DISSOLVED OXYGEN DYNAMICS AND FISH COMMUNITY COMPOSITION IN DENSE EMERGENT PLANTS AT LAKES ISTOKPOGA AND KISSIMMEE, FLORIDA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my loving wife and family

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South Florida lakes (i.e., Tohopekaliga, Kissimmee, Istokpoga, and Okeechobee) have experienced significant changes in littoral habitat since the onset of water level regulation. One of the major changes in habitat has been the persistence in the abundance of dense emergent plants and plant mats (i.e., tussocks), which can affect the physicochemical environment that fishes utilize or avoid. Dissolved oxygen (DO) concentrations and fish communities were evaluated in five emergent plant species (cattail *Typha* spp., pickerelweed *Pontedaria cordata*, smartweed *Polygonum* spp., torpedograss *Panicum repens*, and water primrose *Ludwigia* spp.) at three levels of plant coverage (i.e., percent area coverage; 50-64, 65-79, and 80-95) at Lake Kissimmee (2006) and Lake Istokpoga (2007) during July-August (late-summer) and October-November (fall). Dissolved oxygen was measured using three approaches: 1) Fine-scale temporal measures at fixed locations, 2) Fine-scale spatial measurements in sampling grids, 3) Mid-water column measurements at fish collection sites. Fish communities were sampled using several enclosure devices. Fish were separated into groups based on their ability to cope with stressful water quality conditions (i.e., hyperthermia and hypoxia) as stress-intolerant, stress-moderate, and stress-tolerant. I quantified fish density, richness, and diversity to compare habitats. Centrarchid mortality was estimated experimentally with cages set in high coverage plants, and at different locations and times. Dissolved oxygen exhibited substantial spatial and temporal variability at small scales (i.e., meters and hours). Centrarchid mortality

experiments revealed that mortality was higher when fish were not allowed access to the surface. Stress-tolerant fishes dominated the habitats sampled. Overall, I found higher DO concentrations, higher stress-moderate fish densities, a lower probability of hypoxia, and lower centrarchid mortality in cattail habitats when compared to other habitats sampled in this study. The differences in the factors evaluated in this study (i.e., DO, mortality, and fish metrics) were probably influenced by the structural differences and specific habitat characteristics associated with the individual plant species.

CHAPTER 1
INTRODUCTION

Plants along the littoral zone of lakes are affected by seasonal and year-to-year variation in water levels (Keddy and Fraser 2000). Seasonal variability in water depth can create highly dynamic plant communities (Havens et al. 2005). Water level fluctuation is often considered to be important to maintaining plant diversity and abundance in lakes (Keddy and Reznicek 1986; Fernandex-Alaez et al. 1999; Riis and Hawes 2003) and rivers (Ferreira and Stohlgren 1999; Leyer 2005), and their associated wetlands. Conversely, water level stabilization may result in a decreased number of plant zones and diversity leading to plant communities dominated by invasive species (Keddy and Fraser 2000).

Under stabilized water level conditions, one of the major changes in lake habitat can be the persistence in the abundance of dense emergent plants and plant mats (i.e., tussocks). Dense emergent plant stands and tussocks occur naturally, but the abundance of such formations are exacerbated by stabilized lake levels (Goodrick and Milleson 1974; Azza et al. 2006). The size of a tussock is highly variable ranging from small, isolated patches (i.e., <10 m^2), to large areas that occupy hundreds of hectares of lake shoreline.

Tussocks are typically a more advanced stage of dense plant formation, which occur when dense emergent plant stands become buoyant and float to the water surface. This process usually occurs because of gasses produced during decomposition (i.e., methane and nitrogen) of organic matter and the presence of buoyant aerenchyma tissue in plants (King et al. 1981; Hogg and Wein 1988). Dense emergent plants and tussocks can strongly influence the dissolved oxygen (DO) and substrate characteristics of aquatic habitats. These habitats can reduce DO concentrations in the water column by reducing water circulation and increasing the biological oxygen demand associated with increased production and decomposition of organic matter (Webster and Benfield 1986; Hamilton et al. 1995; Caraco et al. 2006; Rose and Crumpton 2006). The expansion of such conditions can lead to a decrease in habitat for recreationally important fishes (i.e., black crappie, bluegill, largemouth bass, and redear; Allen and Tugend 2002), but can increase habitat for fish species tolerant of low DO. Thus, there is a need to identify the spatial and temporal trends in DO, while simultaneously characterizing the fish community in dense emergent plants and tussock habitats.

Large lakes within the Everglades drainage basin (i.e., Tohopekaliga, Kissimmee, Istokpoga, and Okeechobee) are stabilized for flood control and water supply through the use of water control structures and regulation schedules (Goodrick and Milleson 1974; Toth et al. 1998). Extensive channelization of the Kissimmee River and stabilization of nearby lakes occurred from 1962-1971 (Toth et al. 1998), which had a profound impact on the aquatic ecosystems (Harwell 1997). These lakes are naturally eutrophic floodplain systems that have large shallow littoral zones with a complex mosaic of plant habitats, and thus highly dynamic DO concentrations across spatial and temporal scales.

Floods of various severity and duration historically inundated littoral zones and floodplains creating a sheet-flow of water, which flowed south towards the Everglades, and much of the drainage basin remained inundated for long periods of time (Toth et al. 2002). Organic material was distributed to surrounding areas, while at the same time assimilating nutrients (Steinman and Rosen 2000). Plant communities constantly changed in response to fluctuating water levels, and thus naturally controlled invasive plants (Goodrick and Milleson 1974). However, due to water level stabilization, some portions of the littoral zones now have higher densities of invasive plants and tussocks, and a higher accumulation of organic materials that can depress DO concentrations (Allen and Tugend 2002).

Restoration projects including drawdowns and muck removals have been conducted in some Florida lakes to reverse the detrimental effects of water level stabilization. Some of the projects were considered successful over a prolonged period (e.g., Lake Kissimmee restoration; Allen and Tugend 2002) and others were not (e.g., Lake Tohopekaliga restoration; Moyer et al. 1995). Allen and Tugend (2002) found that habitat restoration at Lake Kissimmee in 1995-1996 improved habitat (i.e., DO levels and moderate plant biomass) for age-0 largemouth bass *Micropterus salmoides* in areas that were previously covered in dense emergent aquatic plants. Herbicide treatments at restored sites maintained quality habitat for sport fish at Lake Kissimmee following the restoration project, but changes in largemouth bass relative abundance and angler catch rates did not occur (Tugend and Allen 2004; Allen et al. 2003). Moyer et al. (1995) found that habitat restoration provided benefits to the sport fishery at Lake Tohopekaliga, but habitats returned to a degraded state three years after restoration. The goal of this project was to characterize the oxygen environment and fish communities across several tussock-forming plant species and coverage levels.

CHAPTER 2
DISSOLVED OXYGEN DYNAMICS

Hypoxia, generally described as DO concentrations less than 2 mg/L, affects the spatial distribution of fish in aquatic environments. Hypoxia is a natural phenomenon for which some fish species have adapted (Moss and Scott 1961; Lewis 1970; Kramer and McClure 1982; Graham 1997), but it has become more severe from anthropogenic eutrophication and poses concerns for fisheries managers (Breitberg et al. 1997; Diaz 2001; Eby and Crowder 2002; Wu 2002).

Hypoxia and the associated fish habitat loss is a concern in lake systems when dense plant stands are able to establish in large portions of the littoral zones (Allen and Tugend 2002). Hypoxic conditions can occur within plant stands and in adjacent areas due to water transport from low DO areas (Caraco et al. 2006). During summer months when water levels are usually low, shallow areas within a lake have a greater probability of becoming hypoxic (Miranda et al. 2001). This becomes problematic for fish sensitive to low DO to survive, especially in shallow, highly vegetated littoral areas.

Fish respond to low DO in many ways: 1) They seek higher DO via movement, 2) Decrease spatial movement to reduce DO consumption, while increasing gill ventilation, 3) Revert to alternative breathing modes such as surface or aerial breathing, 4) Suffocate and a fish kill occurs (Kramer 1987; Miranda et al. 2000). Hypoxic conditions can affect fish survival, growth, and reproduction, which can lead to changes in abundance (Eby et al. 2005).

To study how dense plant stands influenced DO dynamics, I identified several common emergent plants in South Florida that occur in high densities, and would likely have a major effect on DO concentrations. My objectives were to: 1) Evaluate spatial and temporal patterns in hypoxia (DO < 2 mg/L) with several emergent plant species at high coverage levels, 2) Assess how centrarchid mortality estimates varied with high coverage emergent plants, cage location, and time. I hypothesized that higher plant coverage would increase the longevity and area of hypoxic water relative to lower plant coverage, however the relationship would likely vary by plant type. I expected that DO concentrations in October-November samples would be higher than July-August samples due to lower water temperatures, and higher water levels.

Methods

Study Area

The study included two large Florida lakes that support popular fisheries and a wide range of plant habitats (Figure 1). Lake Kissimmee (27.94º N, 81.29 º W) and Lake Istokpoga (27.22 º N, 81.17 º W) are among the largest lakes in Florida (Brenner et al. 1990), 19,807 ha and 12,187 ha, respectively (Florida LAKEWATCH 2005). They are eutrophic systems with mean depths of 1.8 m and 1.5 m, respectively (Florida LAKEWATCH 2005). Each lake has similar fish and aquatic plant communities, substrate qualities, and regional weather conditions. Both lakes have been impacted by water level stabilization due to channelization for flood control, which has caused extensive formation of dense plants and tussocks. Lake Kissimmee underwent a large-scale drawdown and muck removal project in 1996, and a similar project was conducted at Lake Istokpoga in 2001.

Spatial and Temporal Dissolved Oxygen Sampling

Spatial and temporal DO dynamics in high coverage emergent plant stands were quantified using three approaches: 1) Fine-scale temporal measures at fixed locations, 2) Detailed spatial measurements within sampling grids, 3) Mid-water column measurements during fish collections. Sampling effort was spread over a large spatial extent in the littoral zones of each lake.

The first approach was used to measure temporal variability of DO across five emergent plant species (i.e., cattail *Typha* spp., pickerelweed *Pontedaria cordata*, smartweed *Polygonum* spp., torpedograss *Panicum repens*, and water primrose *Ludwigia* spp.), and three coverage levels (i.e., percent area coverage; 50-64, 65-79, and 80-95) during late-summer (July-August) and fall (October-November). Smartweed and water primrose were primarily sampled at the floating tussock stage, while cattail, pickerelweed, and torpedograss habitats were rooted to the lake bottom. I placed three continuously monitoring optical DO probes (Yellow Springs Instruments, Model 600 OMS®) in plant stands of the same plant species, and relocated them to a different stand 5-10 times for each type. The DO measurements (mg/L) were recorded every 15 minutes for a minimum of 48 hrs. The probes were recalibrated prior to each deployment. Each probe was protected inside a 5.1 cm diameter PVC sleeve with holes allowing water access to the probe. The PVC sleeve was attached to a metal stake, which was pressed firmly into the substrate. The units were oriented so that they sampled the mid-water column at all sites.

For the first approach, mean DO concentration of cattail, pickerelweed, and torpedograss, and the associated coverage levels was evaluated using an ANOVA model. The occurrence of hypoxia was assessed using logistic regression for all plant types. Diel variation in mean hourly DO concentrations across plant species and coverage levels was evaluated graphically. Hypoxia was considered to be DO concentrations less than 2 mg/L, as these levels are stressful for many Florida fish species (Moss and Scott 1961; Lewis 1970; Smale and Rathbuni 1995; Burleson et al. 2001). The ANOVA model had DO as the response variable and plant species (i.e., cattail, pickerelweed, and torpedograss), coverage level, and season as independent variables. Occurrence of hypoxia was assessed with logistic regression assuming a binomial error structure to investigate how plant species, coverage level, and season influenced the occurrence of hypoxia (yes or no). Plant species, coverage level, and season were evaluated as independent variables in the logistic regression model. All possible models considering these main effects were fit to the data. The Akaike Information Criterion (AIC) was evaluated to determine the most parsimonious model (Akaike 1974).

For the second approach, I assessed micro-scale spatial variability in DO at vertical and horizontal scales in order to investigate the relationship among DO concentrations, plant type, and vertical depth. This occurred only at Lake Istokpoga, and 25 m^2 grids were sampled in several plant species. Each grid was oriented so that the edge of the grid was close (0-2 m) to an open-water portion of the littoral zone. Sampling grids were sampled during the late-summer and again in the fall, with one grid each in cattail, pickerelweed, and torpedograss. All grids had a gradient in plant coverage (0-100%) in both seasons. Measurements were recorded during two time periods (0800-1000 and 1400-1600) to account for diel fluctuations in DO. Each measurement was sampled at 5-m intervals, and an additional 25 points were measured at random locations, resulting in 61 individual points sampled within each grid. Each point was sampled at three depths in the water column: surface, mid-water, and bottom at each time period. Percent area covered with plants (PAC) was measured at each point. Kriging estimation was used to plot spatial variability of DO in each plant type, depth, and season (Rose and Crumpton 2006).

A fish community assessment was being conducted simultaneously with this study (Chapter 3). The third approach consisted of measuring DO in the mid-water column at fish collection sites using a Hydro-lab Quanta ®. A DO measurement was taken near each fish sample replicate, thus each plant species and coverage level was sampled. At Lake Istokpoga, photosynthetically active radiation (PAR) was measured using a LiCor® light meter at each DO measurement to estimate light availability at fish collection sites. A reference PAR reading was taken by pointing the probe directly at the sun, and a second reading was measured 8 cm below the water surface shortly thereafter. These measurements provided estimates of the proportion of light available in the plant stand.

Centrarchid Mortality

Centrarchid mortality was quantified in dense vegetation to evaluate habitat suitability during hypoxic conditions. Centrarchids (< 150 mm TL) were collected with electrofishing and placed in wire cages (60 cm by 30 cm by 30 cm) in various plant species at the highest coverage level (i.e., 80 to 95%). The experiment consisted of placing ten fish in each of ten cages in three different locations: 1) Four cages allowed fish to access the surface, 2) Four were submerged allowing no access to the surface, 3) Two cages were placed in a well oxygenated open-water area, which served as controls to measure electrofishing and handling-associated mortality. This occurred during the day and night at 10 hr intervals. New fish were collected and placed in cages at each interval. After each 10 hr interval mortality was recorded. I used a binomial likelihood model for each lake to investigate how cage location, plant species, and time influenced mortality (yes or no). The AIC was used to determine the most parsimonious model for predicting fish mortality (Akaike 1974).

Results

Effects of Plant Species and Coverage on Dissolved Oxygen

The fine-scale temporal trend DO samples using fixed probes were only collected at the highest level of coverage (i.e., 80-95%) for Lake Kissimmee in 2006. At Lake Istokpoga, probes were placed in all levels of plant coverage, but smartweed and water primrose did not occur often at low coverages at either lake, and thus, only the high coverage level was available for sampling these species. Lakes were combined for these analyses because few differences were detected in mean hourly DO across plant species at the 80-95% coverage level. We used the fine-scale temporal trend DO data (approach-1) to assess differences in mean DO and hypoxia across seasons, plant species, and coverage levels.

When assessing interactions we only included DO data from cattail, pickerelweed, and torpedograss due to the lack of sampling of smartweed and water primrose at lower coverage levels. Significant interactions were found between plant species, coverage level, and season (ANOVA, $P < 0.001$). Mean DO was lowest in smartweed and highest in cattail, and mean DO increased with plant coverage (Figure 1-2).

In my logistic regression analysis, the model with the lowest Delta AIC considered all main effects and was selected as the best model. The logistic regression model indicated significant correlations with plant species and coverage level ($P < 0.001$, $P = 0.007$, respectively), whereas season was not significantly correlated ($P = 0.052$). The probability of hypoxia ranged from nearly certain for smartweed in both seasons to 0.062 for cattail in the fall. The probability of hypoxia was least for cattail and highest in smartweed, and hypoxia increased with coverage level for all plant species where the three coverage levels occurred (Figure 1-3). Using cattail as a reference (lowest probability of hypoxia), I found that hypoxia was 4.4 times as likely in pickerelweed, 8.7 times as likely in torpedograss, 64.0 times as likely in water primrose, and 230,000,000 times as likely in smartweed. Using the lowest coverage level as a reference, I found that the likelihood of hypoxia was 1.9 times greater for 65-79% coverage, and 2.3 times greater for 80-95% coverage.

Diel patterns in DO concentrations varied among the plant types (Figure 1-4). In general, mean DO was lower in the morning than the afternoon, except in smartweed and water primrose, where mean DO values remained hypoxic throughout the profiles (Figure 1-4). Levels of DO decreased as coverage increased, with the lowest DO concentrations occurring in 80-95% coverage (Figure 1-4).

Results from the fine spatial-scale DO analysis using 25 m^2 grids at Lake Istokpoga indicated substantial horizontal and vertical variation with time of day, plant type, and depth. Overall, all plant types contained small pockets of oxygen exceeding 4 mg/L at the surface in the afternoon (Figures 1-5:1-10). Pockets of higher DO were usually near the open-water edge (left side of Figures 1-5:1-10). However, DO concentrations generally decreased with depth and were lower in the morning (0800-1000) than afternoon (1400-1600) in all plant types (Figures 1-5:1-10). Vertical DO stratification was more noticeable in October samples (Figures 1-6, 1-8, and 1-10) compared to July (Figures 1-5, 1-7, and 1-9). Torpedograss and pickerelweed in October exhibited the lowest DO concentrations across the three plant types tested (Figures 1-6 and 1-8), but open water areas next to these plants generally maintained DO above 2 mg/L on the surface. The DO was higher near open-water and became lower further into the dense plant stands (Figures 1-5:1-10).

Dissolved oxygen measurements from fish collection sites at each lake and for each season were combined for this comparison. Dissolved oxygen and light availability were negatively associated with plant coverage (Figure 1-11). Smartweed and water primrose tended to have lower DO concentrations than other plant species, which agreed with results from other sampling methods (Figure 1-11). Minimum values for all plant species were less than 0.6 mg/L, suggesting that each plant species exhibited hypoxic conditions at some locations and/or times.

Centrarchid Mortality

Centrarchid mortality was quantified in cattail and torpedograss at both lakes. In addition, mortality was quantified in water primrose at Lake Kissimmee, and pickerelweed at Lake Istokpoga. The binomial likelihood model revealed differences in mortality with cage location, plant species, and time at each lake. Lake Kissimmee samples tended to have higher mortality in control cages possibly due to prolonged fish handling time at this system (Figure 1-12), which may have inflated mortality estimates for treatments in the surface and submerged cages.

At Lake Istokpoga, there were no differences in mortality between cattail cages and all control cages. However, at Lake Kissimmee, mortality in cattail followed the same general pattern as other plant species, but overall was lower than other plant species regardless of cage location or time (Figure 1-12). A high probability of mortality was observed in pickerelweed during the day in both surface and submerged cages, but a lower probability was observed at night (Figure 1-12). Fish mortality in torpedograss during the night period was nearly identical at both lakes, but the two lakes differed for daytime samples with higher mortality at Lake Kissimmee than at Lake Istokpoga for torpedograss. Higher mortality was estimated in water primrose than any other plant species (Figure 1-12). There was no clear pattern in mortality with day versus night replicates at either lake (Figure 1-12). In general, there was higher mortality found in submerged cages than other cage locations (Figure 1-12).

Discussion

Effects of Plant Species and Coverage on Dissolved Oxygen

Dissolved oxygen exhibited substantial spatial and temporal variability at small scales (i.e., meters and hours), indicating that small areas of refugia from hypoxia were common within areas that contained high plant coverage overall. There were plant-specific differences in the oxygen environment available to fishes. For example, smartweed and water primrose had consistently low DO concentrations and may contribute the most to habitat loss for hypoxia-intolerant aquatic organisms. These habitats were sampled at the floating tussock stage. They were common in areas with low hydrologic exchange, and were associated with high accumulations of organic sediments. Thus, the sediment oxygen demand was probably high. They had very dense canopies allowing low light attenuation. Oxygen consumption in these habitats was probably higher than other plant species in this study because of low light availability and high sediment oxygen demand. This, in combination with low hydrologic exchange likely caused such extreme hypoxic conditions to occur in these habitats.

Torpedograss and pickerelweed habitats were hypoxic during long periods, except near the open-water-and-plant interface. With few strategies to manage the non-native torpedograss, this plant species may pose problems for managers if densities become high especially in areas where a large portion of the littoral zone is covered (e.g., Lake Okeechobee; Smith et al. 2004). High mean DO concentrations and a low probability of hypoxia in cattail were likely due to increased water turbulence near the open-water-and-plant interface (Rose and Crumpton 2006). Field observations and vegetation maps indicated that cattail tended to grow near shore, but also expanded to the open-water-and-plant interface often adjacent to stands of bulrush *Scirpus* spp. (FWC 2005). Low water levels during sampling left many of the near shore dense cattail stands with little to no water, therefore majority of sampling occurred in offshore cattail stands. Dissolved oxygen in cattails located very close to shore in extremely shallow water depths would probably have been lower, and more similar to other plant types. Therefore, the location of plant stands was very important.

In addition to plant stand location the morphological attributes of the plant species can affect DO. Cattails may cause less drag on water as it circulates through the stand in comparison to other plant species in this study which have smaller diameter stems and higher stem densities (Nepf 1999; Lightbody and Nepf 2006). Less drag may allow for a higher rate of DO dispersal within the plant stand as water is exchanged with open-water areas. Cattail habitats had higher DO concentrations relative to other plant species in this study; however, more DO sampling in other plant types that are known to provide good habitat for centrarchids (e.g., bulrush and maidencane *Panicum hemitomon*) is needed for comparison.

Plant species varied in structural complexity, canopy characteristics, organic sediment accumulations, and other aspects of their life histories, thus variation in DO concentrations were expected. Emergent plant species do not influence DO concentrations in the same way as submersed species (Caraco et al. 2006). Emergent plants are different from submersed plants in that they primarily exchange oxygen with the atmosphere, rather influencing DO concentrations in the water column directly (Lassen et al. 1997; Caraco et al. 2006). Periphyton that utilize emergent and submersed plant below-water surfaces photosynthesize and produce DO (Lassen et al. 1997). Therefore, the surface area that emergent plants create for periphyton probably influenced DO production and consumption more than the plants alone.

Higher plant coverage produces greater surface area for periphyton to utilize, however, it reduces sunlight penetration, which can limit DO production (Scheffer 2004). As plants increased in coverage, the mean DO decreased and the probability of hypoxia increased due to shading. Similar results were found in Eurasian water chestnut *Trapa natans* beds in the Hudson River, New York (Caraco and Cole 2002).

Spatial grid results agreed with results from Nepf (1999), who predicted that turbulence is negatively associated with vegetation density, causing adequate DO levels in areas with lower plant abundance and higher turbulence (Boettcher et al. 2000). Fine-scale spatial sampling indicated that pockets of high DO, which was likely influenced by adjacent open-water areas, may provide refugia for hypoxia-intolerant fish species. This suggests that plant management aimed at providing pathways for water movement within high coverage plant stands may provide higher DO concentrations within the stand, and thus pockets of normoxic refugia for fishes. This can be accomplished by increasing connectivity between open water and near shore vegetated areas (e.g., create strategically placed openings in the cattail and bulrush stands that border the littoral zone at Lake Istokpoga) by using management techniques such as herbicide usage and/or mechanical removal.

Plant stand size and distance to open water was not directly measured in this study, however, fine-scale temporal sampling (approach-1) effort focused on interior portions of large plant stands. This is important because stand size and distance to open water can affect the DO dynamics within a plant stand, which is supported by approach-2 results (Caraco and Cole 2002). A large spatial extent of the littoral zones at both lakes were sampled, so these data should be a good representation of DO concentrations in the study plant communities.

The results from each approach clearly demonstrated both high spatial and temporal variability in DO in littoral plant stands. Low DO concentrations occurred in all the habitats sampled. Therefore, habitat management techniques such as large-scale drawdown and muck removal projects and small-scale herbicidal treatments that limit expansive areas of dense plants in lakes may expand habitat for some fishes (e.g., centrarchids), and also increase overall fish diversity. These strategies should decrease the extent and longevity of hypoxia in lakes.

Centrarchid Mortality

Differences in mortality among plant species were likely due to differences in the DO dynamics associated with the specific plant stand chosen for the experiment. High mortality in control cages at Lake Kissimmee probably was influenced by differences in handling time between sampling occasions (i.e., some sites required up to 1.5 hours of electrofishing and handling to collect the appropriate sample size). Lower mortality was observed in control cages at Lake Istokpoga, where appropriate sample sizes were always obtained in 30 minutes or less.

The mortality estimates coincided with DO results discussed earlier (e.g., low mortality and high DO in cattail; high mortality and low DO in water primrose). Other studies have shown that mortality is higher when fish are confined to sub-surface water during hypoxic conditions (Odum and Caldwell 1955; Weber and Kramer 1983; Miranda et al. 2000). When fish lack access to the surface they are not able to perform aquatic surface respiration, which has been well documented as a mode of surviving hypoxic conditions (Kramer 1987).

Miranda et al. (2000) suggested that fish may utilize the surface layer to find more favorable conditions. My results corresponded to these observations, and clearly showed that in dense plant habitats centrarchids could be subjected to high mortality. Thus, centrarchids would presumably either not utilize these habitats to a large degree or exhibit movements from these areas during hypoxic conditions. Florida fishes are subjected to many dynamic environmental stressors, and they must respond to such stressors with movement or low use of dense plant habitats to reduce mortality.

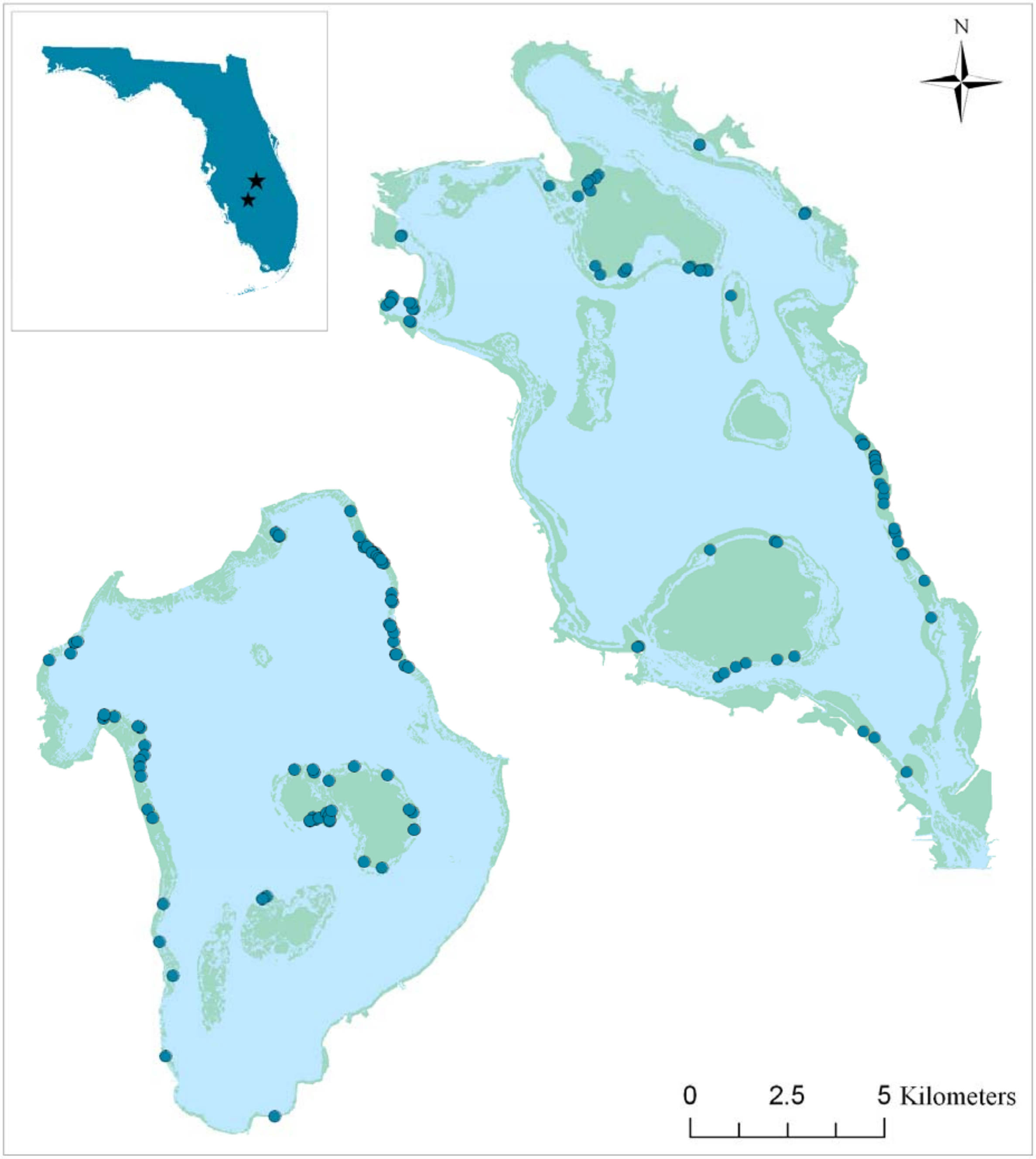

Figure 1-1. Lake Istokpoga (left) is located southwest of Lake Kissimmee (right) within the Everglades drainage basin in Florida, USA. Fish collection sites were distributed throughout the littoral zones of each lake, and are shown as blue dots. Scale indicates size of each lake, but not distance between lakes. Vegetation layers were provided by the Florida Fish and Wildlife Conservation Commission.

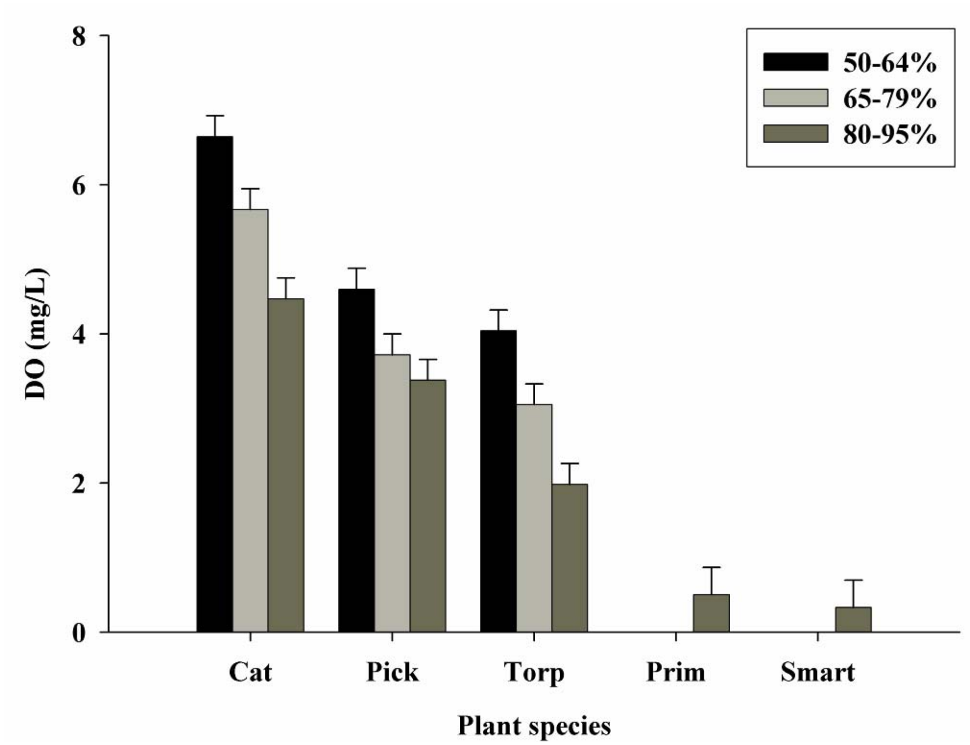

Figure 1-2. Mean DO and standard error according to plant species and coverage level. Measurements from each lake and season were combined. Abbreviations for plant species are: Cat - Cattail, Pick - Pickerelweed, Torp - Torpedograss, Prim - Water primrose, and Smart - Smartweed. Color bars represent different plant coverage levels.

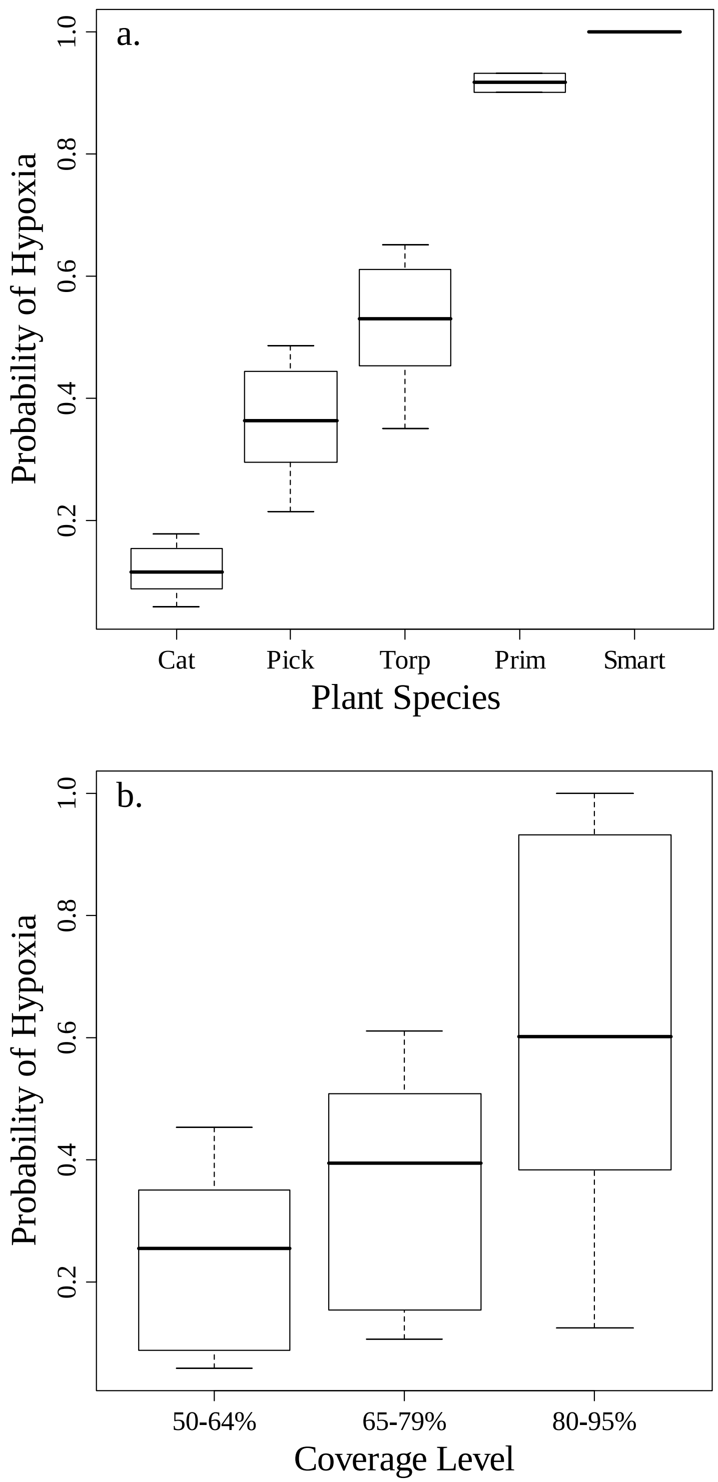

Figure 1-3. Box plots showing the probability of hypoxia for each plant species (a) and coverage level (b). Measurements from each lake and season were combined. Abbreviations for plant species are: Cat - Cattail, Pick - Pickerelweed, Torp – Torpedograss, Prim - Water primrose, and Smart - Smartweed.

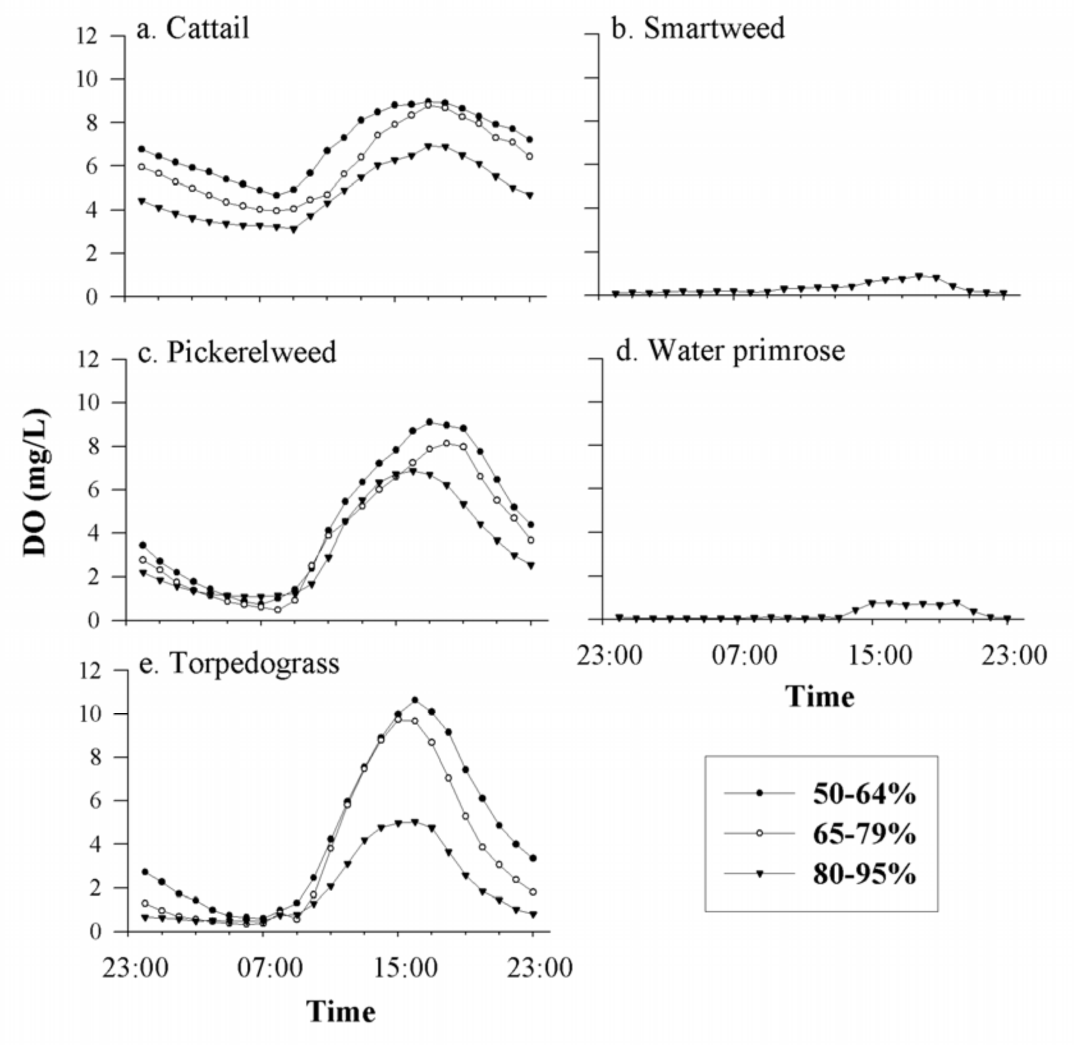

Figure 1-4. Diel profiles of mean hourly DO according to plant species and coverage level. Measurements were combined for each lake and season. Symbols represent different plant coverage levels.

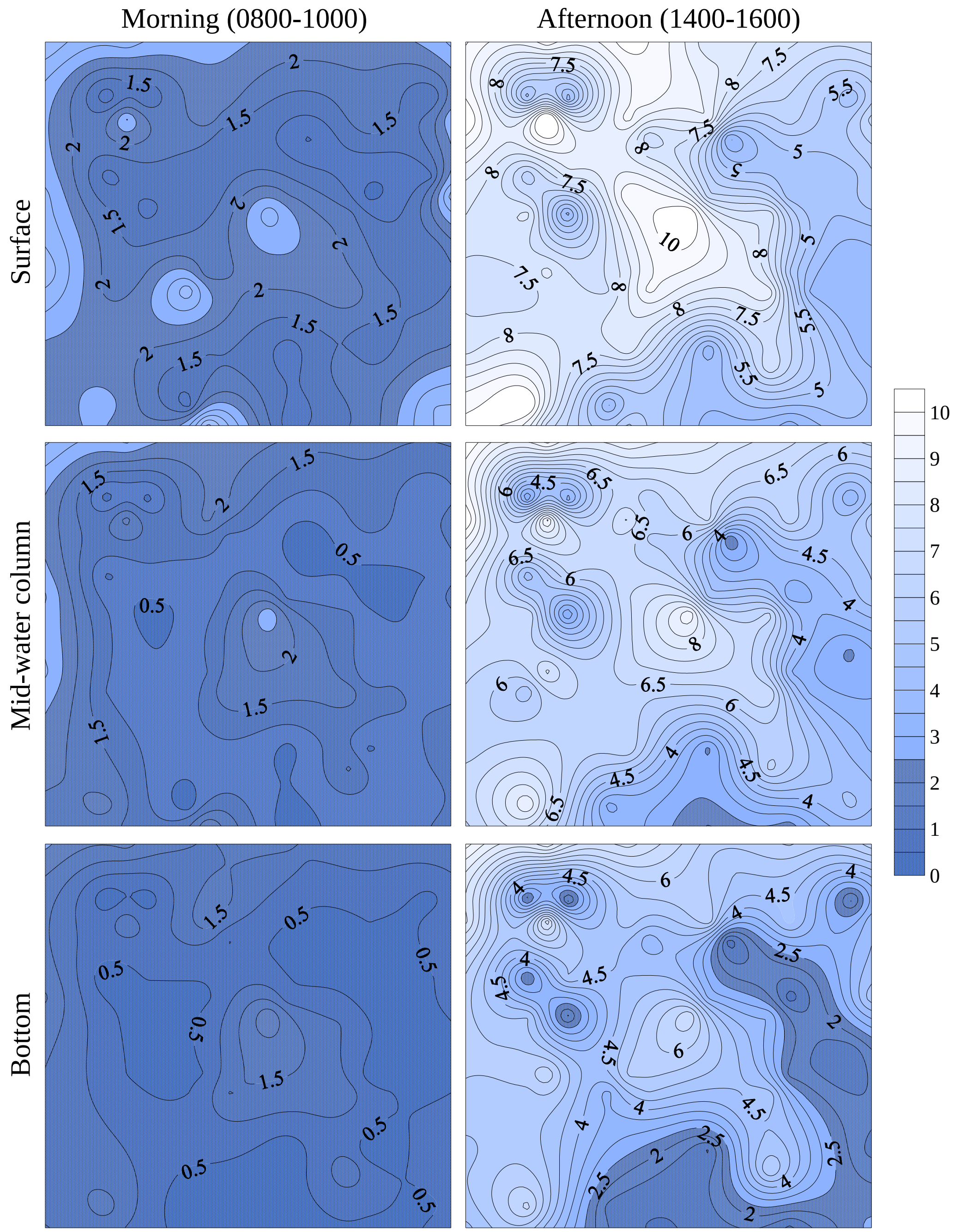

Figure 1-5. Spatial variability of DO in pickerelweed at Lake Istokpoga during July 2007. Morning (left panels) and afternoon (right panels) samples are split into three sampling locations: surface (top panels), mid-water column (middle panels), and bottom (lower panels). The scale ranges from 0-10 mg/L with dark blue indicating low DO and white indicating high DO. Shaded areas indicate hypoxic conditions. Grids were oriented such that the furthest left side of each grid is close (0-2 m) to an open portion (0% plant coverage) of the littoral zone.

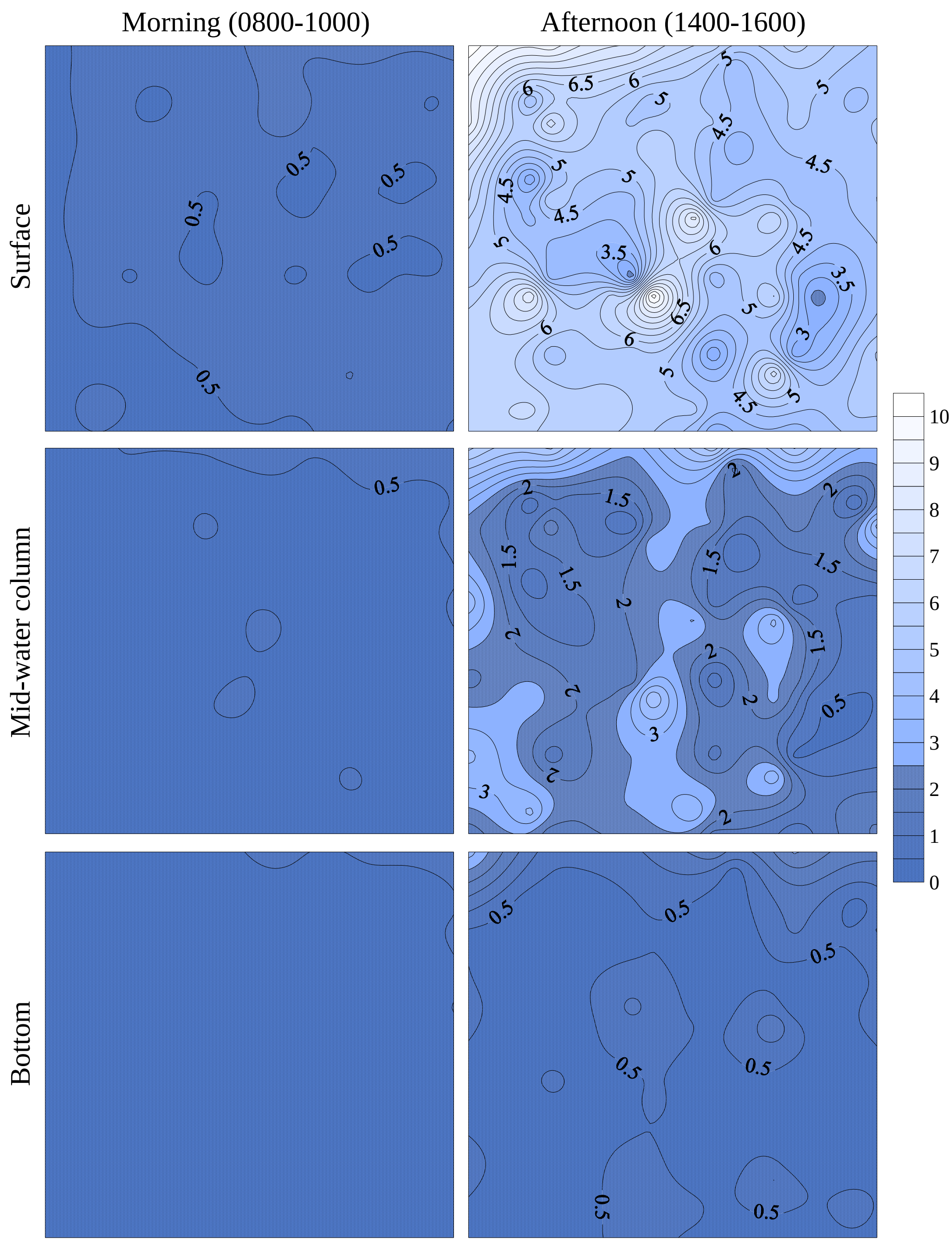

Figure 1-6. Spatial variability of DO in pickerelweed at Lake Istokpoga during October 2007. Morning (left panels) and afternoon (right panels) samples are split into three sampling locations: surface (top panels), mid-water column (middle panels), and bottom (lower panels). The scale ranges from 0-10 mg/L with dark blue indicating low DO and white indicating high DO. Shaded areas indicate hypoxic conditions. Grids were oriented such that the furthest left side of each grid is close (0-2 m) to an open portion (0% plant coverage) of the littoral zone.

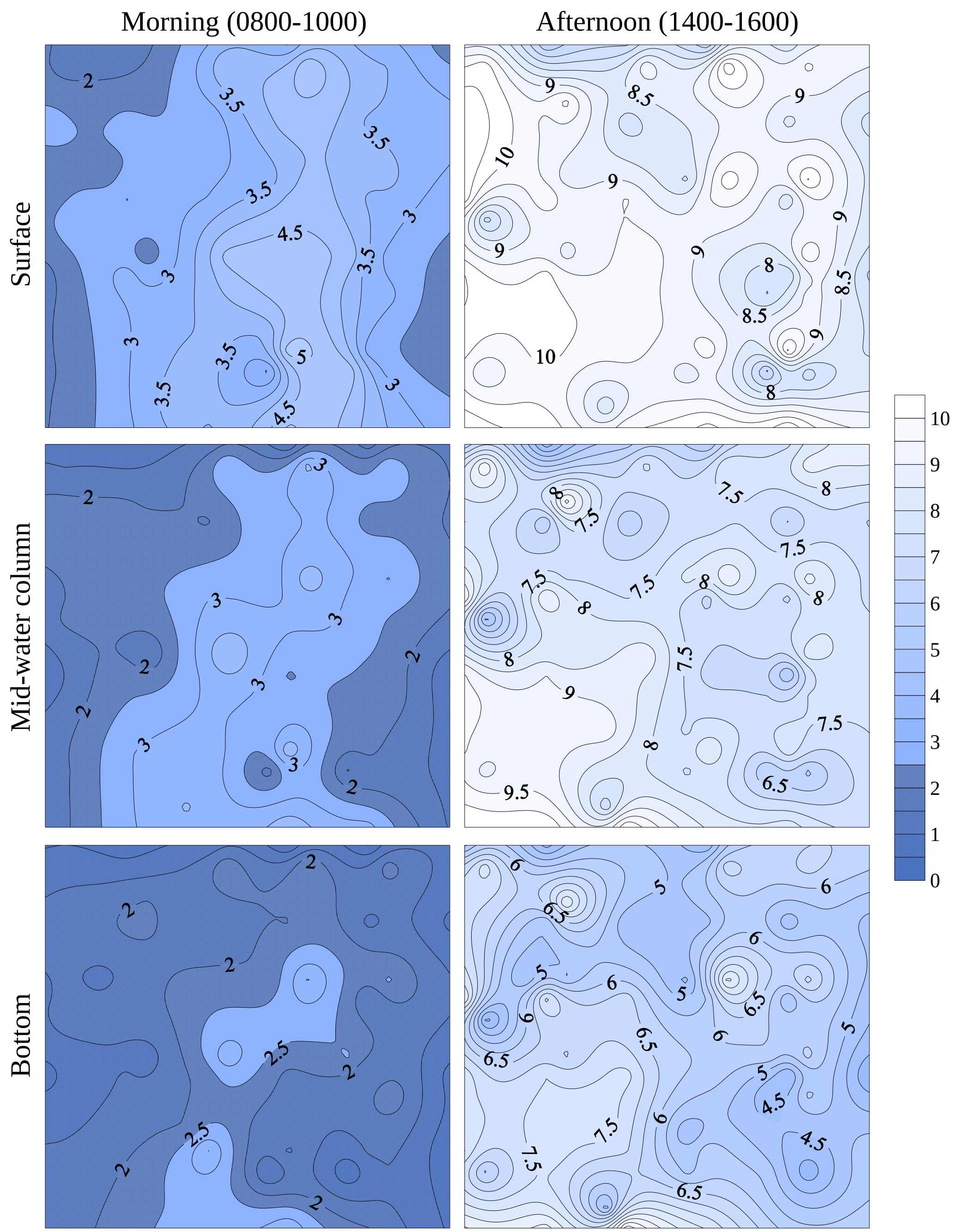

Figure 1-7. Spatial variability of DO in torpedograss at Lake Istokpoga during July 2007. Morning (left panels) and afternoon (right panels) samples are split into three sampling locations: surface (top panels), mid-water column (middle panels), and bottom (lower panels). The scale ranges from 0-10 mg/L with dark blue indicating low DO and white indicating high DO. Shaded areas indicate hypoxic conditions. Grids were oriented such that the furthest left side of each grid is close (0-2 m) to an open portion (0% plant coverage) of the littoral zone.

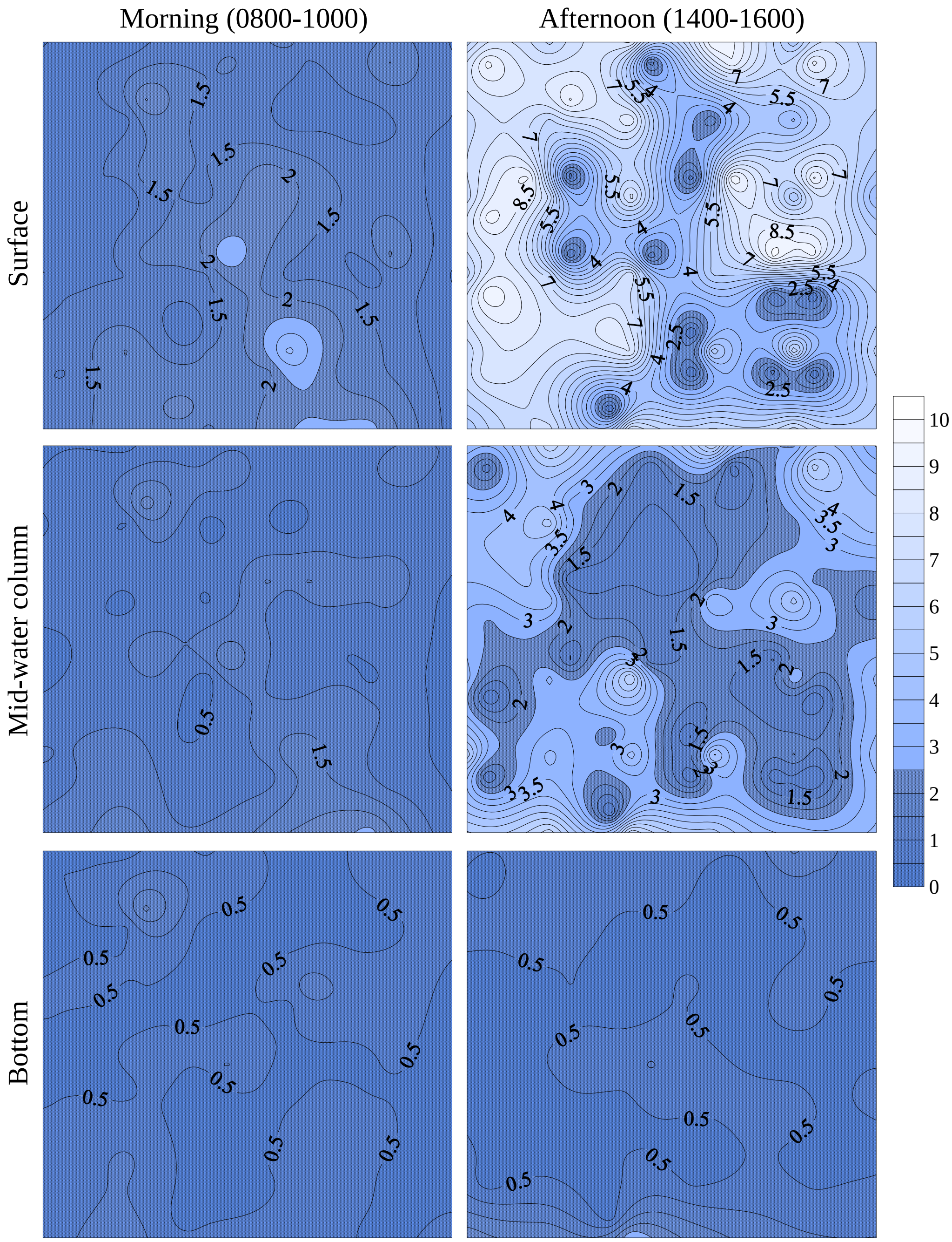

Figure 1-8. Spatial variability of DO in torpedograss at Lake Istokpoga during October 2007. Morning (left panels) and afternoon (right panels) samples are split into three sampling locations: surface (top panels), mid-water column (middle panels), and bottom (lower panels). The scale ranges from 0-10 mg/L with dark blue indicating low DO and white indicating high DO. Shaded areas indicate hypoxic conditions. Grids were oriented such that the furthest left side of each grid is close (0-2 m) to an open portion (0% plant coverage) of the littoral zone.

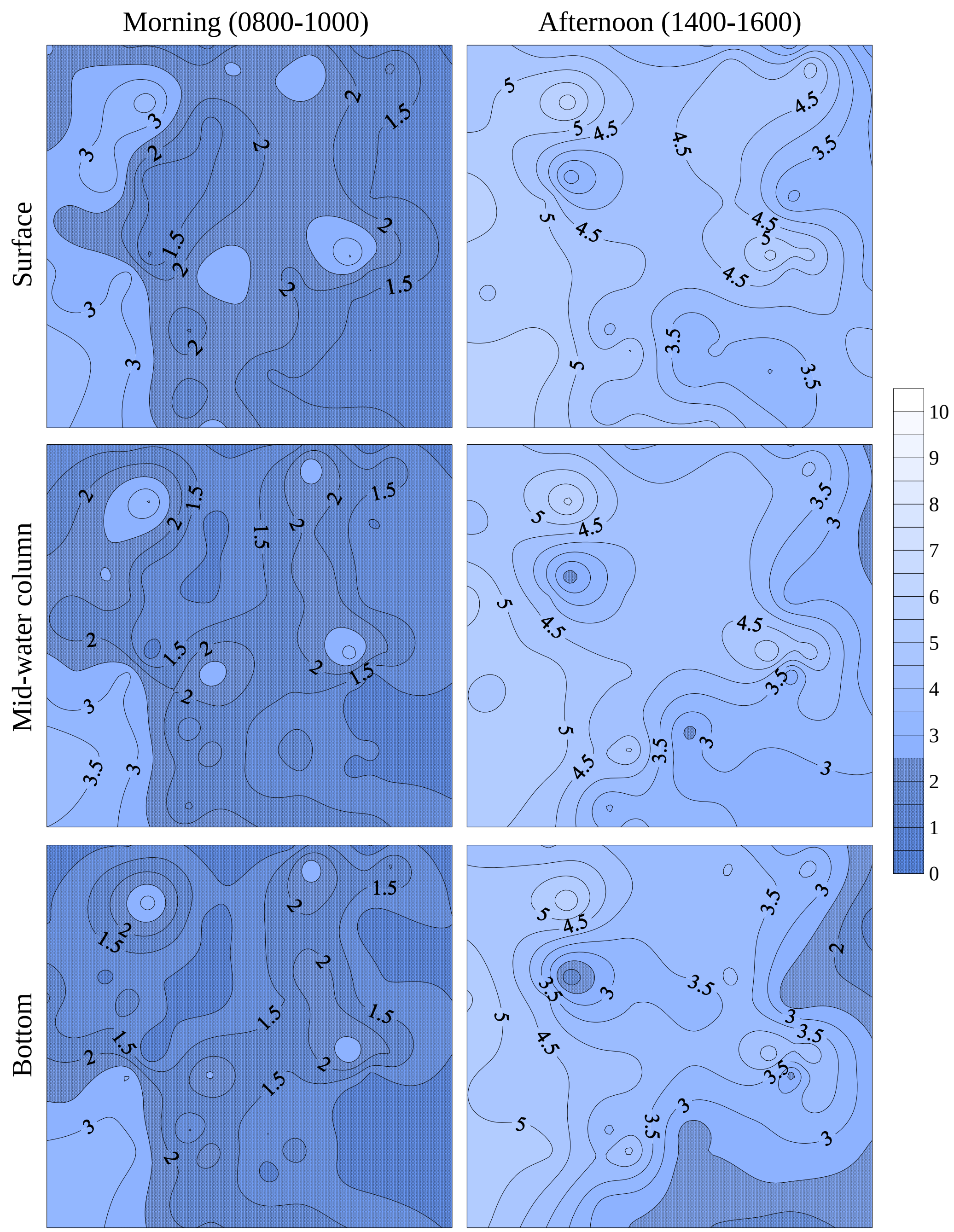

Figure 1-9. Spatial variability of DO in cattail at Lake Istokpoga during July 2007. Morning (left panels) and afternoon (right panels) samples are split into three sampling locations: surface (top panels), mid-water column (middle panels), and bottom (lower panels). The scale ranges from 0-10 mg/L with dark blue indicating low DO and white indicating high DO. Shaded areas indicate hypoxic conditions. Grids were oriented such that the furthest left side of each grid is close (0-2 m) to an open portion (0% plant coverage) of the littoral zone.

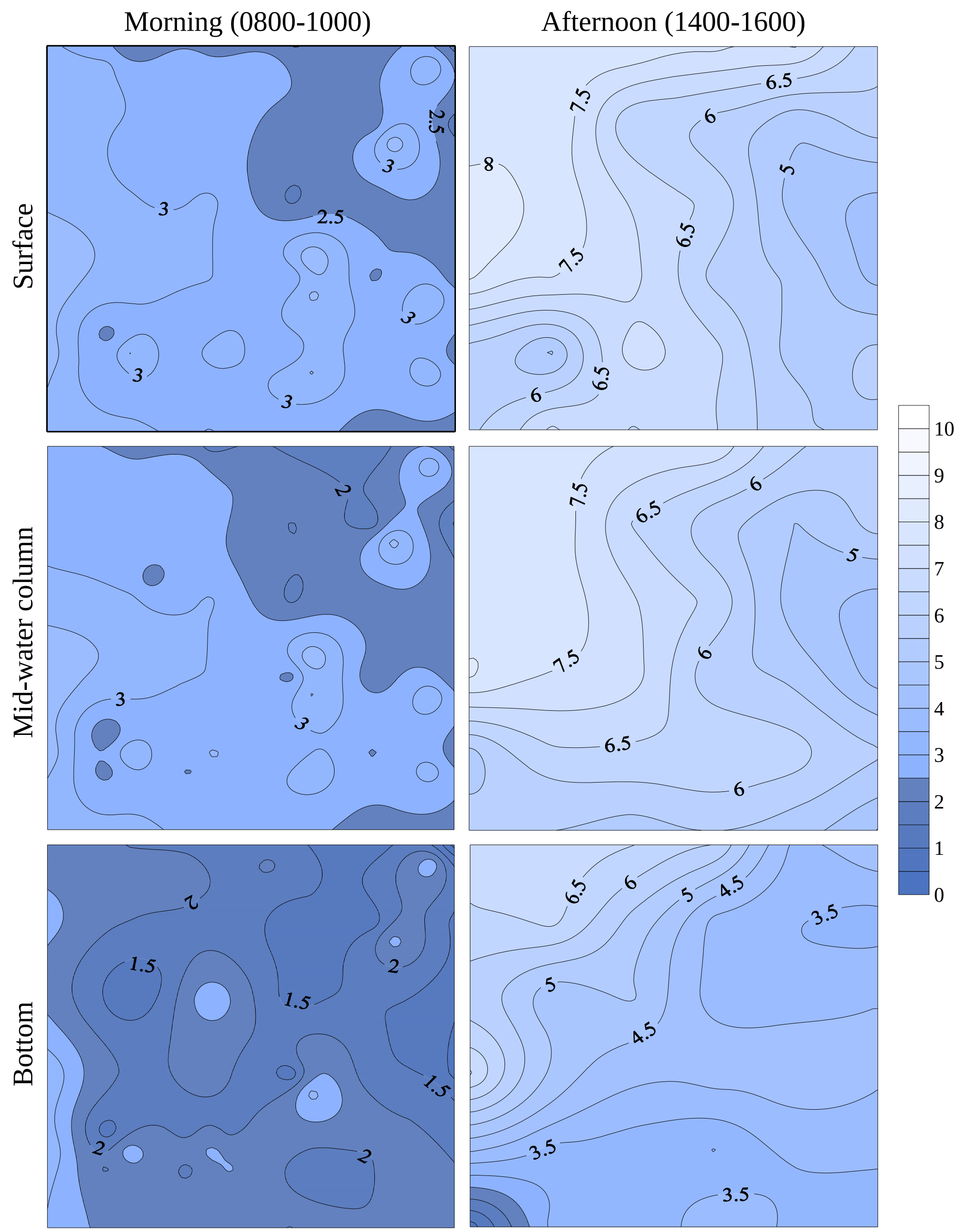

Figure 1-10. Spatial variability of DO in cattail at Lake Istokpoga during October 2007. Morning (left panels) and afternoon (right panels) samples are split into three sampling locations: surface (top panels), mid-water column (middle panels), and bottom (lower panels). The scale ranges from 0-10 mg/L with dark blue indicating low DO and white indicating high DO. Shaded areas indicate hypoxic conditions. Grids were oriented such that the furthest left side of each grid is close (0-2 m) to an open portion (0% plant coverage) of the littoral zone.

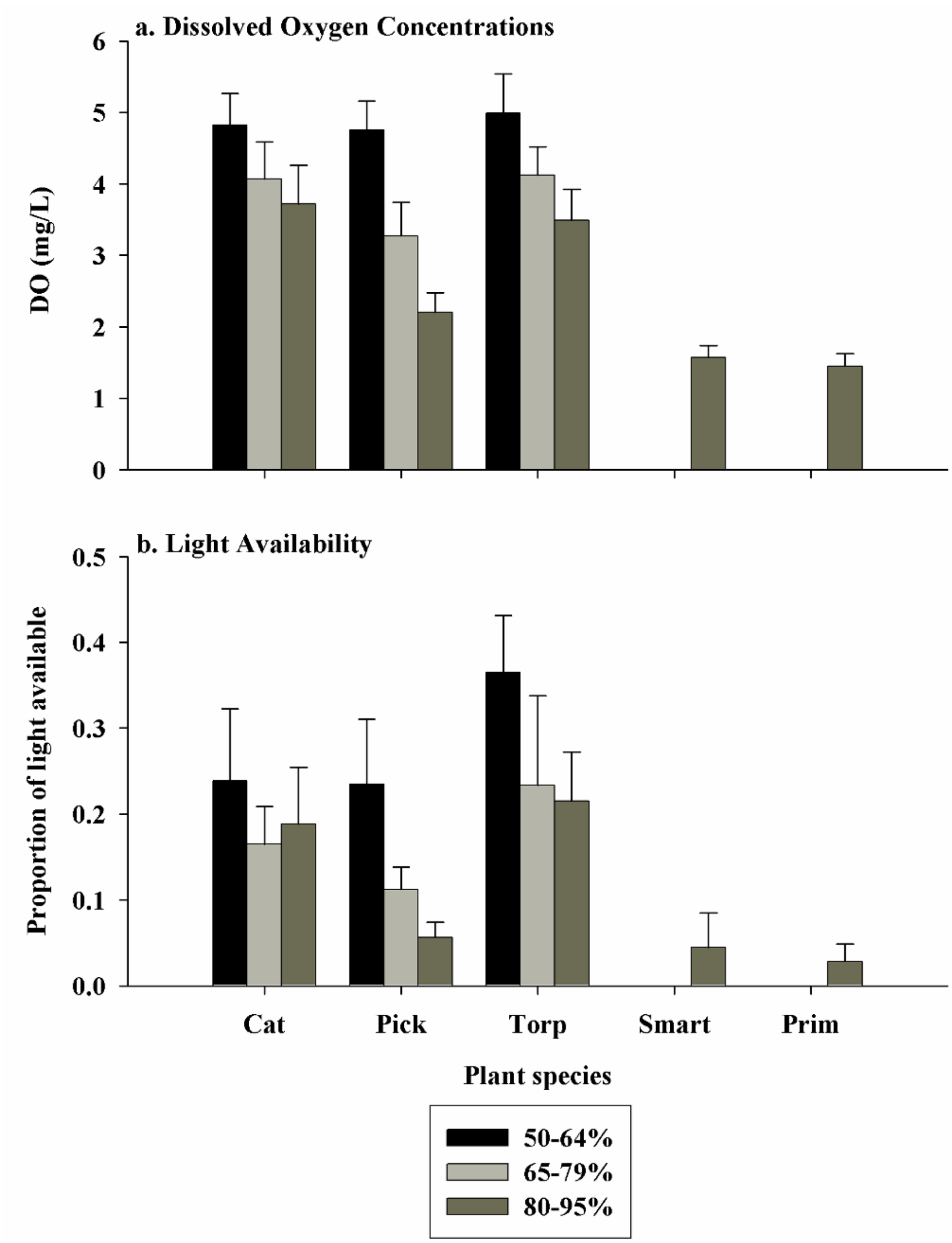

Figure 1-11. Mean DO (a) and light availability (b) with the associated standard error according to plant species and coverage level for measurements taken at fish collection sites. Measurements from each lake and season were combined. Abbreviations for plant species are: Cat - Cattail, Pick - Pickerelweed, Torp - Torpedograss, Prim - Water primrose, and Smart -Smartweed. Coverage levels are indicated by different color bars.

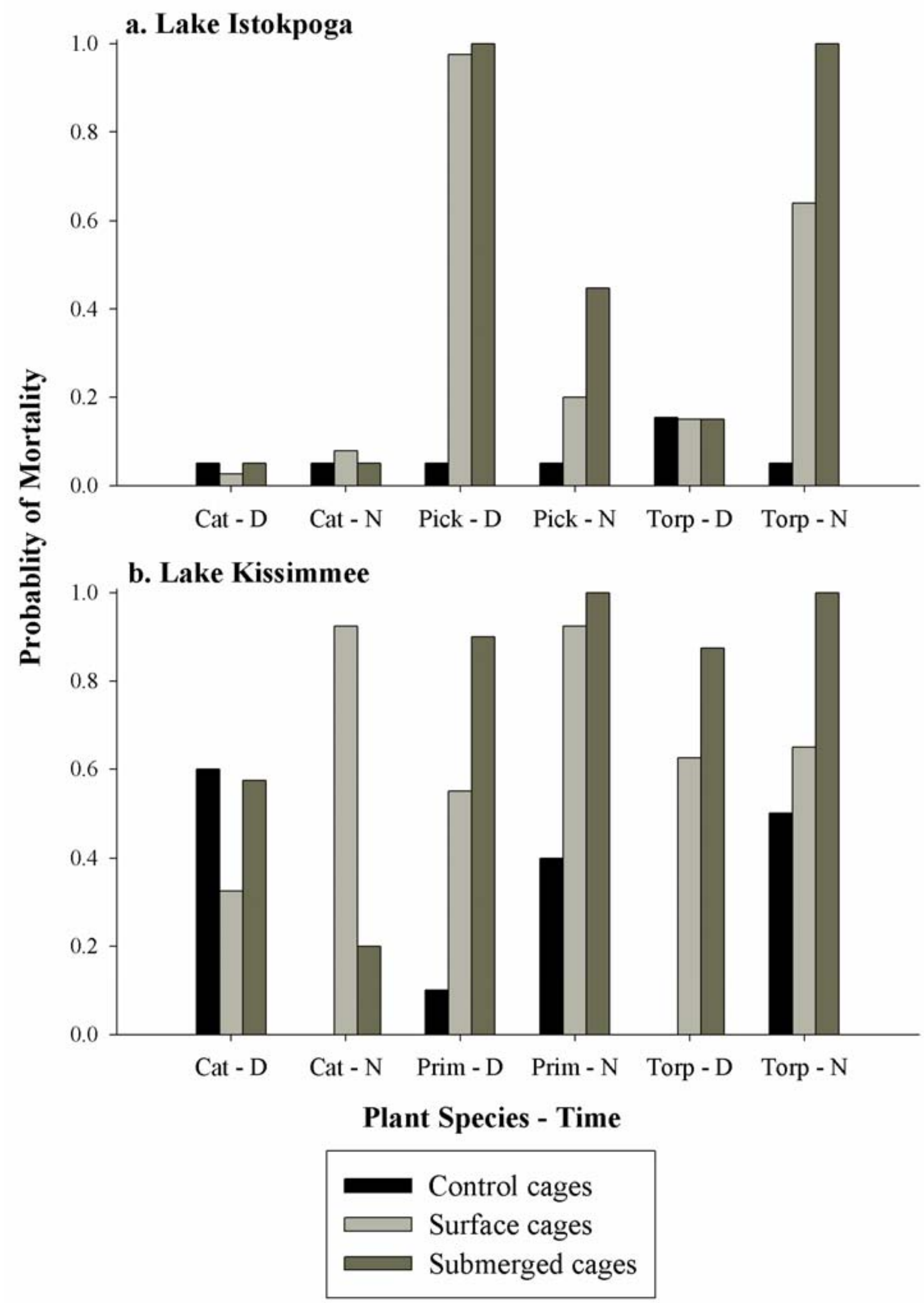

Figure 1-12. Centrarchid mortality estimates at Lake Istokpoga (a) and Lake Kissimmee (b). Abbreviations for plant species are: Cat – Cattail, Pick – Pickerelweed, Prim – Water Primrose, and Torp – Torpedograss. Abbreviations for time are: D – Day and N – Night. Color bars represent different cage locations.

CHAPTER 3
FISH COMMUNITY COMPOSITION

Previous studies have shown that small-bodied fishes dominate fish communities in densely vegetated portions of lakes. High densities of juvenile centrarchids (Miranda et al. 2000), juvenile cichlids (Barrientos and Allen 2008), juvenile and adult cyprinodontoids (Barnett and Schneider 1974; Moyer et al. 1993, 1995; Allen and Tugend 2002), and other juvenile fish species (Meschietti et al. 2000; Pelicice et al. 2005) have been documented in dense emergent and submersed vegetation. Each study found very few large adult piscivores (e.g., adult centrarchids).

Dense interior plant habitats can be advantageous to small-bodied fish for cover due to the complexity of the habitat because it can adversely affect the foraging ability of large adult piscivores. Large adult piscivores often use the edge of dense vegetation or more intermediate plant coverages as feeding grounds because they can locate and ambush prey more effectively (Crowder and Cooper 1982; Savino and Stein 1982; Gotceitas and Colgan 1987). Many studies have shown that intermediate levels of plant coverage provides quality habitat for adult piscivorous fishes (e.g., Sunfishes *Lepomis* spp., black basses *Micropterus* spp., and crappies *Pomoxis* spp., Crowder and Cooper 1982; Dibble et al. 1996; Miranda and Pugh 1997; Miranda and Hodges 2000; Bonvechio and Bonvechio 2006).

Quantitative sampling in dense plant habitats is difficult because of incomplete collections of fish and the small spatial scales that are logistically feasible to sample. The objective of this study was to assess fish richness, density, and diversity across a range of plant species all found at high plant coverage (i.e., percent area coverage > 50%). I hypothesized that the fish community would be dominated by species adapted to low DO conditions and dense vegetation (e.g., poeciliids). I expected there to be low centrarchid densities at high plant coverage.

Methods

Study Design

I used a stratified block study design in which fish community composition was sampled in various plant species over a gradient in plant coverage (50-95%). Sampling occurred in densely vegetated portions of the littoral zones at Lake Kissimmee (2006) and Lake Istokpoga (2007) during late summer (July-August) and fall (October-November). Five emergent plant species at three levels of plant coverage (i.e., percent area coverage; 50-64, 65-79, and 80-95) were evaluated. These species included cattail *Typha* spp., pickerelweed *Pontedaria cordata*, smartweed *Polygonum* spp., torpedograss *Panicum repens*, and water primrose *Ludwigia* spp., which often occur in dense stands and also form tussocks (Hunt 1943; Hanlon and Langeland 2000; Mallison et al. 2001; Smith et al. 2004). Smartweed and water primrose were primarily sampled at the floating tussock stage, while cattail, pickerelweed, and torpedograss habitats were rooted to the lake bottom.

Fish Community Sampling

Fish communities were sampled in each lake using four sampling methods, with gear selection based on habitat complexity (e.g., plant density, canopy height, and water depth). Each site was sampled quantitatively using either a 100 m^2 block net (3.2 mm knotless nylon mesh seine), a 4 m^2 Wegener ring (0.8 mm mesh netting), a 1 m^2 aluminum throw trap, or qualitatively in a 100 m^2 area without the use of enclosures. Three replicates of Wegener rings and throw traps were used to encompass a site. Block nets are efficient at sampling fish in freshwater and marine shoreline habitats, effectively indexing fish diversity, density, biomass, size structure, and relative abundance (Shireman et al.1981; Matlock et al. 1982; Bettoli and Maceina 1996; Rozas and Minello 1997). Wegener rings and throw traps are effective methods for sampling fish in shallow, densely vegetated habitats (Wegener et al. 1974; Kushlan 1981; Bettoli and Maceina 1996; Jordan et al. 1997). Qualitative fish samples were used when gear cannot be deployed in extremely dense plant stands (Allen and Tugend 2002).

Incomplete recovery of fish was accounted for in all sampling gears. Block nets were deployed in a 10 m by 10 m square with 2.3 kg anchors connected to each corner. The Wegener ring and throw trap were tossed into plant stands and pressed firmly into the substrate to decrease escapement. A known number of fathead minnows *Pimephales promelas* were placed into a subsample of the enclosures (total=62) to account for differences in recovery efficiency among samples (N=100 per block net, N=5 per replicate of Wegener Ring and throw trap). Each sampling area was dosed with 3 mg/L of rotenone (CFT™ Legumine), and water was agitated to thoroughly mix the solution. In block nets and qualitative fish samples, fish were captured with dip nets until they ceased to float to the surface. Surface and sub-surface dipping in Wegener ring and throw trap samples occurred until a standardized time of 12 minutes had elapsed and 3 successive sweeps by each investigator yielded zero catch. Vegetation that impeded dip netting was removed from the enclosure.

Fish specimens were separated by site and replicate, placed on ice, and taken to the laboratory where they were identified to species with the exception of mosquitofish *Gambusia* spp. because of difficulties associated with reliable taxonomic identification (N. Burkhead, USGS, personal communication). Subsamples of 50 specimens were counted, measured (mm), and weighed (0.001 g). Remaining specimens of the same species were weighed in bulk. Bulk weights were used to estimate total catch as per Bettoli and Maceina (1996). The proportion of fathead minnows recovered in each sample was used to adjust catches for incomplete recovery, allowing standardized estimates of density for each species. This method assumed that all fish had similar recovery efficiency as compared to fathead minnows.

Fish species were grouped into categories of stressor tolerance to facilitate analysis and interpretation. The three groupings were defined as: 1. stress-intolerant, 2. stress-moderate, and 3. stress-tolerant (Table 2-1). These *a priori* tolerance classifications were based on a species' ability to cope with stressful water quality conditions (i.e., hypoxia and hyperthermia; Barbour et al. 1999). Stress-intolerant species (e.g., inland silverside *Menidia beryllina*) prefer a well-oxygenated water column, which is characterized by pelagic habitat or habitats with low-moderate plant coverage (Weltzien et al. 1999; Barrientos 2005). The stress-moderate group was comprised mostly of centrarchids, which do not possess the same morphological advantages as stress-tolerant fishes, and thus are less tolerant to stressful conditions (Lewis 1970). Stress-tolerant fishes have behavioral (e.g., aerial respiration) and morphological (e.g., dorsally oriented mouths and flattened heads) adaptations enabling them to flourish under low dissolved oxygen conditions (Moss and Scott 1961; Lewis 1970; Kramer and McClure 1982; Graham 1997).

To investigate how density of tolerance groups varied with lake, plant species, and coverage level, I first assessed variability of recovery probability (P_{rec} = the fraction of fathead minnows recovered) with respect to gear, plant species, and coverage level. I estimated P_{rec} at each of the 62 sites where fathead minnows were deployed by dividing the number of minnows recovered in the fish sample by the total number released at the site. I grouped these individual P_{rec} estimates into groups based on gear type, plant species, and coverage level and performed 1,000 bootstrap iterations of the mean for each grouping. I plotted the bootstrap samples for each grouping and used the confidence intervals to determine differences in P_{rec} among groupings.

Tolerance group density was estimated for plant species and coverage levels at each lake. I calculated the density (D) for each stressor tolerance group (g) at each site (s) directly as:

$$D_{gs} = \frac{\left(c_{gs} / \overline{P}\right)}{A_s} \tag{3-1}$$

where c_{gs} was the site-specific catch of a given tolerance group, A_s was the site-specific area sampled, and $\overline{P}$ represented the mean P_{rec} for that plant type, coverage, and sample gear. For example, if I found that P_{rec} varied significantly among gears, plant species, and coverage level, the $\overline{P}$ employed for density estimation was specific to the same sampling gear, plant, and coverage level. Alternately, if the evaluation of P_{rec} revealed no significant variability across gears, plant species, or coverage level, then $\overline{P}$ was calculated from all the available data and applied to any site, regardless of gear, plant species, or coverage level. The variance in mean density for a given fish tolerance group was estimated through 1,000 iterations of a bootstrap procedure which allowed $\overline{P}$ to vary according to data for the plant species, coverage level, and gear associated with each fish density estimate. For each iteration, an individual P_{rec} estimate was resampled with replacement from the appropriate grouping, averaged and applied in equation 1 for each site in each lake, plant species, and coverage level.

To investigate differences and similarities in species richness and diversity, I evaluated overlap in the distributions of 1,000 bootstrap samples. Species richness was estimated from the number of species collected at each site. Qualitative samples were included in richness estimates, but not in density or diversity estimates. Shannon-Weaver diversity indices (*H*') were estimated for each site using Equation 3-2 (Dodds 2002).

$$H'_s = -\sum_{j=1}^{S_s} p_{js} \ln p_{js} \tag{3-2}$$

where *H*'*s* is the site-specific Shannon-Weaver measure of diversity, *S* is the individual fish species at site *s*, *pj* is the site-specific proportion of species *j* (i.e., density of species *j* divided by total density at site *s*). Gears had varying sample areas, which can influence species richness; therefore, I evaluated sampling methods using species-area curves to identify whether the sampling effort was sufficient to measure species richness and diversity (Krebs 1989).

Several variables were measured and recorded at each fish collection site including DO (mg/L), water temperature (°C), water depth (m), substrate depth (i.e., depth of organic layer in m to mineralized soil), percent area covered with plants (PAC), dominant plant species, and plant biomass (kg). Percent area covered with plants and plant biomass was estimated using 0.25 m^2 plastic quadrats (N=3). Quadrats were randomly distributed within each block net and qualitative fish sample. Quadrats were placed directly in the center of each throw trap and Wegener ring replicate. Percent area covered with plants was estimated by visually assessing the percentage of vegetation within each quadrat. Visual estimation was conducted by each investigator, and a value was mutually agreed upon. Living and dead plant parts were pulled from the substrate, placed in a mesh bag, and weighed using a Pesola ® metric spring scale. Mean biomass (kg/m^2) for each site was estimated by multiplying the mean weight from each quadrat by four.

Because this study focused on dense emergent plant species at coverage greater than 50%, I compared fish data from another study in which fish were collected in diverse plant communities at all coverages (0-100%). These data may be more representative of littoral fish communities. In 2003 and 2004, Rogers and Allen (2005) sampled fish in littoral habitats at Lake Istokpoga. One-hundred-meter-squared block nets (N=72) were set using the same methods as this study. They sampled fish in emergent, floating, and submersed plant species (e.g., pickerelweed, spatterdock *Nuphar advena*, and hydrilla *Hydrilla verticulata*). I compared fish abundance and community composition from Lake Istokpoga in this study (i.e., only high plant coverage) to data from Rogers and Allen (2005).

Results

Fish were collected at 154 sampling locations at Lakes Istokpoga (N=77) and Kissimmee (N=77). Thirty-four fish species (39,556 individuals; 31.1 kg wet weight) representing 16 families were collected (Table 2-1). Cyprinodontoid fishes, poeciliids (60% by number, including least killifish *Heterandria formosa*, mosquitofish, and sailfin molly *Poecilia latipinna*), and cyprinodontids (27% by number, including bluefin killifish, flagfish *Jordanella floridae*, golden topminnow *Fundulus chrysotus* and Seminole killifish *F. seminolis*) dominated the catches in the habitats sampled. Fishes important for recreational fisheries, such as black crappie *Pomoxis nigromaculatus*, bluegill, redear sunfish *L. microlophus*, and largemouth bass, all of which are considered stress-moderate species, were much less abundant (5% of total catch) than stress-tolerant species in this study. Similarly, very few stress-intolerant fishes were collected. Mean density for these species was less than 0.2 fish/m^2 and differed significantly from other groups, therefore they were not included in the figures.

Plant biomass varied among species and coverage levels with greatest mean biomass occurring in smartweed and water primrose habitats, 24.2 kg fresh wt/m^2 and 24.1 kg fresh wt/m^2, respectively (Table 2-2). Plant biomass ranged from 1.2 (50% area coverage in torpedograss) to 59 kg fresh wt/m^2 (95% coverage in water primrose; Table 2-2). Mean plant biomass increased with plant coverage (Table 2-2). Pickerelweed and torpedograss often inhabited sandy bottom substrates (mean depth of organic sediment layer = 0.01 m; Tables 2-3 and 2-4). Conversely, cattail, smartweed, and water primrose occurred in areas with higher accumulations of organic sediments (mean depth of organic sediment layer = 0.19 m; Tables 2-3 and 2-4). Mean temperatures were higher in July-August samples (30.8°C) than October-November samples (27.2°C; Tables 2-3 and 2-4).

The evaluation of variability in recovery probability revealed that P_{rec} varied significantly with gear (Figure 2-1), but did not vary significantly with plant species or coverage level. The estimates were similar to previous studies where P_{rec} was estimated (Table 2-5). I, therefore, applied P_{rec} specific to sampling gear used when estimating fish group density for each plant species and coverage level at each lake.

Fish data from cattail, pickerelweed, and torpedograss sites were used to make comparisons between coverage levels, and all coverage levels were used to make comparisons between plant species with regard to fish densities, richness, and diversity. Stress-intolerant and stress-moderate fishes were far less abundant than stress-tolerant fishes in all plants at both lakes, with exception of cattail (Figure 2-2). Stress-tolerant fish density differed between plant species with the highest densities (84.6/m^2) in water primrose at Lake Kissimmee and the lowest in cattail at both lakes (8.3/m^2; Figure 2-2). Stress-moderate fish densities tended to be highest in cattail (3.5/m^2) and pickerelweed (3.9/m^2) at Lake Istokpoga (Figure 2-2). Stress-tolerant fish density was lowest in cattail and highest in water primrose, with stress-moderate fish showing the opposite general relationship (Figures 2-2). Similarly, stress-tolerant fish density was generally higher at high plant coverages (regardless of plant species), and stress-moderate fishes showed the opposite trend (Figure 2-3).

Species tolerance groups reflected trends in individual fish species. For example, the densities of stress-tolerant fishes were directly related to the density of mosquitofish as this fish comprised a large proportion of the overall catch within the group (Table 2-1). Bluegill density was the major contributor to the stress-moderate fish group (Table 2-1).

The fish communities quantified in high-coverage emergent plants were substantially different from a previous study that sampled a wide range of plant types and coverages. The stress-tolerant-dominated fish community found in this study represented a minor part of the fish community from Rogers and Allen (2005; Figure 2-4). Their findings showed a fish community dominated by stress-moderate fishes (specifically due to the marked increase in centrarchid abundance). Stress-intolerant species were nearly non-existent in this study (<0.001% of total catch), but comprised 13% of total catch in Rogers and Allen (2005). Thus, the high-coverage plant types that were sampled in this study all showed large differences in fish community composition relative to a more representative sample of littoral plant communities (Figure 2-4).

The sampling effort was adequate to measure fish richness and diversity based on the species-area curves (Figure 2-5). Fish species richness in smartweed and water primrose (average per site = 6 species) was lower than cattail, pickerelweed, and torpedograss (average per site = 10 species). Rogers and Allen (2005) found higher richness in their study with 12 species collected on average per site.

Stress-tolerant species such as golden topminnow, least killifish, mosquitofish, and warmouth *L. gulosus* were ranked among the top in terms of percent occurrence in each plant habitat. Percent occurrence of bluegill, largemouth bass, and redear sunfish were higher in cattail than any other plant species. Largemouth bass were not found in any fish collection site where smartweed or water primrose habitats were sampled. Overall, cyprinodontoid fishes occurred at a high percentage of sites, and recreationally important species occurred at a much lower percentage of sites sampled. Differences in percent occurrence indicated that similarities in richness values did not show shifts in community structure. For example, even though cattail, pickerelweed, and torpedograss shared similar mean species richness values, torpedograss showed different species composition (higher richness and occurrence of cyprinodontoid fishes).

Species diversity did not follow the same pattern as richness, and no differences were found between plant species (Figures 2-6). Species diversity estimates were low with mean values ranging from 1–1.6. No differences in fish species richness or diversity were found with respect to lake or coverage levels, such that fish richness and diversity did not vary among coverage levels (Figures 2-7).

Discussion

All plants and coverages sampled were dominated numerically (i.e., 90%) by stress-tolerant fishes (mainly cyprinodontoids), and contained low densities of stress-intolerant and stress-moderate fishes. Dissolved oxygen concentrations probably played an important role in structuring the fish community because the highest densities of stress-tolerant fish occurred in plants that displayed the lowest DO. Smartweed, torpedograss, and water primrose habitats had the lowest DO concentrations among the study plants (Chapter 2). Stress-moderate species (e.g., largemouth bass and bluegill) were found in very low DO concentrations, but their densities were much lower than stress-tolerant fishes. Miranda and Hodges (2000) showed increased densities of centrarchids at low plant coverages and related the differences in densities to plant coverage and DO concentrations.

Fish richness followed a similar pattern as the DO results with the lowest DO and fish species richness occurring in smartweed and water primrose. Killgore and Hoover (2001) found a similar reduction in fish richness with low DO concentrations. Sampling occurred in monotypic plant stands, which probably influenced fish diversity estimates because greater habitat heterogeneity generally yields higher species diversity (Gorman and Karr 1978; Tonn and Magnuson 1982; Weaver et al. 1997).

Fish sensitive to hypoxia can escape when such conditions occur in dense plant stands (Miranda et al. 2000). Estuarine fishes have also been found to avoid hypoxia with movement (Wannamaker and Rice 2000). Diel patterns in hypoxia were found in the habitats sampled, and likely affected the timing in which certain species entered and exited a plant stand. Some of the fish found in this study may use these habitats during high DO concentrations, but exit the area as conditions become unfavorable. Sampling occurred during low and high periods of DO, so these transitioning fish were likely accounted for.

Some fish species are able to cope with hypoxic conditions through morphological adaptations (i.e., aquatic surface respiration or gulping; Lewis 1970), and may use hypoxic habitats as a refuge from fish predators sensitive to low DO (Chapman et al. 1995, 2002). However, there is a trade-off because being closer to the water surface makes fish more susceptible to avian predation (Gawlik 2002) and predatory fish species tolerant of low DO (Poulin et al. 1987). Nonetheless, stress-tolerant species, which are mostly comprised of prey species, were generally high in density in all habitats sampled.

Another important factor influencing the fish community is structural complexity of plant stands. It is based on species-specific morphology and plant coverage. Structural complexity can directly affect foraging efficiency, maneuverability, predation, predator avoidance, food choices, and other fish behaviors (Crowder and Cooper 1982; Gotceitas and Colgan 1989; Dibble and Harrel 1997). These factors can affect presence-absence and density of fishes.

The amount and size of interstitial spaces available to fish depends on the structural complexity of the habitat. For example, cattails have large bulky rhizomes, which have several flat leaves that grow as high as 3 m above the water (Hoyer et al. 1996). Torpedograss has a higher density of small-diameter stems with narrow leaves, thus creating a more structurally complex habitat with greater submersed surface area and a greater amount of interstitial spaces than cattails. This allows small-bodied fishes to maneuver more easily than their predatory counterparts. Even though both plant species are structurally different they can have similar PAC values. Therefore, the structural differences in each plant species in this study probably affected fish density and fish richness, more so that plant coverage alone. The richness and density of small-bodied cyprinodontoid fishes (all within the stress-tolerant fish group) were higher in torpedograss habitats than cattail habitats.

High densities and diversity of prey items (i.e., invertebrates) are found in dense plant stands due to high surface area in which they can utilize (De Szalay and Resh 2000). Therefore, high structural complexity may increase food availability for small-bodied fishes that forage on invertebrates (e.g., cyprinodontoids and juvenile centrarchids). This, in combination with their high maneuverability may increase foraging efficiency, and thus, may increase their growth and abundance (Crowder and Cooper 1982).

In this study, fish density was one of the parameters used for assessing habitat quality. Van Horne (1983) suggested that animal densities alone might not be the best indicator of habitat quality. Measuring vital rates such as reproduction, growth, and probability of survival are needed to thoroughly characterize habitat quality (Van Horne 1983). Thus, future studies on fish communities in dense plants need to address this concern. However, the sheer dominance in one fish group over other groups, and the large differences in fish community composition between two separate studies are informative.

Overall, the evidence suggested that fish community composition was influenced by the structural differences and specific habitat characteristics associated with the individual plant species. There were likely plant-mediated indirect effects on fish habitat use based on water quality conditions (e.g., DO concentrations), and direct effects related to the structural complexity of the habitat. The fish communities in this study were probably shaped by a combination of these direct and indirect effects. South Florida freshwater fishes have adapted to fluctuating water levels, but without the fluctuations that have facilitated their adaptations, fish communities may become as homogenous as the habitats in which they use if lakes are not properly managed.

Table 1-1. Fish species grouped according to stressor tolerance. An asterisk (*) denotes non-native status. Numbers indicate the percent (%) of the group total.

Family and Species	Stress-intolerant	Stress-moderate	Stress-tolerant
Atherinidae			
Inland silverside, *Menidia beryllina* (Cope)	9.4		
Callichthyidae			
Brown hoplo, *Hoplosternum littorale* (Hancock)			0.1
Catostomidae			
Erimyzon sucetta (Lacépède)		0.1	
Centrarchidae			
Bluespotted sunfish, *Enneacanthus gloriosus* (Holbrook)			0.9
Warmouth, *Lepomis gulosus* (Cuvier)			1
Bluegill, *L. macrochirus* (Rafinesque)		31.9	
Dollar sunfish, *L. marginatus* (Holbrook)		10.6	
Redear sunfish, *L. microlophus* (Günther)		7.5	
Spotted sunfish, *L. punctatus* (Valenciennes)		4.8	
Largemouth bass, *Micropterus salmoides* (Lacépède)		6.6	
Black crappie, *Pomoxis nigromaculatus* (Lesueur)		1	
Cichlidae			
Mayan cichlid, *Cichlasoma urophthalmus* (Günther) *		1.3	
Blue tilapia, *Oreochromis aureus* (Steindachner) *		1.2	
Clariidae			
Walking catfish, *Clarias batrachus* (Linnaeus) *			0.1
Clupeidae			
Threadfin shad, *Dorosoma petenense* (Lesueur)	3.5		

Table 1-1 (Continued). Fish species grouped according to stressor tolerance. An asterisk (*) denotes non-native status. Numbers indicate the percent (%) of the group total.

Family and Species	Stress-intolerant	Stress-moderate	Stress-tolerant
Cyprinidae			
Golden shiner, *Notemigonus crysoleucas* (Mitchell)		0.5	
Taillight shiner, *Notropis maculatus* (Hay)	79.8		
Pugnose minnow, *Opsopoeodus emiliae emiliae* (Hay)	8		
Cyprinodontidae			
Flagfish, *Jordanella floridae* (Goode & Bean)			3.5
Bluefin killifish, *Lucania goodei* (Jordan)			16.3
Golden topminnow, *Fundulus chrysotus* (Günther)			8.2
Seminole killifish, *Fundulus seminolis* (Girard)			2.3
Elassomatidae			
Everglades pygmy sunfish, *Elassoma evergladei* (Jordan)			0.3
Esocidae			
Chain pickerel, *Esox niger* (Lesueur)		0.1	
Ictaluridae			
Yellow bullhead, *Ameiurus natalis* (Lesueur)		0.7	
Brown bullhead, *Ameiurus nebulosis* (Lesueur)		3.1	
Tadpole madtom, *Noturus gyrinus* (Mitchell)		14	
Lepisosteidae			
Longnose gar, *Lepisosteus osseus* (Linnaeus)			0.01
Florida gar, *L. platyrhincus* (DeKay)			0.01
Loricariidae			
Vermiculated sailfin catfish, *Pterogoplichthys disjunctivus* (Weber) *			0.2

Table 1-1 (Continued). Fish species grouped according to stressor tolerance. An asterisk (*) denotes non-native status. Numbers indicate the percent (%) of the group total.

Family and Species	Stress-intolerant	Stress-moderate	Stress-tolerant
Swamp darter, *Etheostoma fusiforme* (Girard)		16.6	
Poeciliidae			
Mosquitofish, *Gambusia* spp.			40.2
Least killifish, *Heterandria formosa* (Girard)			16.9
Sailfin molly, *Poecilia latipinna* (Lesueur)			9.9
Total Catch	203	3,745	35,608
Percent (%) of Total Catch	1	9	90
Total Number of Species	4	15	15

Table 1-2. Descriptive statistics of plant biomass estimates (kg/m²) at Lakes Istokpoga and Kissimmee.
N = number of sites where biomass was measured.

Plant species	Coverage level (%)	Mean Biomass (kg/m²)	Standard Error	Minimum	Maximum	N
Cattail	50-64	5.97	0.66	3.07	11.73	14
	65-79	6.21	0.72	2.93	10.53	12
	80-95	8.88	0.64	5.73	11.73	11
Pickerelweed	50-64	7.59	0.96	3.87	16.80	13
	65-79	12.05	1.45	5.47	21.50	11
	80-95	16.16	1.44	6.13	25.00	13
Smartweed	50-64	-	-	-	-	0
	65-79	7.27	0.67	5.93	8.00	3
	80-95	24.15	3.56	8.73	48.80	15
Torpedograss	50-64	4.73	0.77	1.20	8.40	12
	65-79	7.67	0.85	3.40	13.73	14
	80-95	12.36	1.72	1.47	23.53	13
Water primrose	50-64	11.50	5.53	6.00	17.06	2
	65-79	13.90	-	-	-	1
	80-95	24.07	2.80	7.73	59.00	19

Table 1-3. Descriptive statistics for variables measured during July-August fish collection sites at Lakes Istokpoga and Kissimmee: dissolved oxygen (mg/L), temperature (°C), water depth (m), and substrate depth (m). N = Number of samples.

Plant species	Variable	Mean	Standard error	Minimum	Maximum	N
Cattail	Dissolved oxygen	4.63	0.39	0.50	10.40	39
	Temperature	31.30	0.44	27.00	37.70	39
	Water depth	0.44	0.04	0.10	1.06	39
	Substrate depth	0.10	0.01	0.00	0.30	39
Pickerelweed	Dissolved oxygen	3.60	0.33	0.61	8.60	50
	Temperature	30.38	0.45	25.30	38.90	50
	Water depth	0.34	0.02	0.10	0.65	50
	Substrate depth	0.02	0.00	0.00	0.10	50
Smartweed	Dissolved oxygen	1.28	0.16	0.35	2.80	21
	Temperature	31.19	0.68	26.90	36.75	21
	Water depth	0.80	0.03	0.50	1.20	25
	Substrate depth	0.27	0.04	0.00	0.50	25
Torpedograss	Dissolved oxygen	4.46	0.31	0.48	9.01	51
	Temperature	30.93	0.53	25.90	40.95	51
	Water depth	0.30	0.02	0.10	0.70	51
	Substrate depth	0.00	0.00	0.00	0.05	51
Water primrose	Dissolved oxygen	1.40	0.17	0.17	2.90	31
	Temperature	30.15	0.43	26.40	34.50	31
	Water depth	0.78	0.11	0.10	2.50	31
	Substrate depth	0.24	0.03	0.00	0.50	31

Table 1-4. Descriptive statistics for variables measured during October-November fish collection sites at Lakes Istokpoga and Kissimmee: dissolved oxygen (mg/L), temperature (°C), water depth (m), and substrate depth (m). N= Number of samples.

Plant species	Variable	Mean	Standard error	Minimum	Maximum	N
Cattail	Dissolved oxygen	3.90	0.40	0.57	5.93	21
	Temperature	26.77	0.28	24.48	28.59	21
	Water depth	0.61	0.04	0.40	1.10	21
	Substrate depth	0.13	0.03	0.00	0.50	21
Pickerelweed	Dissolved oxygen	3.46	0.41	0.45	9.00	37
	Temperature	27.80	0.24	24.77	30.90	37
	Water depth	0.57	0.03	0.20	0.80	36
	Substrate depth	0.00	0.00	0.00	0.05	36
Smartweed	Dissolved oxygen	1.50	0.23	0.25	5.45	21
	Temperature	26.82	0.41	24.08	30.75	21
	Water depth	0.58	0.05	0.20	1.10	21
	Substrate depth	0.23	0.02	0.05	0.50	21
Torpedograss	Dissolved oxygen	3.53	0.47	0.22	8.39	29
	Temperature	27.78	0.36	22.60	30.63	29
	Water depth	0.45	0.03	0.10	0.90	29
	Substrate depth	0.01	0.01	0.00	0.10	29
Water primrose	Dissolved oxygen	2.07	0.34	0.11	5.21	32
	Temperature	26.63	0.25	24.50	28.87	32
	Water depth	0.65	0.09	0.15	1.30	32
	Substrate depth	0.18	0.04	0.00	0.50	32

Table 1-5. Recovery rates from this study and others from the literature. Percentage reported for Wicker and Johnson (1987) includes only recapture rates from plant species similar to this study.

Gear	Method	Mean (%)	Minimum (%)	Maximum (%)	Reference
1-m^2 throw trap with dip nets	Minnows released	69	40	100	This report
1-m^2 throw trap with bar seine	Fin-clipped fish	83	62	100	Jordan et al. (1997)
1-m^2 throw trap with bar seine	Fin-clipped fish	97	93	100	Rozas and Odum (1987)
4-m^2 Wegener ring	Minnows released	69	27	100	This report
100-m^2 block net	Minnows released	26	4	65	This report
100-m^2 block net	Fin-clipped fish	30	10	60	Wicker and Johnson (1987)

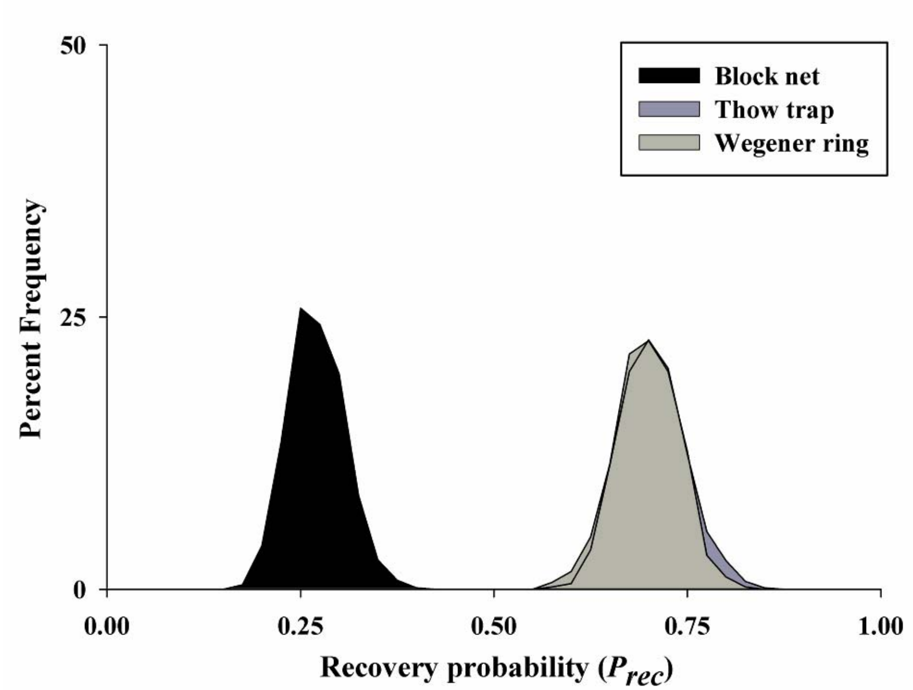

Figure 2-1. The percent composition of a distribution of means for P_{rec} estimates for each gear type. Each gear is represented by a different color area. Distributions resulted from 1,000 bootstrap samples of original P_{rec} data (N=62).

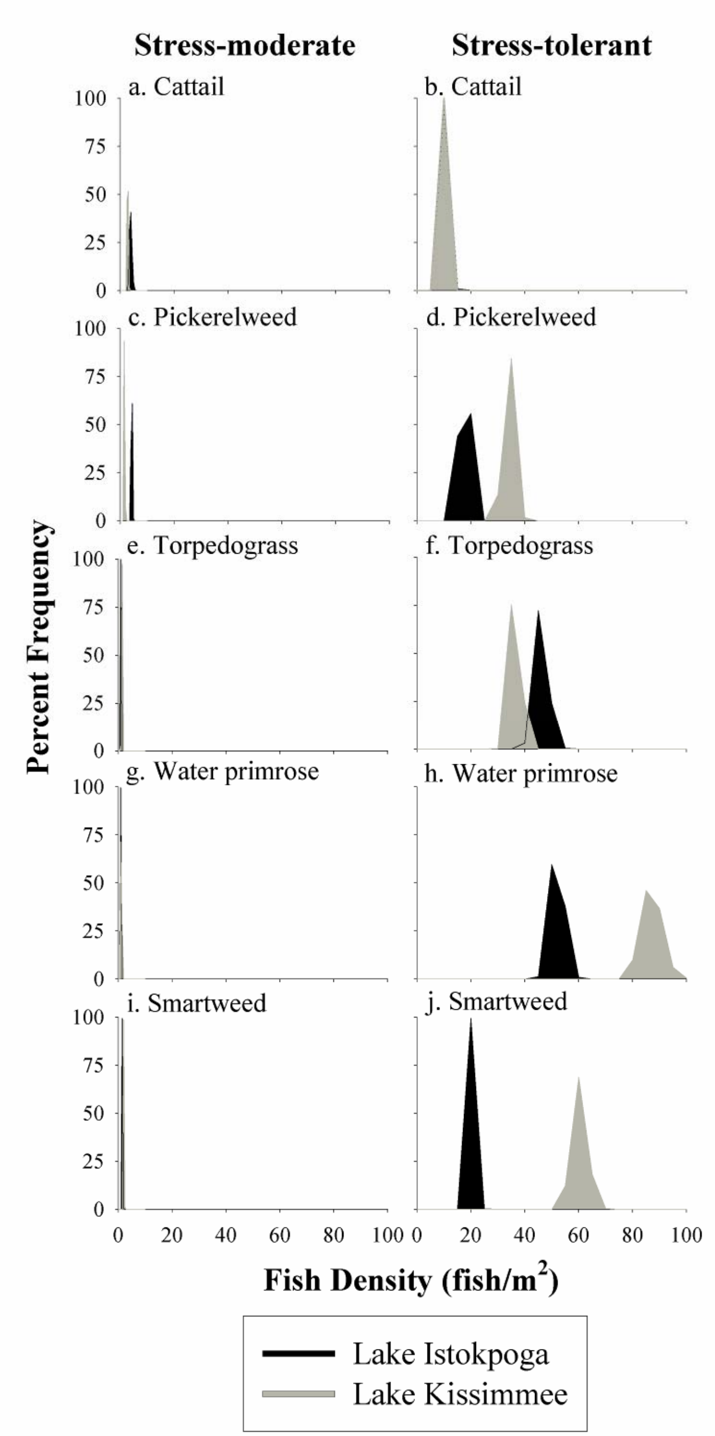

Figure 2-2. The percent composition of a distribution of means for stress-moderate and stress-tolerant densities estimated for cattail (a, b), pickerelweed (c, d), torpedograss (e, f), water primrose (g, h), and smartweed (i, j) at Lake Kissimmee (gray) and Lake Istokpoga (black). Distributions resulted from 1,000 bootstrap samples of original catch data with applied P_{rec} to estimate density.

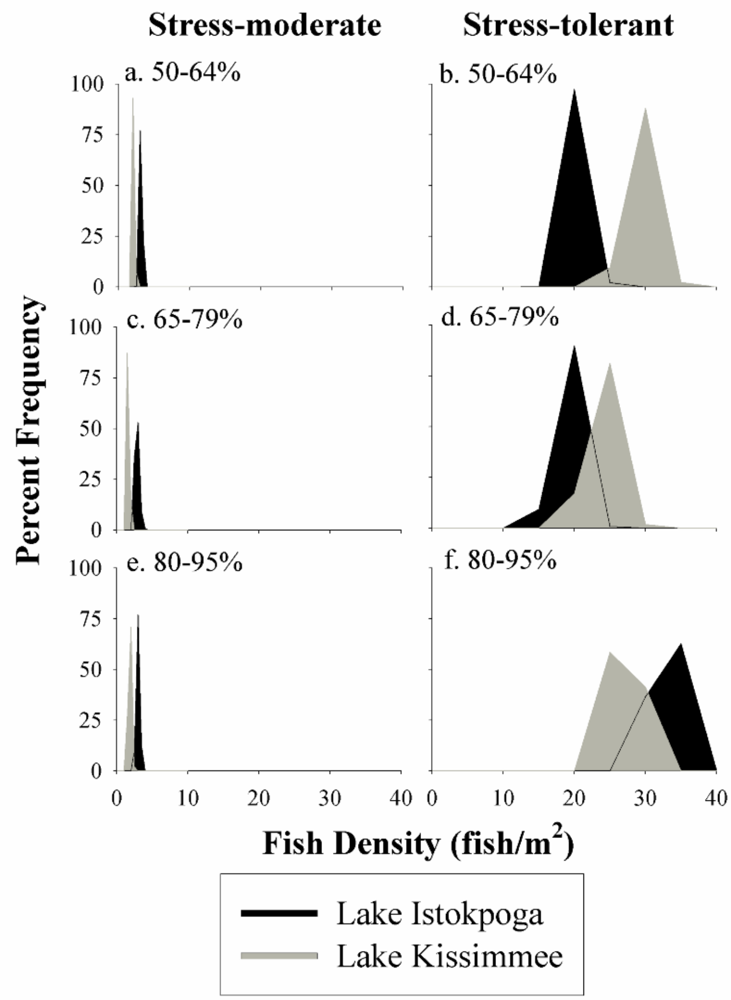

Figure 2-3. The percent composition of a distribution of means for stress-moderate and stress-tolerant densities estimated for plant coverage levels: 50-64% (a, b), 65-79% (c, d), and 80-95% (e, f) at Lake Kissimmee (gray) and Lake Istokpoga (black). Cattail, pickerelweed, and torpedograss sites were only included in this analysis. Distributions resulted from 1,000 bootstrap samples of original catch data with applied P_{rec} to estimate density.

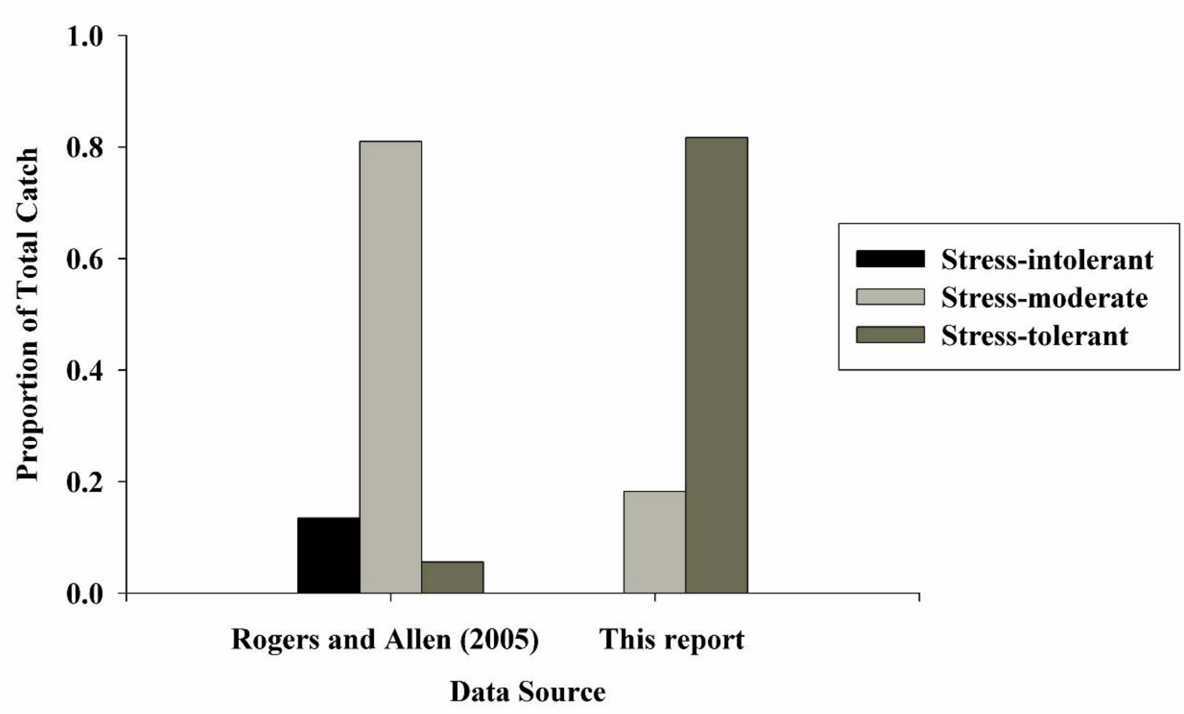

Figure 2-4. Comparison of catch composition between data from Rogers and Allen (2005) and data from this report. Each fish group is represented by a different color bar.

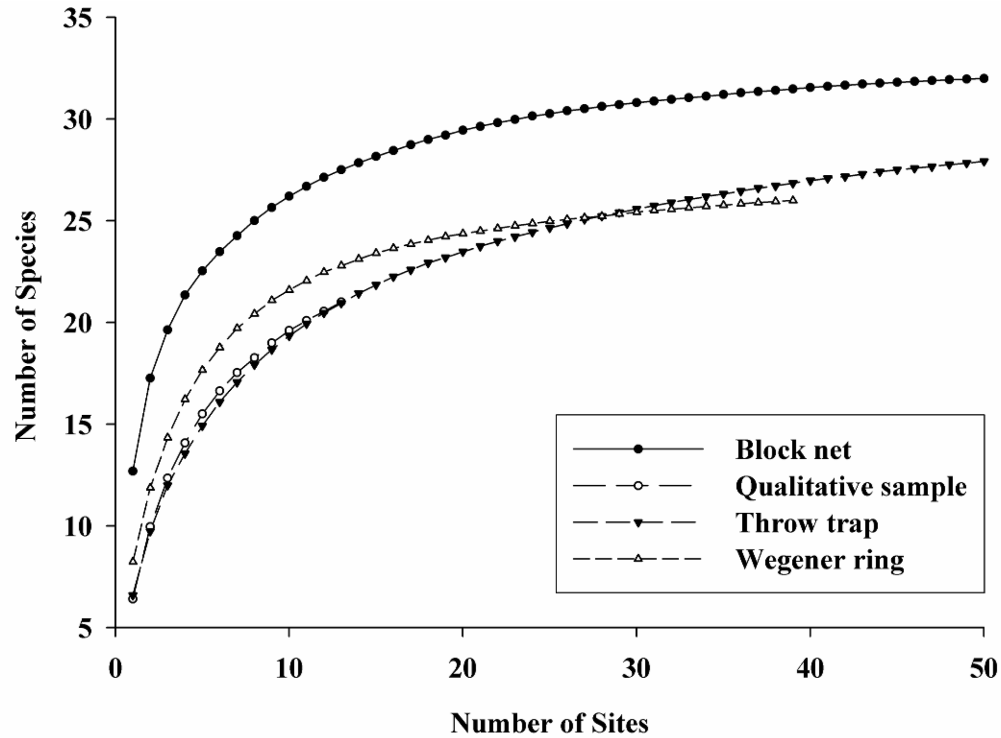

Figure 2-5. Species-area curves for each sampling method used in this study. Each method is represented by a different line type and symbol.

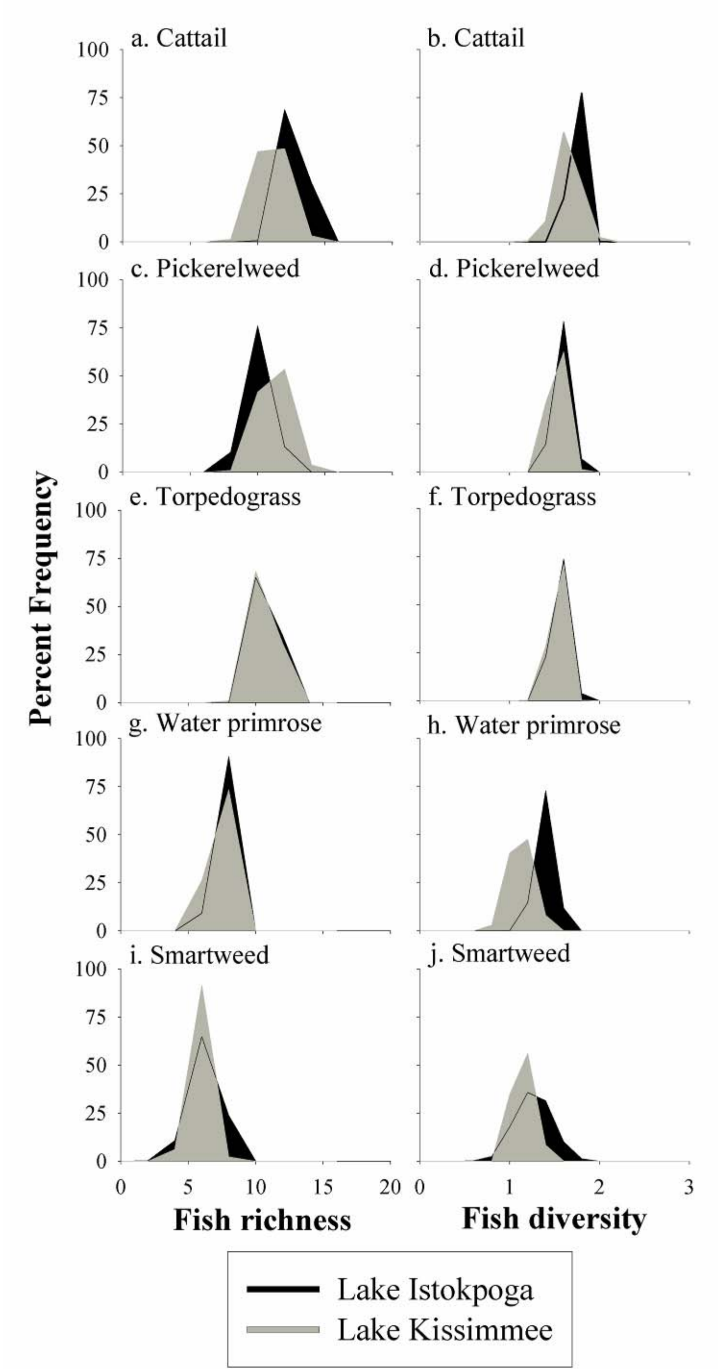

Figure 2-6. The percent composition of a distribution of means for fish richness and diversity estimated for cattail (a, b), pickerelweed (c, d), torpedograss (e, f), water primrose (g, h), and smartweed (i, j) at Lake Kissimmee (gray) and Lake Istokpoga (black). Distributions resulted from 1,000 bootstrap samples of original data.

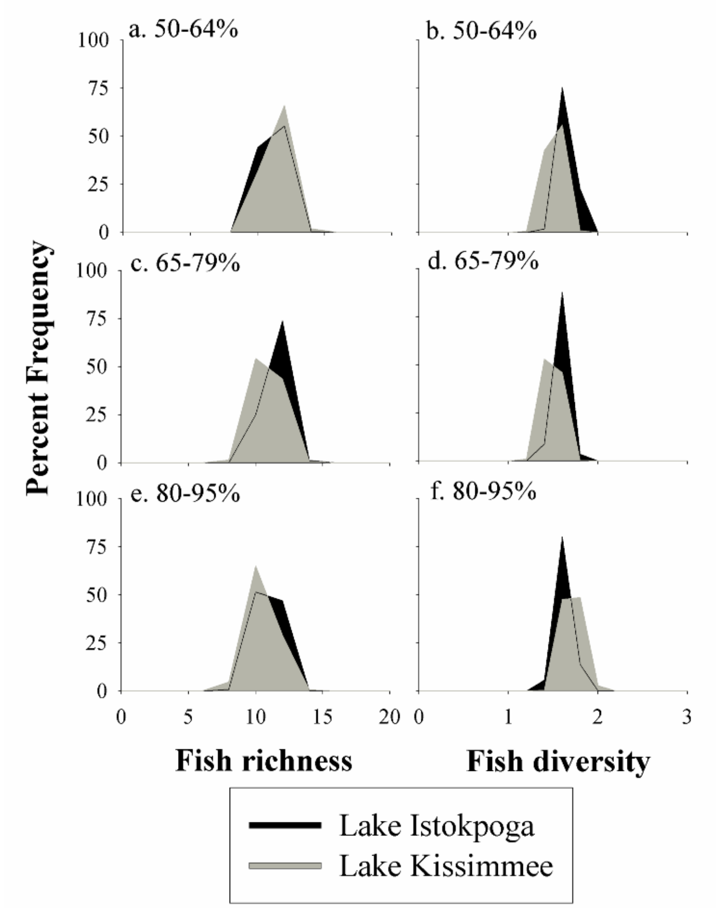

Figure 2-7. The percent composition of a distribution of means for fish richness and diversity estimated for plant coverage levels: 50-64% (a, b), 65-79% (c, d), and 80-95% (e, f) at Lake Kissimmee (gray) and Lake Istokpoga (black). Cattail, pickerelweed, and torpedograss sites were only included in this analysis. Distributions resulted from 1,000 bootstrap samples of original data.

CHAPTER 3
SYNTHESIS AND MANAGEMENT IMPLICATIONS

I found strong differences in mean DO (highest in cattail and lowest in smartweed) and the occurrence of hypoxia among plant species (highest in smartweed and lowest in cattail). Smartweed, water primrose, and torpedograss were most likely to have hypoxia of the plant species we evaluated, but hypoxia was common at the highest coverage level for all plant species we evaluated other than cattail.

Despite the occurrence of hypoxic refugia, all plants and coverages sampled were dominated numerically by stress-tolerant fishes (mainly cyprinodontoids) and contained low densities of stress-intolerant and stress-moderate fishes. Cattail, a plant species often considered as noxious, contained the largest abundance of stress-moderate (e.g., centrarchids) fishes in this study. Overall, I found higher DO concentrations, higher stress-moderate fish densities, a lower probability of hypoxia, and lower centrarchid mortality in cattail habitats when compared to other habitats sampled in this study. Conversely, water primrose showed opposite relationships. However, results from cattail habitats when compared to a diverse community of plant species revealed far fewer stress-moderate fishes.

Smartweed, water primrose, and torpedograss contained the highest abundance of stress-tolerant fishes. These plant species at high coverages probably provide refuge from predation, and are utilized to a much lesser degree by stress-moderate fishes (e.g., centrarchids). Centrarchid mortality experiments revealed that mortality was higher when fish were not allowed access to the surface suggesting that access to the surface is important during hypoxic conditions.

Resource managers interested in maintaining high fish diversity should prevent expansive areas of high coverages for the plant species studied through continued habitat restoration projects in combination with herbicidal treatments. However, managers should first recognize that patches of dense emergent plants provide important habitat for stress-tolerant fishes, and wildlife including birds, reptiles, and amphibians. Results of this study will provide resource managers with data needed to improve aquatic plant management plans in lakes that have undergone water level stabilization.

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BIOGRAPHICAL SKETCH

Aaron was born in 1983, in Asheville, North Carolina, to his proud and supportive parents, Joseph and Audrey Bunch. When he was two, the family moved to Elizabeth City, in northeastern N.C. where he grew up as an athlete, avid fisherman, and outdoorsman. In addition, he spent his time terrorizing his two sisters, Ginny and Jordan. Edenton, N.C. was his home-away-from-home where he spent many weekends with his grandparents who are near and dear to his heart: Paw-Paw, Granny Ruth, and Granny Bunch. After graduating high school, Aaron attended N.C. State University (Raleigh) where he studied fisheries and wildlife sciences. He discovered many facets of fisheries science during his many jobs and internships. Bryn Tracy served as a supervisor, mentor, and friend during his internship with the N.C. Division of Water Quality. Toward the end of his studies he worked for the U.S. Geological Survey studying stream fish assemblages in North Carolina Piedmont streams under the direction of two great supervisors: Douglas Harned and Dr. Thomas Cuffney. Aaron was very involved with the student fisheries society, and he owes many thanks to the advisors and graduate students who created an environment for him to grow professionally. During his time at N.C. State Aaron met his beautiful wife, Meredith. Aaron and Meredith moved to Gainesville, FL, where they worked for Dr. Mike Allen as fisheries technicians, and soon thereafter Aaron started graduate school under his advisement. The couple looks forward to starting a family.