Student Research Highlight

Hydrilla impacts on dissolved oxygen and fish habitat quality in two Florida lakes

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Abstract

The fast growth and dense structure of some macrophyte species can alter water chemistry and impact fish habitat quality. Hydrilla, *Hydrilla verticillata* is an invasive aquatic weed which exhibits rapid growth and may contribute to low dissolved oxygen concentrations (hypoxia, DO <2.0 mgL^{-1}) during warm summer months. We evaluated the spatial and temporal dynamics of dissolved oxygen in three habitat types: open water, edge of beds, and the dense hydrilla bed interior, in two Florida lakes. Our results showed that habitat type, month, and depth all significantly influenced dissolved oxygen and up to 100% of the water column was severely hypoxic (DO <1.0 mgL^{-1}) in dense and edge habitat types in late summer in the small lake. However, we found no hypoxia in the large lake. These results suggest that lake morphology and size could influence the impacts of hydrilla on water quality. Additionally, increasing edge habitat may not greatly influence DO concentrations unless substantial open-water area adjacent to dense beds is maintained for adequate water cycling.

Introduction

Submersed macrophytes offer beneficial fish habitat by providing ample food resources and refuge from predators (Crowder and Cooper 1982). However, macrophytes at high densities can alter water chemistry and adversely affect habitat quality (Caraco et al. 2006). Invasive aquatic plants frequently obtain higher biomass and coverage than many native plants due to rapid growth, lack of natural predators, and adaptation ability (Gurevitch et al. 2006). The morphology of macrophyte species, such as branching and leafing, can contribute to low dissolved oxygen (DO) by shading sunlight during the day, respiring at night, and reducing water circulation (Bowes et al. 1979; Caraco et al. 2006).

Hydrilla verticillata (commonly called hydrilla, as well as water thyme or Florida elodea) is an invasive aquatic weed exhibiting dense stemming throughout the water column and produces a thick, branching mat at the surface. Hydrilla supports high abundance of small and young fishes attracted by structural habitat and macro-invertebrate resources (Barnett and Schneider 1974; Tate et al. 2003); however, the inverse relationship between vegetation density and dissolved oxygen (DO) may influence how fish use this habitat (Miranda and Hodges 2000; Burleson et al. 2001). Maximum growth of hydrilla combined with rising water temperatures during summer and nightly respiration can potentially result in hypoxic (DO <2.0 mgL^{-1}) conditions considered unsuitable for fish utilization (Miranda et al. 2000).

Our objectives were to (1) evaluate DO dynamics at temporal and spatial scales across three habitat types (open water, edge of hydrilla beds, and dense hydrilla bed interior) and compare these results between one small and one large Florida lake. This information will help resource managers determine where suitable habitat may be limited and require management actions.

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Methods

Study Area: Sampling took place on Sandmine Lake (28°91 N, 81°57 W) in Lake County and Lake Tohopekaliga (28°10 N, 81°23 W) in Osceola County, Florida. Sandmine Lake is a 121-hectare man-made lake and former sandmine operation in the Lake Norris Conservation Area, owned by the St. Johns River Water Management District (SJRWMD 2011). Its depth is variable from 2-9 meters. The study area was located in the southern end, adjacent to the deepest portion (mining area) of the lake where consistent open water was found with adjacent dense hydrilla beds. By late summer, the high majority of the lake was covered with *Hydrilla* mats except for the deep mining area.

Lake Tohopekaliga (Toho) is a 9,186-hectare lake in the Kissimmee Chain of Lakes, and a popular sportfishing destination in central Florida (D'Andrea 2010). Its depth ranges from 2-5 meters. The study area was located in Goblet's Cove on the eastern portion of the lake. Lake Toho is heavily managed for its sport fishery, recreational boating, and the endangered snail kite, *Rostrhamus sociabilis*. Both lakes contain fish species common to Florida, including sportfish such as sunfish (*Lepomis spp*., largemouth bass, *Micropterus salmoides*, and crappie, *Pomoxis nigromaculatus*.

Dissolved Oxygen Sampling

We used Yellow Spring Instruments (YSI, Model 556 MPS) handheld multiparameter sondes to evaluate the spatial and temporal fluctuation of dissolved oxygen (mgL^{-1}) from June – October 2012. Sampling was conducted during early morning hours when DO was expected to be lowest due to nightly macrophyte respiration (Hannan and Anderson 1971); specifically, this was from dawn until a maximum of four hours after dawn. We also collected data in the afternoon, from four hours before dusk until a maximum of one-half hour after dusk, for comparison. Twenty-five water quality samples were recorded at random sites within each habitat type (dense, edge, open water) at three defined depths: surface (0.00-0.61 m), mid (0.61-1.21 m), and deep (1.21-1.81 m). Due to hurricane conditions in late October, we were only able to obtain 15 samples from Sandmine Lake early morning sampling, and no data was attainable for afternoon sampling or at Lake Toho. Each sampling locale was a minimum one boat length from the previous location. Six to seven samples were taken at least one meter apart at each locale and marked with Global Positioning System receivers.

Although the lake bottom was deeper than 1.82 m, the Florida Department of Environmental Protection (FDEP) recommends DO sampling be conducted in the upper half of the water column or upper 2 m where total lake depth exceeds 4 meters. The rationale is that the littoral zone habitat is most often utilized by the fish and invertebrates under consideration, and thus focus should be on this stratum (FDEP 2012).Currently, the minimum dissolved oxygen standard is set at 5.0 mgL^{-1} by the FDEP; however, a statewide review revealed that 52-70% of sampled Florida lakes and rivers fail this criterion (FDEP 2012). The state of Florida has now proposed a new DO criterion based on regional regression analysis of average condition indices and daily average DO saturation to determine minimum DO concentrations for systems experiencing naturally-low DO. This analysis concluded that DO saturation of 38% (3.0 mgL^{-1}) reached during the daily workday period (8:00 – 17:00) is necessary for healthy biological systems in Peninsular Florida (FDEP 2012). With consideration of this report, the typical diel cycle of oxygen output and uptake by plants, and the primary literature on the hypoxia tolerance of fishes, we categorized dissolved oxygen concentrations and hypoxia as "severe" being less than 1.0 mgL^{-1}, "stressful" being DO 1.0-2.0 mgL^{-1}, and "adequate" being over 2.0 mgL^{-1} (Moss and Scott 1961; Miranda et al. 2000).

Vegetation sampling

We also collected hydrilla biomass samples to compare relative vegetation density with dissolved oxygen concentrations. A vertical biomass rake (Johnson and Newman 2011) was used to collect hydrilla samples at four random locations within dense hydrilla beds every month in both lakes. Collected vegetation was placed in a dry oven set at 77-79°C for a minimum of 48 hours, and weighed. Biomass samples were averaged and extrapolated to kgm^{-2} dry weight.

Analysis

Analysis of variance (ANOVA) was used to determine if dissolved oxygen varied by month (4 or 5 months: June – September/October), habitat type (3 types: dense, edge, open water), and depth (3 depths: surface, mid, deep) in full factorial design, separately for each lake, and for afternoon dissolved oxygen means. Factorial design was chosen a priori because we believed that all factors could influence dissolved oxygen simultaneously. Post-hoc analyses were performed for specific comparisons with Tukey's Honestly Significant Difference test. These comparisons were 1) surface versus deep DO within each habitat type in June and September, and 2) surface DO between habitat types in September. Surface level was chosen for between-habitat comparisons because it was consistently the highest DO throughout the water column.

Results

Sandmine Lake

For early morning and afternoon DO means, all main effects (month, habitat type, and depth) and lower-level interactions were highly significant (ANOVA, $p<0.001$). However, the three-way interaction was also highly significant, indicating that all factors in combination have substantial influence over dissolved oxygen, as well as influence over each other, during the summer season (ANOVA, $p<0.001$).

Dissolved oxygen declined with month and depth over the summer season in all habitat types (Figure 1). Surface-level DO was significantly higher than deep for all habitat types in June (Tukey HSD, $p<0.001$), indicating a strong DO gradient. Low dissolved oxygen was first seen in August, with hypoxia extending throughout the entire water column in dense and edge habitat types. Dissolved oxygen declined to severe hypoxia in September with a very weak depth gradient; surface DO was not significantly higher than deep DO in any habitat type (Tukey HSD, $p>0.05$). Between-habitat comparisons showed mean surface DO in edge habitat was not significantly higher than in dense habitat, and although hypoxia in open water was less severe than in dense and edge habitat types, it was not significantly higher (Tukey HSD, $p>0.05$).

Instance of hypoxia declined in the afternoon so that DO reached the FDEP recommended minimum (DO ≥ 3.0 mgL^{-1}) in the surface of the water column in all habitat types (Figure 2).

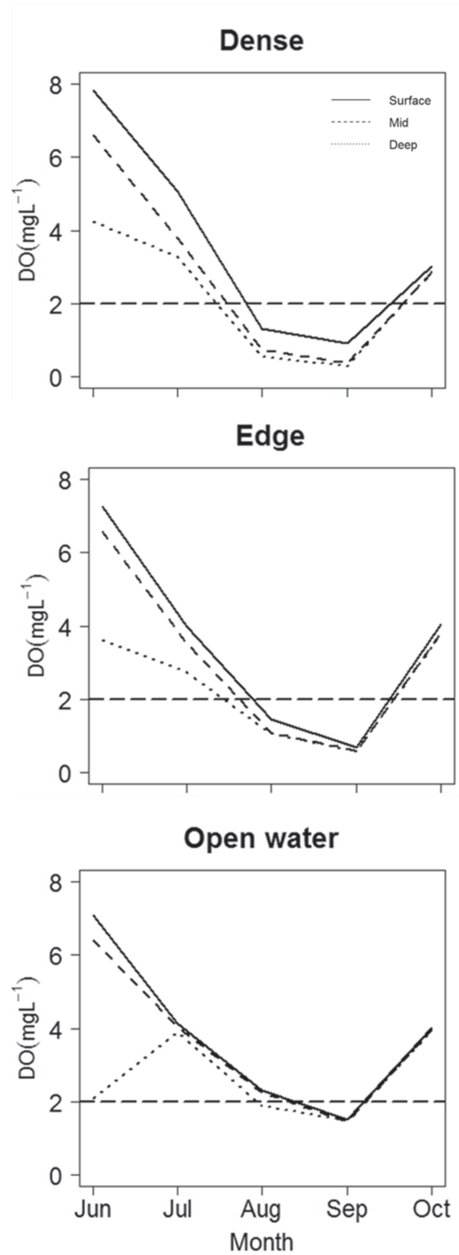

Figure 1. Early morning mean dissolved oxygen concentrations (N=25 for June – September, N=15 for October) for dense, edge, and open water habitat types by month and depth at Sandmine Lake, June – October 2012. Long-dashed line set at 2.0 mgL^{-1} represents the threshold of hypoxia.

Surface DO was significantly higher than deep DO (Tukey HSD, $p<0.001$), indicating the return of a substantial DO gradient in all habitat types. Between-habitat comparisons of surface DO showed edge habitat was not significantly higher than dense habitat (Tukey HSD, $p>0.05$) and not significantly different from open water (Tukey HSD, $p>0.05$). Interestingly, dense habitat surface DO was significantly higher than open water (Tukey HSD, $p<0.001$).

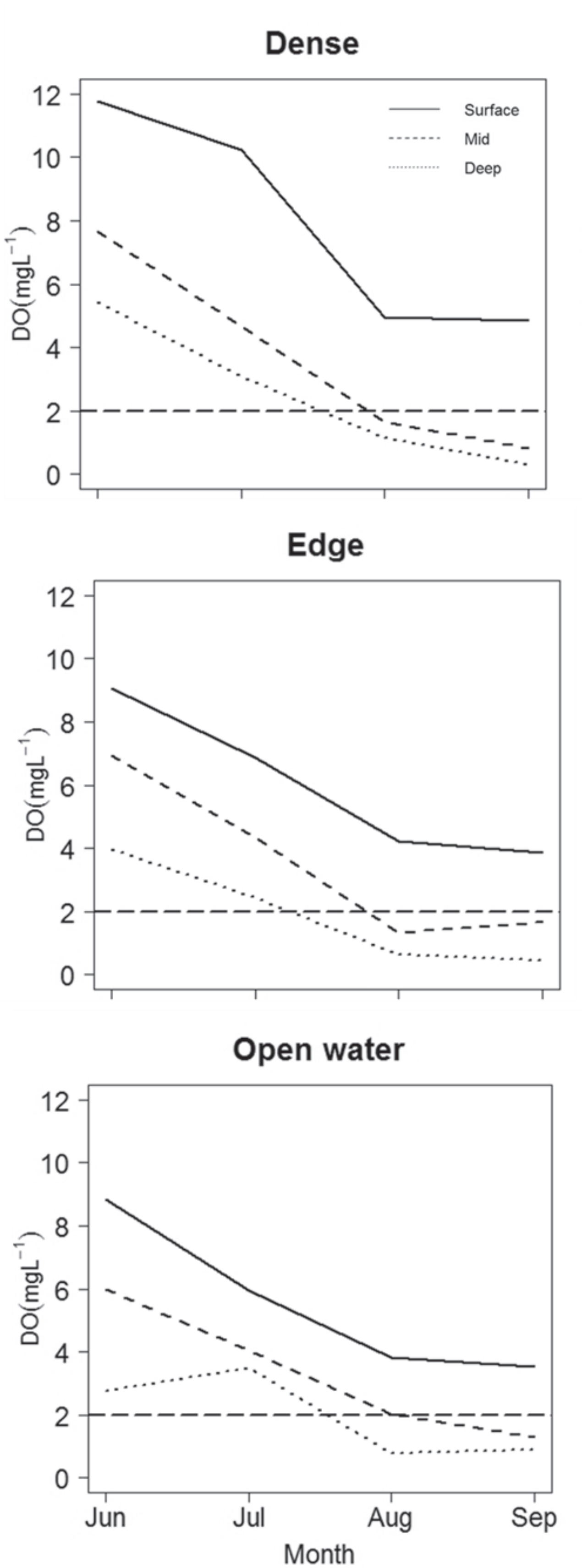

Figure 2. Afternoon mean dissolved oxygen concentrations (N=25) for dense, edge, and open water habitat types by month and depth at Sandmine Lake, June – September 2012. Long-dashed line set at 2.0 mgL^{-1} represents the threshold of hypoxia.

Mid-level DO was consistently hypoxic in all habitat types (though severely in dense habitat) for both times of day; thus, hypoxic conditions were maintained at this stratum from August through September. Instance of hypoxia and severity declined in October.

Lake Tohopekaliga

Dissolved oxygen did not decline to hypoxic concentrations at any time or depth over the summer season in Lake Tohopekaliga (Figure 3). Regardless, the ANOVA model found similar results to that of Sandmine Lake in that all main effects and lower-level interactions were highly significant, as well as the three-way interaction of month, habitat, and depth, suggesting these factors significantly influence each other and dissolved oxygen in this lake (ANOVA, $p<0.001$). There was a strong DO gradient in all habitat types in June (Tukey HSD, $p<0.001$) which became very weak in September (Tukey HSD, $p>0.05$). Although data collection was not possible in October, it is unlikely hypoxia occurred if it was not evident in September when hydrilla growth and day length were at a maximum. Between-habitat comparisons for September in Lake Toho showed mean surface DO did not vary significantly between any habitat types (Tukey HSD, $p>0.05$).

Similarly, ANOVA analysis of afternoon dissolved oxygen showed all main effects, lower-level interactions, and the three-way interaction of month, habitat type, and depth to significantly influence dissolved oxygen (ANOVA, $p<0.001$). While there was a weak DO gradient in September during early morning hours, a strong DO gradient return in the afternoon in vegetated habitat types (Tukey HSD, $p<0.001$), but not in open water (Tukey HSD, $p>0.05$) (Figure 4). Between-habitat comparisons showed that surface DO had a positive relationship from open water into dense hydrilla, with dense habitat was significantly higher than edge or open water (Tukey HSD, $p<0.001$), and edge significantly higher than open water (Tukey HSD, $p<0.001$).

Vegetation Biomass

Hydrilla biomass maintained very high densities throughout summer into October at Sandmine Lake, with the lowest dryweight biomass density close to 1.5 kgm^{-2} or well above (Figure 5).

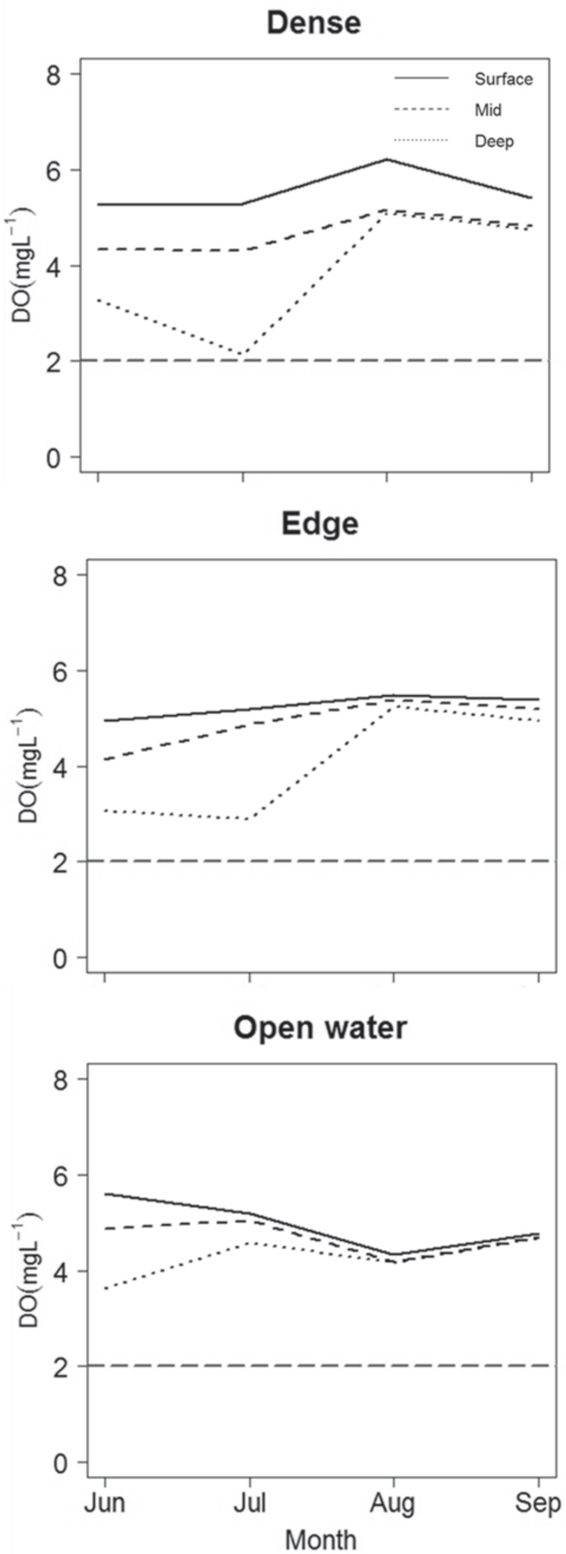

Figure 3. Early morning dissolved oxygen concentrations (N=25) for dense, edge, and open water habitat types by month and depth at Lake Tohopekaliga, June – September .2.

Relative density of hydrilla was 2-3 times less at Lake Tohopekaliga as compared with Sandmine Lake. Samples were variable with the rake method; however, consistent method of collection allowed us to see a general trend of hydrilla growth and relative density among months and between lakes.

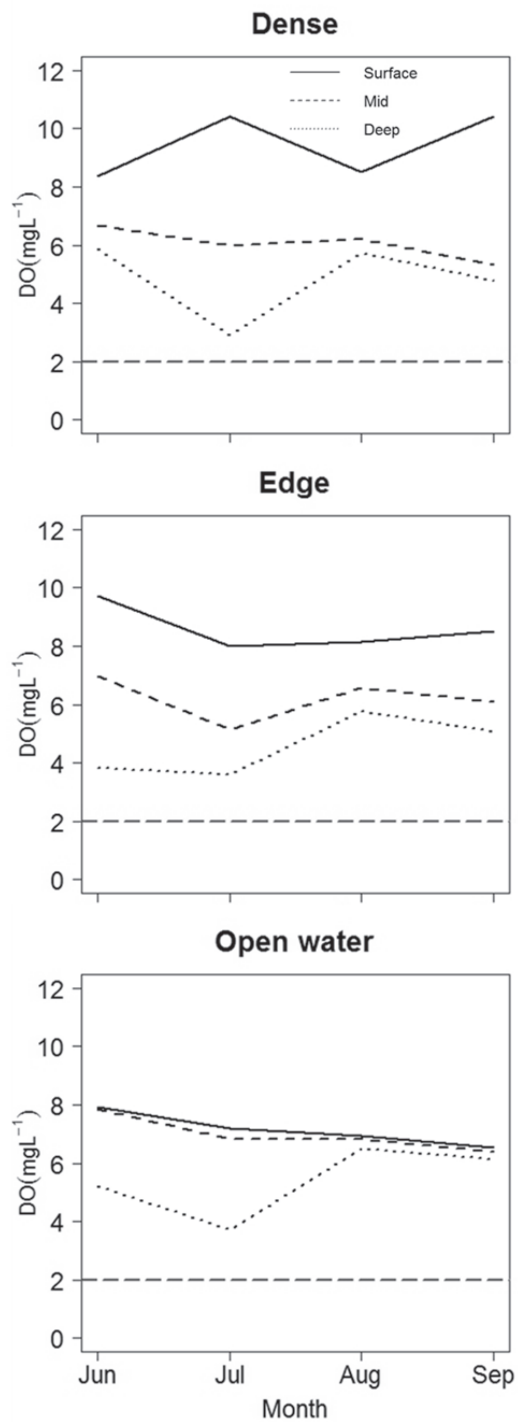

Figure 4. Afternoon mean dissolved oxygen concentrations (N=25) for dense, edge, and open water habitat types by month and depth at Lake Tohopekaliga, June – September

Discussion

Contrary to our expectations, edge habitat did not exhibit improved dissolved oxygen concentrations compared to dense habitat late in the summer season where hypoxia occurred (Sandmine Lake). In fact, the dense hydrilla bed showed similar or improved conditions compared to the edge habitat in late summer. This contrasts with the bay study by Miranda and Hodges (2000), who found dense macrophyte beds to be severely hypoxic (<1.0 mgL^{-1}) and the edge to have significantly improved DO concentrations. However, the negative gradient from open water into dense hydrilla was similar to Bunch et al. (2010) who found a negative gradient from open water into dense emergent plants.

The extensive hydrilla infestation at Sandmine Lake may have reduced water circulation in the open water and edge sampling areas (Carter et al. 1991; Miranda and Hodges 2000). Miranda and Hodges (2000) found dissolved oxygen concentration in edge habitat to have a negative relationship with overall macrophyte coverage of the bay. Water circulation increases nutrient availability and promotes oxygen production by phytoplankton (Frodge et al. 1990; Fee et al. 1992). Maximum hydrilla growth and widespread matting throughout resulted in minimal open water surface area, mainly only found in the mining area too deep for plant growth. If water movement is hindered by adjacent macrophyte beds, this could impact either open water or edge DO concentrations.

Dissolved oxygen did not decline to hypoxic levels at any depth or during any month in Lake Tohopekaliga. The large size and fetch of this lake is capable of generating substantial wave action, which increases water circulation (Stewart 1961) and probably maintained adequate DO concentrations. Additionally, Lake Tohopekaliga is a natural Florida lake and experiences gradual depth changes; this is contrasting to the man-made, sudden depth changes at Sandmine Lake which limits hydrilla growth in the deep mining area and creates a well-defined edge.

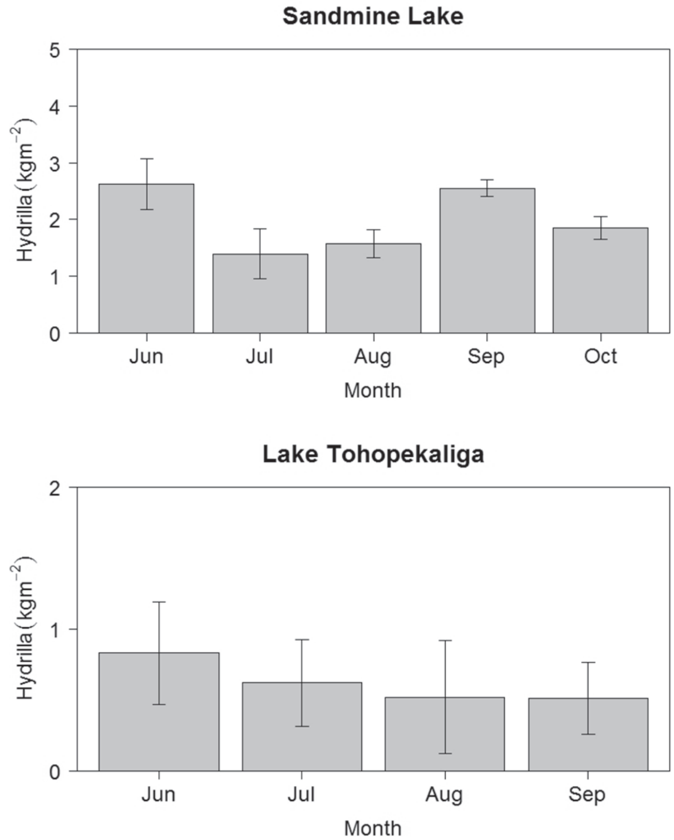

Figure 5. *Hydrilla* dry weight biomass samples (N=4) collected monthly from Sandmine Lake and Lake Tohopekaliga, June – September 2012. Note differing y-axes scales. Bars are standard error.

Vegetation biomass samples suggested that hydrilla in Sandmine Lake may have very spatially-dense root crowns and allocate growth energy to vertical stemming and surface branching.

The gradual depth changes in Lake Toho may allow hydrilla to lengthen rhizome growth between root crowns, taking advantage of horizontal expansion over vertical growth ("guerilla" strategy, McCreary 1991). Less-dense stemming and reduced hydrilla canopy may facilitate deeper sunlight transmission for photosynthesis and better water circulation. As the treatment and subsequent cost of hydrilla management is correlated with plant density (Koegel et al. 1977), this may be a consideration in management strategies of such differing lakes.

Depth significantly influences DO concentrations and thus fish habitat utilization and distribution throughout the water column.

Dissolved oxygen exhibited a negative relationship with depth during all months in both lakes; however it is not as significant in the absence of hypoxia at Lake Toho. Hypoxia in the deeper portions of the water column at Sandmine Lake is likely due to the decomposition of macrophyte and detritus material by aerobic bacteria and shading by the surface canopy, resulting in oxygen consumption and respiration rather than oxygen production (Cole 1994).

Complete hypoxia in the vegetated habitats was not for extended periods of time. Furthermore, we did not see evidence of fish kills on any sampling day when hypoxia was severe. Dissolved oxygen is positively correlated with fish abundance (Troutman et al. 2007) and thus has a significant influence over fish habitat utilization. Distribution of fish temporally (i.e., over hours of a day and seasonally), and spatially (i.e., vertically and horizontally) can fluctuate depending on water quality conditions (Suthers and Gee 1986; Miranda et al. 2000; Troutman et al. 2007). Fish alter their behavior when confronted with hypoxia by changing activity (reduced swimming rate and/or increased gill ventilation rate), air breathing (in bimodal species), increasing aquatic surface respiration, or by selecting new habitat by depth or migration (Kramer 1987). Suthers and Gee (1986) found yellow perch *Perca flavescens* to migrate from emergent vegetation when confronted with hypoxia. Contrastingly, Miranda et al. (2000) did not see a change in fish catch rates when dense submergent Southern naiad *Najas guadalupensis* became hypoxic, indicating a lack of migration. Moving from the hypoxic area to more suitable habitat can lead to overcrowding, decreased growth, and lower survival if adequate habitat is limited (Eby et al. 2005).

Alternatively, it has been widely shown that smaller fish have higher tolerance for low DO than larger fishes (Moss and Scott 1961; Burleson et al. 2001; Robb and Abrahams 2003). Consequently, small fish may not be excluded from hypoxic habitat, although this may limit their growth (Weber and Kramer 1983). Since vegetation growth is not uniform, microhabitats of elevated oxygen concentration may function as areas of refuge for fish during times of poor water quality (Miranda et al. 2000; Bunch et al. 2010).

Further study of fish community behavior and tolerance of adverse conditions in the natural environment would be beneficial for aquatic plant management decisions and strategies, as the occurrence of hypoxia over the summer season may impact how fish utilize these habitats spatially and temporally. The strategy selected by fish to manage hypoxia may largely depend on species and size. It is likely that smaller fishes (i.e., sunfish) utilize dense aquatic plant habitat more often than large predatory species (i.e., largemouth bass), which may prefer edge habitat (Barnett and Schneider 1974; Miranda and Hodges 2000). If smaller fishes are better able to manage hypoxia or possess coping mechanisms for low DO encountered seasonally in the environment, they may not be excluded from this habitat and vegetation removal may not be necessary. Ultimately, organisms will opt for whichever strategy requires the lowest energy expenditure, weighing the cost of migration, food resources, and risk of predation (Kramer 1987).

If management is required, macrophyte removal may only be needed for short, limited periods during times of high temperature and maximum macrophyte growth in late summer. Hypoxia was found only for part of the day due to diel fluctuation, and not a continual state. Submersed macrophytes provide valuable resources and support higher fish abundance and diversity than open water areas (Barnett and Schneider 1974). This habitat should be managed in a way to maintain some macrophyte coverage but also improve the overall ecosystem condition.

Our results also show that hydrilla beds from different lakes can experience very different dissolved oxygen dynamics. The size and morphology of the lake may influence overall DO concentrations. Sandmine Lake likely represents an extreme hydrilla infestation; however, with over 90 percent of Florida lakes considered small (<300 ha) (Shafer et al. 1986) and the prevalence of hydrilla in many of these systems, it is important to understand how severe hydrilla infestations affect dissolved oxygen concentrations in small lakes.

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