ASSESSMENT OF FISH AND PLANT COMMUNITIES IN LAKE APOPKA, FLORIDA

By

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Abstract of Thesis Presented to the Graduate School
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Since the 1960s, an enormous amount of time and resources has been expended by the State of Florida and other government entities trying to improve the water quality in Lake Apopka, a hypereutrophic lake in central Florida; however, the lake remains in a turbid algal state in the early 2000s. The objective of this study was to assess the effectiveness of the restoration efforts in returning Lake Apopka back to its historic primary use of recreational fishing for largemouth bass (*Micropterus salmoides floridanus*). The assessment was accomplished by surveying the fish populations and aquatic plant communities in the lake to determine if there has been an increase in the abundance of largemouth bass or an expansion in the area occupied by aquatic vegetation. Fish were sampled by electrofishing on three occasions in June – August 2004. Submersed macrophyte beds, primarily eel-grass (*Vallisneria americana*), and floating-leaved and emergent plants were sampled in October 2004. The mean largemouth bass catch rate in 2004 was 7 fish/hr. The combined catch rate from 1989 to

1993 was also 7 fish/hr, thus showing that the largemouth bass population did not increase in relative abundance during the last decade. The abundance of largemouth bass continues to be lower than expected for Lake Apopka's trophic status in comparison to other Florida lakes. Submersed, floating-leaved, and emergent plants covered less than 1% of the surface area of the lake in 2004, indicating that the rooted aquatic vegetation has not expanded in the last several decades. Eel-grass colonized a total lake bottom area of approximately 900 m^2 in 2004 compared with an estimated 11,032 m^2 in 1999. Eel-grass has drastically declined during the past five years since it was replanted around the shore in 1999. It now occupies only 8% of its former area that it occupied in 1999. The restoration efforts at Lake Apopka have not yet been successful in restoring the largemouth bass fishery or in expanding the area occupied by aquatic vegetation. Reducing the abundance of planktonic algae through nutrient management is the primary restoration strategy for agencies such as the St. Johns River Water Management District (SJRWMD). Other factors besides light attenuation by planktonic algae, however, are involved in limiting the abundance of largemouth bass and expansion of aquatic macrophytes. The depth and fluidity of sediments, and wind resuspension of sediments, are also major factors. It could be several more decades before the largemouth bass fishery is improved while relying on the current restoration strategy unless alternative management strategies are also utilized. Three alternative management strategies or ideas that have been discussed are drawdown, artificial reefs or barriers, and stocking.

INTRODUCTION

Lake Apopka is the fourth largest lake in Florida with a surface area of 12,465 ha (Hoge et al. 2003). It is located northwest of Orlando, Florida, in both Orange and Lake counties (Figure 1). It is shallow (1.6 m mean depth) and polymictic. It is hypereutrophic with high nutrient and chlorophyll levels (100 µg/L mean total phosphorus (TP) and 59 µg/L mean chlorophyll *a* (chl*a*)), and low transparency (0.35 m mean Secchi depth (SD)) (Hoge et al. 2003). These limnological parameter values (TP, chl*a*, and SD) are mean 2004 values obtained from the St. Johns River Water Management District (SJRWMD). The lake is nearly round except that it is shaped like a funnel or gourd neck at the southern end of the lake (Figure 1). Vegetable farms (muck farms) were established on the north end of the lake after 1940 for World War II wartime food production.

Prior to 1950, Lake Apopka contained clear water, and dense growths of Illinois pondweed (*Potamogeton illinoensis*) and eel-grass (*Vallisneria americana*) down to depths of 2.4 m (Clugston 1963, Chestnut and Barman 1974). About 80% of the lake was inhabited by aquatic plants. Clugston (1963) reported that Illinois pondweed began at about 180 m from the shoreline and extended across the entire length and breath of the lake except in deep-water areas (≥ 2.4 m). Water hyacinth (*Eichhornia crassipes*) grew profusely around the entire shoreline of the lake (Clugston 1963). Boating around the lake was restricted to trails through submersed vegetation and to openings not covered by extensive mats of water hyacinth (Clugston 1963).

Lake Apopka was nationally renowned as a premier largemouth bass (*Micropterus salmoides floridanus*) fishing lake (Dequine 1950, Dequine and Hall 1951, Shofner 1982). Anglers came from throughout the United States to fish for trophy-sized largemouth bass (Davis 1946, Dequine 1950, Clugston 1963, Chestnut and Barman 1974). By the early 1950s, there were an estimated 13 fishing camps with a value to the local economy of over one million dollars annually (Dequine and Hall 1951, Shofner 1982).

Lake Apopka was changed in the early twentieth century by flood plain alteration, water level stabilization, and urban and agricultural runoff (Huffstutler et al. 1965). Also, in the 1940s, farms at the north end of the lake expanded by draining marsh areas. Following the expansion of the farms, farmers began to pump an increased amount of nutrient-rich water back into Lake Apopka (Clugston 1963). A hurricane in 1947 uprooted many of the macrophytes in the lake according to Mr. John Dequine (retired biologist, Florida Game and Fresh Water Fish Commission, personal communication), Clugston (1963), Schneider and Little (1969), Lake Apopka Restoration Council (1986), and Bachmann et al. (1999). Within several years, the remaining macrophytes disappeared in other parts of the lake as well, coinciding with a switch to a turbid algal state (Clugston 1963). There is controversy about the role of the hurricane in the loss of the macrophytes and about whether the switch from rooted macrophytes to algae was the result of natural causes or the result of the numerous human activities (Schelske and Brezonik 1992, Bachmann et al. 1999, Lowe et al. 1999, 2001, Canfield et al. 2000, Schelske et al. 2000, Schelske and Kenney 2001). Regardless of the mechanisms, sport fishing for largemouth bass declined in the late 1950s and early 1960s (Clugston 1963, Huffstutler et al. 1965, Lake Apopka Restoration Council 1986).

According to Johnson and Crumpton (1998), the largemouth bass fishery and aquatic vegetation community have been functionally non-existent at Lake Apopka since the 1960s. Dequine and Hall (1951) estimated that over 9,513 largemouth bass were harvested in January 1951 alone. Johnson and Crumpton (1998) stated that the combined harvest over the last two decades (from 1978 to 1998) probably would not equal that one month's harvest.

Aquatic vegetation in the 1980s and 1990s has only occupied a narrow belt around the shoreline of the lake, comprising less than 1% of the surface area of lake (Canfield and Hoyer 1992, Johnson and Crumpton 1998). Dominant emergent plant species were cattail (*Typha* spp.) and woody wetland species (red maple (*Acer rubrum*) and Carolina willow (*Salix caroliniana*)), which occupied 38% and 44% of the shoreline, respectively, in 1997 (Johnson and Crumpton 1998). There were isolated stands of aquatic grasses (maidencane (*Panicum hemitomon*), torpedograss (*Panicum repens*), Egyptian paspalidium (*Paspalidium geminatum*)), and soft-stem bulrush (*Scirpus validus*), which together occupied 8% of shoreline (Johnson and Crumpton 1998). The dominant floating-leaved plant species was water hyacinth in 1986, occurring in 27% of transects (Canfield and Hoyer 1992). The occurrence of floating-leaved or submersed plant species was not reported by Johnson and Crumpton (1998). The relative species richness of aquatic macrophytes (10 species) and fish (16 species) in 1986 was low in comparison with other Florida lakes (Canfield and Hoyer 1992).

A thick layer of flocculent sediments (1.5 m mean thickness) covers 90% of the lake bottom in almost all areas of the lake (Schneider and Little 1969). There is a firm bottom in some parts of the west shore and in some parts of the shoreline in the gourd neck area. These unconsolidated sediments are often resuspended by the wind, contributing to the high turbidity, and do not allow plants to anchor their roots (Carter et al. 1985, Doyle 2001, Doyle and Smart 2001) or largemouth bass to successfully nest (Porak et al. 1999).

Point sources of nutrient loading from sewage and citrus processing plants were eliminated by the 1980s, and discharges from farming operations were reduced in 1992 (Johnson and Crumpton 1998, Bachmann et al. 1999, Canfield et al. 2000, Hoge et al. 2003). The majority of these farmlands were purchased by the SJRWMD in the late 1990s. The SJRWMD continues to conduct management efforts to restore Lake Apopka under the Lake Apopka Surface Water Improvement and Management (SWIM) program (Conrow et al. 1993, Hoge et al. 2003).

The current restoration program strategy, headed by the SJRWMD, is based primarily on reducing external nutrient loading, focusing primarily on phosphorus (P) reductions (Hoge et al. 2003). The P criterion proposed by the SJRWMD for the lake is 55 µg/L (Hoge et al. 2003). Other projects of the current restoration program have included removing gizzard shad (*Dorosoma cepedianum*) from the lake and planting macrophytes around the shore in the 1990s. Despite the enormous amount of time and resources that have been expended trying to improve the water quality in Lake Apopka and to return the lake to its former clear-water, macrophyte-dominated state, nationally renowned for its largemouth bass fishery, the lake remains in a turbid algal state (Bachmann et al. 1999).

There is a lack of unanimity regarding the efficacy of restoration efforts (Bachmann et al. 1999, 2001a, b, Lowe et al. 1999, 2001, Canfield et al. 2000, Schelske et al. 2000, Schelske and Kenney 2001). Some authors do not believe that the restoration program, based primarily on an external P reduction program, will be successful in improving the water clarity or in expanding the aquatic vegetation needed as habitat for largemouth bass in the near-future (Bachmann et al. 1999, 2001a, b, Canfield et al. 2000). Alternative hypotheses regarding the limiting factor responsible for causing the turbidity of the water, for example wind resuspension of sediments (Bachmann et al. 1999, 2000a, b), have been put forth but have not yet been acted upon.

Recent management strategies have not included alternative methods and ideas such as drawdown or artificial barriers that could reduce the turbidity in the water from resuspended particles and potentially improve the largemouth bass fishery. For example, a major drawdown could consolidate and compact the sediments (Wegener and Williams 1974, Moyer et al. 1995) if the technical problems, such as the amount of water to be moved and the length of time that the lake would stay drained, could be resolved (United States Environmental Protection Agency (USEPA) 1979). Also, placing artificial barriers around the perimeter of the lake could provide calm, protected waters and improve the habitat for largemouth bass in those areas (Canfield et al. 2000).

No studies have been conducted to find out if the aquatic plants, which were planted by the SJRWMD in or before 1999, have expanded in area to determine if the restoration program has been successful in one of its primary objectives of restoring lake habitat (Hoge et al. 2003), and to determine if the money that has been expended has been well spent. For example, more than $100,000,000 in Federal and State funds were used to purchase farms, with drainage to the lake, to take them out of production. A marsh flow-way was also constructed to remove phosphorus-rich particles from the lake water (Conrow et al. 1993, Hoge et al. 2003). A study was needed to assess the response of the fish and plant communities in Lake Apopka to these restoration activities because of the controversy over the successfulness of the restoration program.

Previous studies to assess the fish and plant communities in Lake Apopka were conducted by Canfield and Hoyer (1992) and Johnson and Crumpton (1998). The objective of this study was to evaluate the effectiveness of the restoration program in restoring the largemouth bass fishery and the aquatic plant community. This objective was accomplished by sampling the littoral fish populations and the aquatic macrophyte community. The criteria, for determining if the restoration program was effective, was whether or not the largemouth bass population has increased in abundance (catch rate as number/hr or kg/hr) in the last two decades, or the aquatic macrophyte community, used as habitat by largemouth bass, has expanded in area (m^2 or ha) since 1999. To make this determination, the abundance and structure of the littoral fish populations and aquatic macrophyte community, surveyed by this study in 2004, were compared, and tested as appropriate, to those of previous studies.

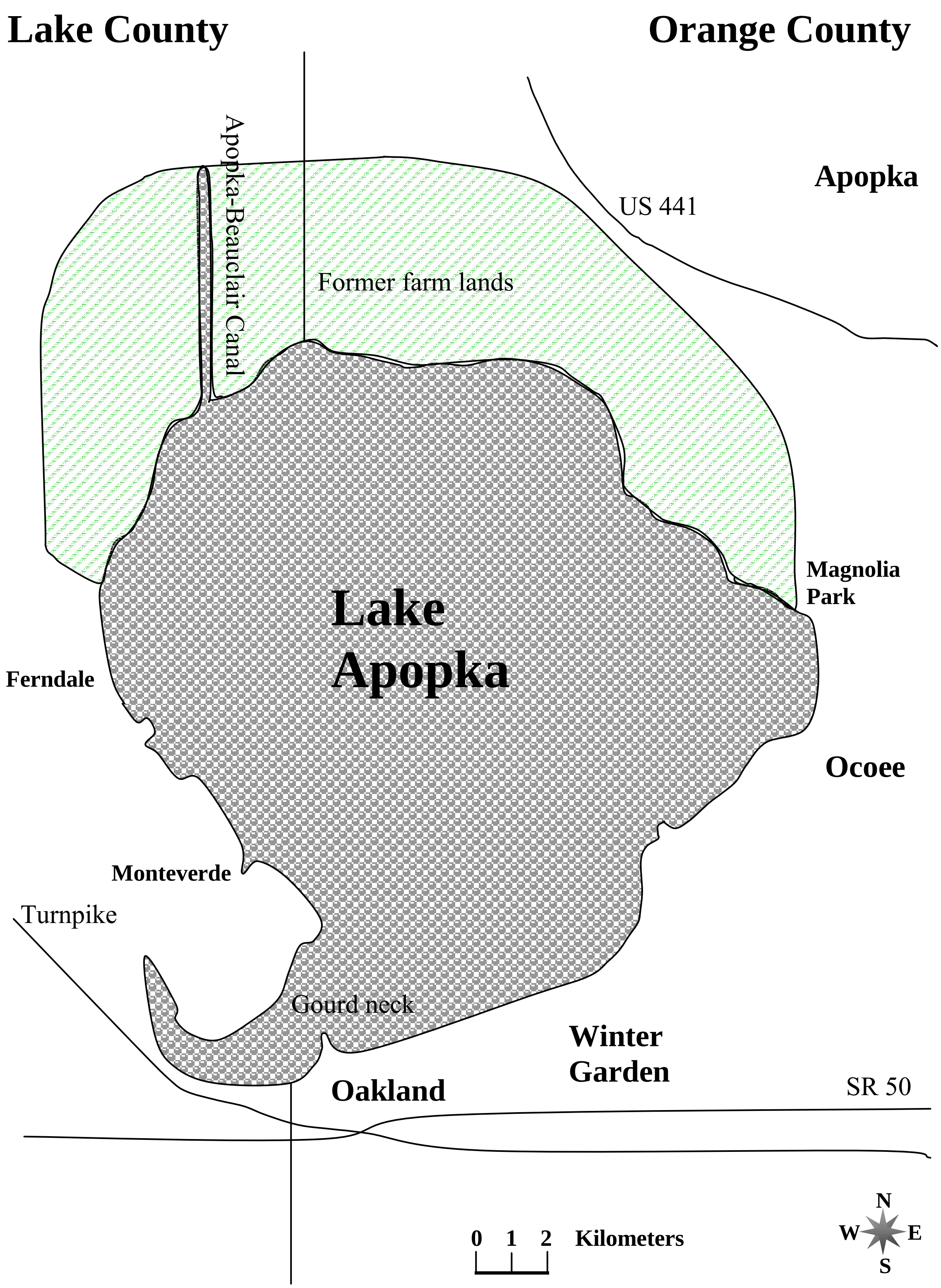

Figure 1. Lake Apopka and surrounding area (modeled using Hoge et al. 2003, page 14).

MATERIALS AND METHODS

Fish

Fish were electrofished in near-shore areas of the main part of Lake Apopka, excluding the gourd neck area and the adjoining canals. Ten transects were sampled once monthly in June, July, and August 2004 using a Coffelt Mfg., Inc. control box. Ten additional transects were sampled in June using a Smith-Root, Inc. control box as part of a control box comparison study, thus totaling 40 transects. Transects were evenly spaced around the lake in all habitats. Each transect was 10 minutes in duration, with continuous current input. Methods were similar to those used by Canfield and Hoyer (1992), Hoyer (University of Florida (UF), unpublished data), and Johnson and Crumpton (1998).

Fish were collected, identified to species, measured to the nearest mm total length (TL), and released back into the lake. Individual fish weights were calculated from measured lengths using total weight to length regression formulas developed for individual Florida freshwater fish species by Hoyer and Canfield (1994). The total number and weight of fish were calculated by transect and then averaged across the 40 transects to yield catch per unit electrofishing effort (number or kg/hr of electrofishing) statistics.

At each electrofishing transect, the depth and dominant vegetation, if present, were recorded. Dissolved oxygen (DO) concentration (mg/L), Secchi disc depth (SD) (m), specific conductance (μS/cm at 25 C), and water temperature (C) were measured at four near-shore stations, when the electrofishing was conducted (one station in each of the north, east, south, and west regions of the lake). Dissolved oxygen concentration, specific conductance, and water temperature were measured by using a Yellow Springs Instrument Company Model 85 Meter.

Coffelt Mfg., Inc. control boxes were used in collecting fish in previous studies at Lake Apopka by Canfield and Hoyer (1992) and by Hoyer (UF, unpublished data). Coffelt Mfg., Inc. recently went out of business and the only company that now manufactures electrofishing control boxes is now Smith-Root, Inc. The Florida Fish and Wildlife Conservation Commission (FFWCC) replaced all of its Coffelt Mfg., Inc. control boxes with control boxes manufactured by Smith-Root, Inc. in the 1990s, but the UF, Department of Fisheries and Aquatic Sciences (FAS) uses both brands of control boxes. Because the catch rate of this study (which used both brands of control boxes) was compared to previous studies by Canfield and Hoyer (1992), Hoyer (UF, unpublished data), and Johnson and Crumpton (1998) that did not all use the same brand of control box, it was important to conduct a comparison study to account for any possible differences that might be due to using different control boxes.

A comparison study was conducted in June 2004 by using control boxes manufactured by Smith-Root, Inc. and Coffelt Mfg., Inc. to simultaneously collect fish in 10 paired transects in similar habitat. The data from paired transects were used to test for differences in catch rate between the two control boxes using a paired *t* test. Each boat started from the middle of the habitat, 10 m apart, and worked away from each other to the ends of the habitat. The two boats used in the comparison study were set up identically except for the control boxes. Both boats were 5 m in length, made of aluminum, powered by 50-hp Mercury motors, and equipped with 5000-watt Honda

EG5000X generators (Table 1). Both boats had one boom with an attached 62-cm diameter ring, with six 1-cm diameter, 1.2-m long, stainless steel cables in place, for transmitting electricity into the water. Both control boxes were set at 7-9 amps, 180-190 volts, 60-80 pulses per second, and (pulsed) alternating current output (Table 2). All persons participating in the study had prior experience in electrofishing. One person, in each boat, dipped fish.

Although the equipment and sampling design used in this study were similar to previous studies on Lake Apopka, there were some differences. Johnson and Crumpton (1998) was the only study that used two electric booms. A study was not conducted to determine if having two booms would result in collecting more fish than using only one boom. Additionally, no studies were found in the literature that compared the efficiency of using two booms versus one boom.

Johnson and Crumpton (1998) had the most samples (870 transects in 1989 – 1993, and 150 transects in 1996 – 1997) (Table 3). They collected fish in 5-min transects using random sampling in 1989 – 1993, and both random and selected sampling in 1996 – 1997. All the other studies collected fish in 10-min transects using evenly distributed sampling. Hoyer (UF, unpublished data) sampled only the northern half of the lake, whereas, all of the other studies sampled the entire lake.

Aquatic Macrophytes

Dominant plant species were recorded at each of the evenly spaced, electrofishing transects during each sampling occasion. Four fathometer transects (north to south, west to east, northwest to southeast, and southwest to northeast) were run across the entire diameter (~17 km) of the lake in August 2004 to record the location and amount, if any, of submersed vegetation in Lake Apopka. The procedures for using a recording fathometer and determining quantitative vegetation parameters have been described previously (Maceina and Shireman 1980). The widths of floating-leaved and emergent plant zones (m) were estimated by eye at 30 transects evenly spaced around the lake in October 2004. Estimating fixed distances was practiced just prior to sampling and consistent methods were used to make and record estimations of distance. Dissolved oxygen concentration and SD were measured at four near-shore stations, on the date that vegetation was sampled (one station in each of the north, east, south, and west regions of the lake).

The 16 largest beds of eel-grass, reported by the SJRWMD (Conrow and Peterson 2000), were sampled in October 2004. Eel-grass was the only submersed macrophyte sampled in this study because it was the only submersed macrophyte reported to be abundant (~ 1 ha) in the lake besides hydrilla (*Hydrilla verticillata*, ≤ 0.5 ha) (Conrow and Peterson 2000). Hydrilla was not sampled during this study because contact herbicide has been applied regularly by the SJRWMD to keep it from expanding (Erich Marzolf, environmental scientist, SJRWMD, Palatka, FL, personal communication). The location and abundance of hydrilla also changes frequently.

All sampled eel-grass beds were located on the west side of the lake, with a few exceptions. Only a few small beds were reported on the north, east, or south sides of the lake (Conrow and Peterson 2000). Seven additional sites were sampled in the north (3 sites), east (1 site), and south (3 sites) regions of the lake, even though they were small (Conrow and Peterson 2000), so that the entire lake would be represented by the locations that were chosen. Sites were found using GPS coordinates obtained from the SJRWMD.

At each site, the area (m^2) of the plant bed was estimated by eye from the boat for all but the largest beds. Estimating fixed distances was practiced just prior to sampling and consistent methods were used to make and record estimations of distance. Plant beds, over 100 m^2 in area, were walked around while simultaneously measuring their area (m^2) with a handheld GPS receiver. The percent density (from 0 to 100% for sparse to dense aggregations) was estimated by eye. The type of soil (sand or some degree of silt/mud) was determined by pushing on the substrate with a rod. The maximum water depth (m) that the plant bed was growing in was determined by lowering a Secchi disk until it rested on the substrate and measuring the vertical distance (m) from the substrate to the water surface with the attached cord.

Light attenuation in Lake Apopka was measured (in quanta units) using a photometer (LI-COR model LI-1400 data logger) attached to an underwater quantum sensor (LI-192SA) and a spherical quantum sensor (LI-193SA). Three samples, spaced 15 m apart, were taken at the center of the lake on three sampling occasions (once monthly in June, August, and October 2004) for a total of nine samples. Irradiance measurements were taken at the center of the lake because of depth limitations near shore. A sample consisted of taking a series of downwelling irradiation measurements every 0.2 m into the water column starting from the surface until either depth or light became limited (as seen by negative irradiance measurements), whichever was reached first. Measurements were taken with the spherical quantum sensor laying facing up on the deck to measure ambient atmospheric irradiance and with the underwater sensor attached to a graduated rod that was held straight out and away from the sampler's body on the sunny side of the boat with the rod aligned vertically.

The maximum depth of colonization (MDC) is the maximum depth at which an aquatic macrophyte species is capable of colonizing. Mittelboe and Markager (1997) stated that the MDC was defined by the deepest growing plant observed. Since MDC is thought to be primarily limited by irradiance (Chambers and Kalff 1985, Carter et al. 1985), measurements of downwelling irradiance in the water column, and calculations of the percent of downwelling surface irradiance at depth, can be used to determine the theoretical MDC (Korschgen et al. 1997). One percent of downwelling surface irradiance (I_o) is generally taken as the theoretical MDC of aquatic macrophytes (Dennison 1987, Valiela 1995) because it is the compensation depth at which photosynthesis and plant respiration are equivalent (Korschgen et al. 1997).

Aquatic macrophytes are not always able to colonize down to their theoretical MDC except under optimal conditions (Spence 1972, Barko and Smart 1981, Chambers and Kalff 1985, Scheffer et al. 1992, Hudon et al. 2000). The lower depth limit, with some exceptions, more commonly occurs at light levels between 5 and 10% I_o (Sheldon and Boylen 1977, Barko et al. 1982, Chambers and Kalff 1985, Kimber et al. 1995a, b). Dennison (1987) stated that the maximum depth limit for freshwater macrophytes was roughly equivalent to the Secchi disc depth, which is often taken as the 10% light level (Strickland 1958).

The maximum depth of growth (MDG) is defined in this paper as the maximum depth corresponding to the minimum percent of I_o at which an aquatic macrophyte species predominantly grows down to, as limited by light attenuation (Sheldon and Boylen 1977, Kenworthy and Fonseca 1996, Nichols 1997, Moore et al. 2003). Other studies have more strictly defined the MDG as the maximum depth corresponding to the minimum percent of I_o needed for there to be a specified production (number or g) or elongation (cm) of leaf, meristem, or shoot, or production (g) of biomass, within a specified period of time (days) (Barko and Smart 1981, Barko et al. 1982, Loreny and Herderndorf 1982, Dennison 1987, Duarte and Kalff 1987, Sand-Jensen and Madsen 1991, Korschgen et al. 1997, Blanch et al. 1998, Bintz and Nixon 2001, Grimshaw et al. 2002, Nielsen et al. 2002). The theoretical MDG for eel-grass was established in this study by referencing previous studies on the minimum percent of I_o needed for eel-grass to grow. For example, the maximum depth corresponding to a minimum referenced percent of I_o, needed for eel-grass to grow, was taken as the MDG.

The data from the light meter measurements were used to determine the theoretical MDC and MDG of eel-grass in Lake Apopka. The theoretical MDC and MDG were chosen as 1% I_o and 8% I_o, respectively, because authors in the literature have reported that eel-grass and other aquatic vascular plants are capable of colonizing down to depths of 1% I_o and that they grow down to about 8% I_o (Sheldon and Boylen 1977, Barko et al. 1982, Carter and Rybicki 1985, 1990, Duarte and Kalff 1987, Goldsborough and Kemp 1988, Sand-Jensen and Madsen 1991, Zimmerman et al. 1994). For each sample, the ratio of downwelling irradiance at depth (I_d) to I_o, taken as a percent, was calculated using Microsoft Office Excel 2003 to determine theoretical MDC and MDG. For example, the ratio of I_d to I_o, taken as a percent, yields the percent downwelling irradiance at a given depth in the water column. Then, the water depth corresponding to 1% and 8% I_o equals the theoretical MDC and MDG, respectively.

The total area (m^2) of eel-grass that was found in Lake Apopka during this study was subtracted from the total area reported by the SJRWMD in 1999 (Conrow and

Peterson 2000) to determine if eel-grass was expanding, remaining constant, or declining. The observed and theoretical MDC and MDG were compared to determine if the maximum depth at which eel-grass was found to be growing agrees with the theoretical depth to which it should be able to grow. The observed MDG used in my analysis was derived from the maximum depth (m) at which eel-grass was measured to be predominantly growing. Similarly, the observed MDC used in my analysis was derived from the maximum depth at which eel-grass was found to be growing at the 23 sites sampled.

The area of the lake, that was available for eel-grass to colonize and grow based on the observed MDC and MDG, was calculated using a bathymetric map (Danek and Tomlinson 1989). This area was compared to the total area of eel-grass found to determine the percentage of available area that eel-grass inhabited under the current light regime. The percentage of the total lake area that eel-grass was theoretically able to colonize and grow, under the current light regime, was also calculated.

Statistical Analyses

The catch rates of total fish and largemouth bass of this study were compared to the catch rates of previous studies conducted in 1986 by Canfield and Hoyer (1992); in 1987 – 1996, excluding 1990, by Hoyer (UF, unpublished data); and in 1989 – 1993 and 1996 – 1997 (largemouth bass only) by Johnson and Crumpton (1998). *T* tests were used, where appropriate, to determine if there had been a statistical difference in the abundance of total fish or individual fish species in the near-shore region of Lake Apopka. Raw data were available only for Johnson and Crumpton (1998) for 1989 – 1993, and not for 1996 – 1997. Their report and tables were used to determine the catch rate of largemouth bass, bluegill (*Lepomis macrochirus*), and redear sunfish (*Lepomis* *microlophus*) for 1996 – 1997. Microsoft Office Excel 2003 was used to analyze all data (the fish and plant data collected in this study, as well as data collected by other individuals).

The population of largemouth bass at Lake Apopka, from 1986 to 2004, was graphically compared to 60 other Florida lakes sampled by Canfield and Hoyer (1992), by plotting the mean catch per unit effort (CPUE) (kg/hr) of largemouth bass for all of the lakes against their corresponding mean chl*a* (µg/L) value. Four separately identified data points were given for the individual studies that sampled Lake Apopka from 1986 to 2004. Chlorophyll data points, for the individual studies conducted at Lake Apopka, were the mean yearly chlorophyll values, for the years in which Lake Apopka was sampled, obtained from the SJRWMD. Chlorophyll data points, for the 60 lakes sampled by Canfield and Hoyer (1992) were the mean chlorophyll values reported in Canfield and Hoyer (1992). Data were transformed to their logarithms (base 10) to reduce heterogeneity of variance. The resulting plot allows comparison of the mean CPUE of largemouth bass of all the lakes based on their mean chl*a* values.

The efficiency of collecting total fish using control boxes manufactured by different companies, Smith-Root, Inc. versus Coffelt Mfg, Inc., was tested for significant differences using a paired *t* test. The efficiency of collecting two categories of fish was also tested using paired *t* tests. Centrarchids (warmouth (*Lepomis gulosus*), bluegill, redear sunfish, and largemouth bass) were lumped into one category. Other non-centrarchids (Florida gar (*Lepisosteus platyrhincus*), bowfin (*Amia calva*), gizzard shad, blue tilapia (*Tilapia aurea*), yellow bullhead (*Ameiurus natalis*), brown bullhead

(*Ameiurus nebulosus*), and channel catfish (*Ictalurus punctatus*)) were lumped into a second category.

Table 1. Electrofishing boat setup used by different studies at Lake Apopka, Florida.

Study	Generator Model	Number of Booms	Number of Persons Dipping Fish
This Study (2004)	Honda EG5000X	1	1
Johnson & Crumpton (1998)	Honda EG5000X	2	1
Hoyer (Unpublished data)	Honda EG5000X	1	1
Canfield & Hoyer (1992)	Honda EG5000X	1	1

Table 2. Electrofishing control box settings used by different studies at Lake Apopka, Florida.

Study	Control Box Model	Output Mode	Output Amps	Output Volts	Pulse Width	Frequency
This Study (2004)	Coffelt VVP-15	Pulsed AC	7 – 9	180	50%	80 – 100
	Smith-Root VI-A	Pulsed AC	6 – 8	177	2 ms	—
Johnson & Crumpton (1998)	Smith-Root VI-A	Pulsed AC or Pulsed DC	5 – 7	177 – 500	2 – 5 ms	—
Hoyer (Unpublished data)	Coffelt VVP-15	Pulsed AC	7 – 9	180	50%	80 – 100
Canfield & Hoyer (1992)	Coffelt VVP-15	Pulsed AC	7 – 9	180	50%	80 – 100

Table 3. Electrofishing methods used by different studies at Lake Apopka, Florida.

Study	Month and Years Sampled	Number of Samples (N)	Elapsed Time of Each Transect With Continuous Current	Sampling Method	Region of Lake
This Study (2004)	Jun 2004	20	10	Proportioned by habitat	Entire lake[a]
	Jul 2004 – Aug 2004	20	10	Evenly distributed	Entire lake[a]
Johnson & Crumpton (1998)	Mar 1989 – Nov 1993[b]	870	5	Random	Entire lake
	Nov 1996 – Sept 1997[c]	180	5	75 random, 75 selected	Entire lake
Hoyer (Unpublished data)	Mar 1987 – Jan 1996[d]	62	10	Evenly distributed	Northern half only
Canfield and Hoyer (1992)	Aug 1986	9	10	Evenly distributed	Entire lake[a]

[a]Not including the gourd neck area or canals.

[b]Twenty-nine months were sampled bimonthly in the odd months of the year.

[c]Six months were sampled bimonthly in the odd months of the year.

[d]Sampling was conducted only in January, February, or March.

RESULTS AND DISCUSSION

Fish

Twenty species of fish were collected in 2004 (Table 4). Canfield and Hoyer (1992), Hoyer (UF, unpublished data), and Johnson and Crumpton (1998) collected 16, 22, and 26 species, respectively. These differences in species richness are within a range that would be expected from a stable fish community when temporal and personnel differences in sampling are accounted for (Reynolds 1983, Hardin and Conner 1992, Andrus 2000, Ott and Longnecker 2001, Bayley and Austen 2002).

Since Johnson and Crumpton (1998) took the most number of samples (870), bimonthly, over a five-year period, using natural laws of probabilities (Ott and Longnecker 2001), it would be expected for them to encounter more rare species than the other studies that took less samples or took all of their samples in only one or a few months, or only in a certain season of the year. Also, since Canfield and Hoyer (1992) only sampled on one date, it is reasonable that they collected the smallest number of species.

Differences in the manner in which personnel sample can result in changes in the number and type of fish collected (Reynolds 1983, Hardin and Conner 1992, Andrus 2000, Bayley and Austen 2002). Personnel, that are meticulous in collecting every fish regardless of size, are likely to collect a greater quantity of smaller, rare species. Also, misidentification can result in an incorrect number of fish species being recorded.

There was no significant difference in the number of total fish, centrarchids, or non-centrarchids collected between Smith-Root, Inc. and Coffelt Mfg., Inc. control boxes ($p > 0.05$ for all three tests), although there were some interesting findings. When the Smith-Root, Inc. control box was used, slightly more fish (23) were collected overall for all 10 combined transects than when the Coffelt Mfg., Inc. control box was used. There was higher variation in the total number of fish collected with the Coffelt Mfg., Inc. control box (standard error = 7.1/hr) than with the Smith-Root, Inc. control box (standard error = 6.1/hr). Also, when the Coffelt Mfg., Inc. control box was used, proportionally more centrarchid fish were caught than non-centrarchids compared to the Smith-Root, Inc. control box.

These results may apply only to conditions present at Lake Apopka during the time of sampling (Bayley and Austen 2002). For example, the high mean conductivity (453 µS/cm at 25 C) in Lake Apopka at the time of sampling, decreased the efficiency of collecting fish, while using either brand of control box (Kolz 1989). Reynolds (2000) stated that conductivity was the single most important environmental factor in electrofishing. Temperature is also important. It affects the ability of the fish to float, respond, and escape (Reynolds 2000). Mean water chemistry parameters during sampling were 5.9 mg/L DO, 0.37 m SD, and 31.6 C water temperature (Table 5).

The total catch rate in 2004 was 156 fish/hr. Mean catch for Canfield and Hoyer (1992), Hoyer (UF, unpublished data), and Johnson and Crumpton (1998) (1989 – 1993 data) were 203, 268, and 365 fish/hr, respectively (Figures 2 and 3). Comparison of the yearly mean total catch rate over time suggests that the mean total abundance of fish has declined since 1993 in the near-shore region in Lake Apopka ($p \leq 0.05$).

The total catch rate of this study was only tested for differences with Johnson and Crumpton (1998), for the data from 1989 – 1993, because the data of that time period were the most representative, of the different studies, of the fish populations in Lake Apopka, based on the fact that they took the most samples (870 transects), bimonthly, over an extended period of time (5 years) (Materials and Methods, Table 3). Canfield and Hoyer (1992) only sampled on one occasion (9 transects). Hoyer (UF, unpublished data) only sampled the northern half of the lake (62 transects).

Johnson and Crumpton (1998) was the only study that used two electric booms. Using two booms could help explain why their mean total catch rate was higher than Canfield and Hoyer (1992) and Hoyer (UF, unpublished data) during the same, or close to the same, time period. If using two booms enabled Johnson and Crumpton (1998) to collect more total fish than they would have collected using just one, it would result in a larger reported difference in the catch rate of total fish over time.

Additionally, the mean total catch rate remained stable or increased from 1986 – 1993 (Figure 3). In 1993, the total catch rate seems to have declined dramatically. Johnson and Crumpton (1998) stated that the abundance of open water fish species (gizzard shad, threadfin shad (*Dorosoma petenense*), blue tilapia, and black crappie (*Pomoxis nigromaculatus*)) as well as centrarchids (bluegill, redear sunfish, and largemouth bass) all declined from 1989 – 1993 to 1996 – 1997. It was appropriate, therefore, to test for a decrease in the total catch rate from 1993 to 2004.

Part of the reason for the decline in the total abundance of fish may be attributed to the extensive harvesting of gizzard shad. For example, Crumpton and Godwin (1997) reported that, from January 1993 through June 1997, commercial fishermen harvested over 5 million gizzard shad weighing about 2.3 million kg from Lake Apopka.

Secondly, adverse environmental conditions present at the time of sampling could also have reduced the total catch rate in 2004. For example, Hurricane Charley passed over central Florida on 13 August (National Oceanic and Atmospheric Administration (NOAA) 2005), just five days prior to the date that fish were sampled on 18 August. A widespread mud plume was observed in the center of the lake while sampling fish on that date. A widespread fish kill was also observed across the entire north half of the lake. Additionally, the mean DO concentration (3.48 mg/L) for the near-shore stations in August was low.

Lastly, it is possible that the decrease in mean yearly chl*a* from about 97µg/L in 1990 to 59 µg/L in 2004 could have resulted in decreased productivity in the lake as well as a reduction in the abundance of open water fish species (Bachmann et al. 1996). These chl*a* values were based on unpublished data obtained from the SJRWMD.

Because it was suspected that the adverse environmental conditions in August 2004 affected the total catch rate, the 2004 total catch rate was divided by month. The mean total catch rates for June, July, and August were 149, 285, and 44 fish/hr, respectively. The mean total catch rate in August was much lower than the two previous months and contributed to the low total catch rate in 2004. Comparison of total catch rate among all the studies, by using the same months that were sampled in 2004, would have provided a direct comparison. Unfortunately, none of the previous studies sampled in the same months (June, July, and August) as this study in 2004 (see Materials and Methods, Table 3).

Comparison of the 2004 individual fish species percent of total, with Johnson and Crumpton (1998), for 1989 – 1993, suggests that there has been a decrease in percent of total fish for open water fish species (gizzard shad, threadfin shad, black crappie, blue tilapia, and brown bullhead) over time (Figures 4 and 5). These open water species composed 11% of the total fish number in 2004, a decrease from 56% of the total number in 1989 – 1993. These values represent a species composition change from open water species being most abundant in the near-shore region in previous years (1989 – 1993) to centrarchids being dominant in 2004. A decrease in gizzard shad and threadfin shad (from 34 to 5% of total fish numbers) contributed the largest proportion of the change. No dramatic changes in the abundance of rare species were observed.

Centrarchids (warmouth, bluegill, redear sunfish, and largemouth bass) comprised 78% of the fish collected in 2004, an increase from 29% of the fish in 1989 – 1993 (Figures 4 and 5). The most abundant species in 2004 were bluegill and redear sunfish with catch rates of 86 and 16 fish/hr, respectively (Table 6). The catch rates for these species in 1989 – 1993 were 73 and 18 fish/hr, respectively (Table 7). Comparison of the mean catch rate over time suggests that bluegill abundance is similar from previous years, even though there is a statistical difference ($p \leq 0.05$).

This difference in the catch rate of bluegill and redear sunfish over time is within a range expected from a stable fish population, given the natural fluctuations in fish populations, and the temporal differences in sampling (Swingle 1950, Latta 1975, Ott and Longnecker 2001). Latta (1975) stated that the abundance of fish populations changes dynamically in response to changing environmental (e.g., temperature, wind, dissolved oxygen, competition, predation) and biological (e.g., reproduction, growth, and mortality) factors. Swingle (1950) stated that fish populations are regulated by the number of offspring in the present year, and the number remaining in the population from the previous year. He also stated that fish populations dynamically change depending on the number and ratio of predator and forage fish present. Ott and Longnecker (2001) stated, that as time increases between sampling occasions, greater differences in abundance between samples can be expected. These changes in the abundance of bluegill and redear sunfish over time are not very big considering all of the possible stochastic environmental and biological changes over time, the amount of time that has passed between sampling occasions, and the natural variation in sampling.

The catch rate of small (< 14 cm total length (TL)) bluegill and redear sunfish was 66 and 2.6 fish/hr, respectively, in 2004 (Table 8). The catch rate of large (≥ 14 cm TL) bluegill and redear sunfish was 20 and 14 fish/hr, respectively, in 2004. Bluegill and redear sunfish were dominated by small length classes in 2004, as in the past, based on summary data taken from Table 5 in Johnson and Crumpton (1998), and presented in this study (Table 8). Redear sunfish reached slightly larger mean length than bluegill (Figures 6 and 7). Johnson and Crumpton (1998) reported that the annual mean catch rate of large (≥ 14 cm) bluegill and redear sunfish were lower in 1996 – 1997 than values from 1989 – 1993. Note that Johnson and Crumpton (1998) summary data was from 1989 – 1992 instead of for 1989 – 1993. The catch rate of bluegill and redear sunfish ≥ 14 cm seems to have rebounded in 2004 to be similar to values reported for 1989 – 1993 by Johnson and Crumpton (1998).

The lake-wide largemouth bass catch rate in 2004 was 6.9 fish/hr. Canfield and Hoyer (1992), Hoyer (UF, unpublished data), and Johnson and Crumpton (1998) (for

1989 – 1993, and 1996 – 1997) collected 1.3, 0.8, 6.5, and 3.6 fish/hr, respectively (Figures 8 and 9). Comparison of the yearly mean largemouth bass catch rate over time shows that the mean catch rate of 6.9 fish/hr in 2004 was not statistically different from the combined mean catch rate of 6.5 fish/hr in 1989 – 1993 ($p > 0.05$), slightly more than one decade ago. This indicates that the largemouth bass population has not significantly increased in abundance over the last decade.

The mean largemouth bass catch rate of this study (6.9 fish/hr) was only tested for an increase in largemouth bass abundance with that of Johnson and Crumpton (1998) for 1989 – 1993 because mean catch rate of that study was the highest (6.5 fish/hr) of the previous studies (as well as the fact that their data were most representative of the fish populations in Lake Apopka, as explained earlier). Testing for an increase in largemouth bass abundance with Johnson and Crumpton (1998) for 1989 – 1993, was more conclusive than testing for an increase with the other studies, which had lower mean catch rates. It should be noted, however, that if using two booms enabled Johnson and Crumpton (1998) to collect more largemouth bass than they would have collected using just one boom, it would result in a smaller reported difference in the catch rate of largemouth bass over time.

Largemouth bass collected in 2004 ranged in size from 7.1 to 51.6 cm TL (Figure 10), and in calculated weight from 3.4 to 2096 g. There was a low catch rate of small (<24 cm) largemouth bass, as in previous years (Table 8). The fact that small fish (< 24 cm) are represented shows that reproduction is occurring in Lake Apopka.

Largemouth bass were absent from the 16 – 23.9 cm TL size group. This suggests that juveniles may be particularly vulnerable to predation and other sources of mortality at this size (Beverton and Holt 1957). On a statewide basis, largemouth bass that average 24 cm TL are about 1 to 2 years old (Porak et al. 1999). The dominant size group in 2004 was 24 – 31.9 cm TL. If one-year-old fish are undergoing extremely high mortality, this size group would logically be a mixture of two-year-old and older fish. Largemouth bass that are recruited into the larger size groups (≥ 24 cm) seem to be less susceptible to mortality as shown by the greater frequency of fish in those size groups.

An alternative explanation for the absence of 16 – 23.9 cm fish is that fish in Lake Apopka have rapid growth (Dr. Charles Cichra, professor, UF, personal communication). Sampling was conducted from June through August while largemouth bass in Apopka likely spawn from February through April. The small fish could thus be young-of-the year fish. Rapid growth could result in fish between one and two years old exceeding 24 cm TL by summer. Largemouth bass from Lake Apopka should thus be aged to determine whether the low abundance of 16 – 23.9 cm TL largemouth bass is due to high mortality or rapid growth.

Largemouth bass are reproducing, growing, and recruiting to large size in Lake Apopka, but on a population basis, their abundance is low (≤ 7 fish/hr), especially when compared with other Florida lakes. Many Florida lakes have mean electrofishing catch rates of more than 20 largemouth bass/hr. For example, Lakes Okahumpka, Miona, Wales, Clear, Baldwin, and Susannah were reported to have 26, 60, 92, 232, 42, and 129 fish/hr, respectively (Canfield and Hoyer 1992).

Comparison of largemouth bass populations from Lake Apopka and 60 other Florida lakes, sampled by Canfield and Hoyer (1992), shows that the abundance of largemouth bass at Lake Apopka in 2004 continues to be lower than expected for its trophic status as estimated by its chlorophyll content (Figure 11). The relationship between largemouth bass and trophic status is positive suggesting that eutrophic and hypereutrophic Florida lakes will have a high abundance of largemouth bass (Bachmann et al. 1996). Lake Apopka is a hypereutrophic lake and in the absence of other limiting factors, it would be expected to have a high abundance of largemouth bass. But the results of this study as well as two out of three other previous studies on Lake Apopka indicate that the abundance of largemouth bass is low (Figure 11), suggesting that something is limiting their abundance. The amount of quality habitat is most likely the limiting factor (Porak et al. 1999).

The first year of life is critical to the survival of largemouth bass. The structure provided by aquatic vegetation, terrestrial brush, and rockpiles offers age-zero largemouth bass protection from predators (Aggus and Elliot 1975, Crowder and Cooper 1979, Savino and Stein 1982, Durocher et al. 1984, Dibble and Kilgore 1994). Suitable prey such as zooplankton and small forage fish are more readily available in aquatic vegetation and other structure than in open areas (Durocher et al. 1984, Gutreuter and Anderson 1985, Dibble and Kilgore 1994).

Availability of food of the proper type and size contributes to differential growth in young largemouth bass (Aggus and Elliot 1975, Shelton et al. 1979, Timmons et al. 1980, Gutreuter and Anderson 1985, Olson 1996). Faster growing juveniles make the switch to piscivory earlier than slower growing fish (Gutreuter and Anderson 1985, Olson 1996). Rate of growth is one of the primary determinants of the recruitment of largemouth bass to stock size (Kramer and Smith 1962, Aggus and Elliot 1975, Olson 1996). A higher percentage of fast growing largemouth bass that reach a large size in their first winter are recruited than slow growing fish (Kramer and Smith 1962, Davies et al. 1982, Gutreuter and Anderson 1985).

Expanding cover in Lake Apopka would result in a decrease in mortality of age-zero largemouth bass due to decreased predation in their critical first year of life. Additionally, young-of-the-year largemouth bass would be able to obtain more of the proper type and size of food, thus enabling them to grow faster to maturity. As a result, a higher percentage of juvenile largemouth bass would likely be recruited to stock size in Lake Apopka.

Submersed and emergent aquatic macrophytes provide additional benefits to both adult and young largemouth bass. They provide spawning substrate (Kramer and Smith 1962, Chew 1974) and protect spawning nests from wind and waves (Kramer and Smith 1962, Holcomb et al. 1975a, b). Aquatic macrophytes are an important component of the ecosystem of a lake (Durocher et al. 1984, Dibble et al 1996). Plants have the ability to affect water chemistry. Their abundance is inversely related with phytoplankton biomass as measured by chlorophyll, and is positively related to water clarity as measured by use of a Secchi disc (Canfield and Hoyer 1992). However, aquatic plants do not increase the lake-wide clarity of water nor decrease the phytoplankton biomass until there is 30 to 50% coverage (percent volume inhabited (PVI)) (Canfield and Hoyer 1992). A narrow belt of aquatic plants will not reduce lake-wide phytoplankton biomass. A 15% coverage (PVI) could help largemouth bass populations, however, by providing critical habitat needed by age-0 largemouth bass during their first year of life (Canfield and Hoyer 1992).

Aquatic plants could be particularly helpful in solving problems associated with fluid sediments in Lake Apopka. They would help stabilize the bottom by anchoring the sediments (Carter and Rybicki 1985) and they would reduce turbidity from wind resuspension of the sediments (Canfield and Hoyer 1992, James and Barko 1994). Plants would additionally tend to retard large waves by baffling wave action and thus provide protection for less well-anchored species such as coontail (*Ceratophyllum demersum*) (Carter and Rybicki 1985) and reduce shoreline erosion (Canfield and Hoyer 1992).

Previous studies have indicated that for some lakes, the lack of aquatic vegetation can be detrimental to fish populations. For example, Canfield and Hoyer (1992) demonstrated in a 60-lake study of Florida lakes that there exists a potential for depressed fish populations at low levels of aquatic macrophytes (< 15% coverage (PVI)). Porak et al. (1999) suggested that a lack of aquatic plants was detrimental to the survival of young largemouth bass due to decreased shelter and food supply.

In large, shallow Florida lakes without macrophytes, such as Lake Apopka, the shoreline habitat is the only refuge from predation for juvenile largemouth bass (Hoyer and Canfield (1996a, b). The limited shoreline habitat in Lake Apopka may not be sufficient for adequate largemouth bass recruitment. The addition of about 15% coverage (PVI) of aquatic macrophytes or other structure would allow sufficient young-of-the-year largemouth bass to recruit into adulthood to allow Lake Apopka and other similar lakes to reach their carrying capacity (Hoyer and Canfield 1996a, b).

Aquatic Macrophytes

Lake Apopka continues to have a low abundance of aquatic macrophytes (≤ 0.9 percent area covered (PAC) and ≤ 0.4% PVI). The plants only occupied a narrow (mean = 19.4 m) belt around the shoreline in 2004, with a few exceptions. There were some isolated stands of soft-stem bulrush (8.5 ha) that existed around the perimeter and in the northern portion of the lake (Hog Island), as previously noted by Johnson and Crumpton (1998). Remnant stands of aquatic grass, primarily Egyptian paspalidium (1.5 ha), also existed in various places around the perimeter of the lake.

Vegetated areas are important largemouth bass habitat. Johnson and Crumpton (1998) reported that soft-stem bulrush and aquatic grass (Egyptian paspalidium, maidencane, and torpedograss) sites contained the largest total mean biomass for all four principle sportfish species (largemouth bass, bluegill, redear sunfish, and black crappie) in both 1989 – 1993 and 1996 – 1997 sampling periods for Lake Apopka. Total mean biomass for sportfish was lowest in open sites.

The most commonly occurring plants in 2004 were cattail, duck potato (*Sagittaria lancifolia*), and pickerelweed (*Pontederia cordata*) (Table 9). No submersed vegetation existed in the open area of the lake outside of the narrow belt of emergent aquatic plants. Essentially, the rooted aquatic vegetation in Lake Apopka has not expanded in the last two decades and remains similar to what the lake had after the loss of its 80% coverage of aquatic plants in 1947 (Clugston 1963, Schneider and Little 1969, Holcomb 1977, Lake Apopka Restoration Council 1986, Johnson and Crumpton 1998).

Eel-grass was the only submersed vascular aquatic macrophyte besides hydrilla that was observed in 2004. Eel-grass is a versatile submersed aquatic plant that is capable of surviving in a variety of growing conditions (Jaggers 1994). It can inhabit a variety of sediment types (sand, silty sand, or mud) (Korschgen and Green 1988, Catling et al. 1994). It is more shade adapted (Meyer et al. 1943) than several other submersed aquatic plants (e.g., *Myriophyllum* spp. and *Potamogeton* spp.) because of its physiological adaptability to low (1% I_o) light regimes (Titus and Adams 1979, Carter and Rybicki 1985, Korschgen and Green 1988, Catling et al. 1994, Rybicki and Carter 2002). It is capable of surviving and even flourishing in eutrophic water (Catling et al. 1994, Jaggers 1994). It is also capable of making major comebacks after restoration (Carter and Rybicki 1990, Kimber et al. 1995a, b).

Studies have reported, however, that eel-grass, grown from tubers, did not survive in greater than 0.25 m of sediment (Carter et al. 1985, Rybicki and Carter 1986, Korschgen and Green 1988). Studies also found that there were significant population declines caused by excessive (numerically undefined) turbidity or highly variable turbidity (Korschgen and Green 1988, Jaggers 1994). Korschgen and Green (1988) noted that it was subject to uprooting by tropical storms. For example, Tropical Storm Agnes, which struck the East Coast in 1972, was cited as a factor in the decrease of eel-grass in different portions of the Chesapeake Bay (Kerwin et al. 1976, Bayley et al. 1978). Carter et al. (1985) reported that storm damage was also partially responsible for the decline of eel-grass in the Potomac River in the 1930s. They indicated that deposition of 0.15 – 0.25 m of sediments from storms were sufficient to completely wipe out populations of eel-grass, naiad (*Najas gracillima* and *N. guadalupensis*), and common elodea (*Elodea canadensis*). Years or decades may be required for recovery after exceptionally severe storms (Carter et al. 1985).

The growth of eel-grass in Lake Apopka has been a special concern to Florida agencies (Jaggers 1994). It is a valuable plant that is used as refuge and habitat for invertebrates and fish populations (Hoyer et al. 1996). Eel-grass was planted by the FFWCC to an unknown degree in the 1990s (William Johnson, administrator, FFWCC, Eustis, FL, personal communication). It was also planted in plots around the shore of Lake Apopka by the SJRWMD during drought conditions in 1998 and 1999 (Conrow and Peterson 2000).

Of the 23 eel-grass sites that were sampled, beds were present at 15 sites (Table 10). Twelve of the sites, where eel-grass was present, were located on the west side of the lake; two closely spaced sites were located on the south side; and one site was located on the east side. No plants were found at seven of the sites, and only a single plant was found at one site. All but two of the 15 beds were small (< 100 m^2). There was one medium (279 m^2) bed near Smith Island (on the west shoreline). There was another medium (536 m^2) bed near Monteverde Boat Ramp (also on the west shoreline). No large (> 1000 m^2) plant beds were found during this study.

The density of the plant beds ranged from 1 to 100%. The average density of eel-grass was estimated to be 50%, at those sites where it was present. Hurricane Jeanne passed over central Florida on 25 September 2004 (NOAA 2005), one week before eel-grass was sampled on 1 October 2004. An attempt was made to find eel-grass uprooted by the recent hurricane, but only a couple of plants were observed to be uprooted.

The total lake bottom colonized by eel-grass in 2004 was approximately 900 m^2 (Table 10). The SJRWMD reported an area of 11,032 m^2 in 1999 (Conrow and Peterson 2000). Therefore, the observed eel-grass area in 2004 was only 8% of that reported by the SJRWMD. The drought in 1999 – 2000, followed by rising waters in 2000 should have created ideal growing conditions for the expansion of eel-grass. The natural drawdown would have oxidized and compacted the exposed sediments. Oxidation would have released nutrients from the soil, stimulating plants to regenerate and expand

(Wegener and Williams 1974, Moyer et al. 1995). Compaction of the soil would have provided a firmer bottom for rooting and holding plants. However, this study shows that eel-grass drastically declined during the past five years at Lake Apopka. This suggests that there is a limiting factor that is preventing eel-grass from surviving and expanding.

Studies in the upper Mississippi River and Chesapeake Bay (Carter and Rybicki 1990, Kimber et al. 1995a, b) reported that eel-grass only grew to 12 – 15% incident light (I_o) because of turbidity in the water column caused by suspended sediments. Later, when the turbidity from suspended sediments was reduced through restoration efforts, eel-grass recolonized those study sites, but only grew down to depths of 5 – 10% I_o.

The observed and theoretical MDC and MDG of eel-grass, in Lake Apopka in 2004, were compared to determine if eel-grass was growing to its potential depth, as referenced by the primary literature. The observed MDC and MDG of eel-grass in June – August 2004 were 1.3 and 0.8 m, respectively, at a mean lake surface elevation of 20.3 m (66.5 ft) National Geodetic Vertical Datum 1929 (NGVD 29). Hydrologic data were obtained from the SJRWMD (2005). The theoretical MDC and MDG were 1.3 and 1.0 m based on the mean depths corresponding to light meter measurements of 1 and 8% I_o. Eel-grass, therefore, seems to be growing near its potential MDC and MDG because the observed values of MDC and MDG agree closely to the theoretical values.

However, the four hurricanes (Charlie, Frances, Ivan, and Jeanne, NOAA 2005), all of which occurred before my sampling, that passed over Florida in the summer of 2004, dropped ≥ 0.4 m of total precipitation, and undoubtedly influenced the results. When the hurricanes are accounted for by calculating the observed MDC and MDG at a lower lake level (20.0 m, NGVD 29), eel-grass would be predominantly growing at 12 –

15% I_o and reaching a maximum depth at 5% I_o. These results indicate that other environmental factors are limiting the depth of growth of eel-grass other than light attenuation.

The area of the lake that is available for eel-grass to colonize and grow at the observed MDC and MDG (at lake surface elevation 20.3 m, NGVD 29) was calculated to be 3940 and 848 ha, respectively. As a percent, eel-grass is only inhabiting 0.002% of the 3940 ha available at MDC and 0.011% of the 848 ha available at MDG under the current light regime, strongly indicating that other factors are involved in limiting the growth and survival of eel-grass besides light attenuation.

The 3940 and 848 ha, at MDC and MDG, represents an estimated 32% of the lake available for eel-grass to colonize and 7% of the lake available to grow in under the current light regime. This indicates that there is enough irradiance in the water column for eel-grass to colonize in shallow water around the shoreline of the lake but that the light conditions in the water column need to significantly improve before eel-grass can be expected to grow well enough to occupy a larger proportion of the total lake area.

There is a general belief that irradiance primarily controls the depth-distribution of aquatic macrophytes (Barko and Smart 1981, Chambers and Kalff 1985, Carter and Rybicki 1990). Studies have recognized, however, that other environmental factors besides nutrient enrichment and phytoplankton shading are also responsible for limiting aquatic macrophyte colonization. Chambers and Kalff (1985) stated that wave action and substrate type also play a major role in determining the distribution and abundance of aquatic macrophytes. Spence (1972) indicated that turbulence and wave action influenced aquatic macrophyte colonization. Carter et al. (1985) reported that, other than phytoplankton, storm pressure, grazing pressure, substrate characteristics, and suspended sediments are all factors that in different circumstances could be individually or jointly responsible for limiting the depth-distribution (or spatial extent) of aquatic macrophytes.

Eel-grass in this study was only found at sites having firm sediments and not at any sites with sediments deeper than 0.25 m. These observations agree with studies that reported that eel-grass, grown from tubers, did not survive in greater than 0.25 m of sediment (Carter et al. 1985, Rybicki and Carter 1986, Korschgen and Green 1988). The depth of sediments (1.5 m mean thickness) covering 90% of Lake Apopka's bottom (Schneider and Little 1969) is too thick to allow eel-grass to inhabit those areas. The depth and fluidity of sediments, and wind resuspension of sediments, are probably major factors that are limiting the growth and survival of eel-grass in Lake Apopka. These hypotheses are supported by the fact that Lake Apopka is a large, shallow, and nearly round lake with a long fetch (Bachmann et al. 1999). Because of these combined attributes, the bottom sediments are often resuspended in the lake (Scheffer et al. 1992, Bachmann et al. 1999). Carter et al. (1985) stated that where fetches are long, eel-grass plants are easily uprooted from fine sediments.

Table 4. Common and scientific names of fish collected by individual studies at Lake Apopka, Florida.

Common Name	Scientific Name	Canfield and Hoyer (1992) (for 1986)	Hoyer (UF) (unpubl. data) (1987-1989) (1991-1996)	Johnson and Crumpton (1998) (for 1989-1993)	This Study (for 2004)
Florida gar	*Lepisosteus platyrhincus*	x	x	x	x
Longnose gar	*Lepisosteus osseus*			x	x
Bowfin	*Amia calva*			x	x
Gizzard shad	*Dorosoma cepedianum*	x	x	x	x
Threadfin shad	*Dorosoma petenense*	x	x	x	x
Black crappie	*Pomoxis nigromaculatus*	x	x	x	x
Blue tilapia	*Tilapia aurea*		x	x	x
Golden shiner	*Notemigonus crysoleucas*	x	x	x	
Lake chubsucker	*Erimyzon sucetta*		x		
Taillight shiner	*Notropis maculatus*		x	x	
Yellow bullhead	*Ameiurus natalis*	x	x	x	x
Brown bullhead	*Ameiurus nebulosus*	x	x	x	x
Channel catfish	*Ictalurus punctatus*		x	x	x
White catfish	*Ictalurus catus*	x	x	x	
Tadpole madtom	*Noturus gyrinus*	x		x	x
Seminole killifish	*Fundulus seminolis*	x	x	x	x
Bluefin killifish	*Lucania goodei*		x		
Eastern mosquitofish	*Gambusia holbrooki*	x	x	x	x
Sailfin molly	*Poecilia latipinna*			x	
Pugnose minnow	*Opsopoeodus emiliae*			x	
Brook silverside	*Labidesthes sicculus*			x	x
Inland silverside	*Menidia beryllina*			x	x
Tidewater silverside	*Menidia peninsulae*	x	x		
Everglades pygmy sunfish	*Elassoma evergladei*		x		
Warmouth	*Lepomis gulosus*		x	x	x
Bluegill	*Lepomis macrochirus*	x	x	x	x
Redear sunfish	*Lepomis microlophus*	x	x	x	x
Spotted sunfish	*Lepomis punctatus*			x	
Largemouth bass	*Micropterus salmoides*	x	x	x	x
Sunshine bass	*Morone chrysops X M. saxatilis*	x	x		
Atlantic needlefish	*Strongylura marina*			x	x

Table 5. Water chemistry parameters measured for Lake Apopka, Florida, in June – October 2004.

Water Quality Parameter	Location	Number of Samples	Average	Range
Dissolved oxygen (mg/L)	Near shore stations	16	5.9	(0.8 – 11.9)
Secchi depth (m)	Near shore stations & center of the lake	18	0.37	(0.20 – 0.49)
Specific conductance (µS/cm at 25 C)	Near shore stations	12	453	(403 – 506)
Water temperature (C)	Near shore stations	10	31.6	(29.5 – 33.7)

Table 6. Mean electrofishing catch per unit effort and standard error of fish number (number/hr) and weight (kg/hr) for Lake Apopka, Florida. Forty 10-min transects were sampled in June – August 2004.

Common Name	Number (number/hr)	Standard Error	Calculated Weight (kg/hr)	Standard Error
Florida gar	7.4	1.28	5.6	0.99
Longnose gar	0.6	0.36	0.2	0.11
Bowfin	0.8	0.32	0.9	0.43
Gizzard shad	6.6	2.15	0.8	0.29
Threadfin shad	1.7	0.74	0.0	0.00
Black crappie	6.9	1.30	1.2	0.31
Blue tilapia	0.8	0.38	0.4	0.17
Yellow bullhead	0.2	0.15	0.0	0.03
Brown bullhead	1.7	0.61	0.6	0.22
Channel catfish	0.6	0.47	0.1	0.07
Tadpole madtom	0.5	0.33	0.0	0.00
Seminole killifish	2.7	0.86	0.0	0.01
Eastern mosquitofish	3.5	1.34	0.0	0.00
Brook silverside	0.2	0.15	0.0	0.00
Inland silverside	0.3	0.21	0.0	0.00
Warmouth	12.6	3.85	0.8	0.24
Bluegill	86.4	20.52	4.1	1.05
Redear sunfish	16.4	5.05	1.6	0.47
Largemouth bass	6.9	1.60	4.1	1.11
Atlantic needlefish	0.2	0.15	0.0	0.01
Total	156.5		20.3	

Table 7. Mean yearly and combined electrofishing catch per unit effort and standard error of fish number (number/hr) for Lake Apopka, Florida, by Johnson and Crumpton (1998). Eight hundred seventy 5-min transects were sampled bimonthly from March 1989 to November 1993.

	Number (number/hr)						
Common Name	1989	1990	1991	1992	1993	Combined 1989-1993	Standard Error[a]
Florida gar	3.9	3.6	5.1	6.1	8.3	5.4	0.85
Longnose gar	0.3	0.5	1.7	0.7	1.1	0.9	0.24
Bowfin	0.8	0.7	0.6	0.7	0.8	0.7	0.04
Gizzard shad	101.8	71.8	59.3	43.4	42.5	63.8	10.96
Threadfin shad	49.4	47.1	107.5	56.0	37.3	59.6	12.38
Black crappie	26.2	33.7	34.8	52.3	68.8	43.2	7.71
Blue tilapia	7.1	7.6	8.5	15.3	17.7	11.2	2.18
Golden shiner	9.2	7.9	7.1	5.2	6.5	7.2	0.67
Taillight shiner	2.6	6.8	4.6	6.5	8.2	5.7	0.98
Yellow bullhead	2.6	1.4	1.4	1.8	2.9	2.0	0.31
Brown bullhead	45.0	25.7	24.8	14.4	22.5	26.5	5.04
Channel catfish	0.1	0.0	0.0	0.0	0.0	0.0	0.0
White catfish	0.6	0.9	1.8	3.8	16.5	4.7	3.00
Tadpole madtom	0.0	0.0	0.0	0.1	0.0	0.0	0.01
Seminole killifish	3.6	7.4	12.8	10.8	9.3	8.8	1.57
Eastern mosquitofish	4.2	10.6	7.3	6.1	7.4	7.1	1.05
Sailfin molly	0.1	0.7	0.5	0.3	0.6	0.4	0.12
Pugnose minnow	0.0	0.0	0.1	0.0	0.0	0.0	0.01
Brook silverside	0.0	0.0	0.0	1.9	0.0	0.4	0.37
Inland silverside	12.3	15.7	15.9	6.1	3.5	10.7	2.53
Warmouth	5.6	6.0	4.3	9.5	11.7	7.4	1.37
Bluegill	62.0	67.3	55.3	97.6	83.2	73.1	7.67
Redear sunfish	11.1	18.1	15.3	21.1	24.6	18.1	2.33
Spotted sunfish	0.5	0.2	0.1	0.0	0.0	0.1	0.09
Largemouth bass	5.6	6.5	5.9	7.9	6.2	6.5	0.41
Atlantic needlefish	0.1	0.1	0.1	0.2	0.3	0.2	0.03
Total	356.0	341.0	375.0	369.0	381.0	364.0	7.17

[a]The combined catch per unit effort number (number/hr) was averaged by month and then by year to obtain the standard error.

Table 8. Annual mean electrofishing catch per unit effort number (number/hr) of two size groups of largemouth bass, bluegill, and redear sunfish collected in Lake Apopka, Florida, by Johnson and Crumpton (1998) for June – May of 1989 – 1990, 1990 – 1991, and 1991 – 1992, and November 1996 – September 1997 (bimonthly samples), and by this study for June – August 2004 (once monthly samples).

Common Name	1989-1990[a]	1990-1991[a]	1991-1992[a]	1996-1997	2004
Largemouth bass (≥ 24 cm)	4.8	4.8	6.0	2.4	6.0
Largemouth bass (< 24 cm)	2.4	1.2	1.2	1.2	0.9
Bluegill (≥ 14 cm)	22.8	18.0	20.4	15.6	20.0
Bluegill (< 14 cm)	40.8	54.0	66.0	31.2	66.5
Redear sunfish (≥ 14 cm)	9.6	9.6	9.6	1.2	13.8
Redear sunfish (< 14 cm)	4.8	6.0	12.0	3.6	2.6

[a] Summary data from 1989 – 1992 and 1996 – 1997 were taken from Johnson and Crumpton (1998), Table 5, which did not report the catch rate of size groups in 1993.

Table 9. Occurrence of plant species in twenty evenly-spaced transects around Lake Apopka, Florida, in 2004.

Common Name	Scientific Name	Percent of Transects
Aquatic Plants		
Cattail	*Typha spp.*	95
Duck potato	*Sagittaria lancifolia*	65
Pickerelweed	*Pontederia cordata*	45
Soft-stem bulrush	*Scirpus validus*	30
Water pennywort	*Hydrocotyle umbellata*	30
Egyptian paspalidium	*Paspalidium geminatum*	25
Water primrose	*Ludwigia octovalvis*	25
Eel-grass	*Vallisneria americana*	20
Wild taro	*Colocasia esculenta*	15
Torpedograss	*Panicum repens*	10
Hydrilla	*Hydrilla verticillata*	5
Terrestrial Brush		
Carolina willow	*Salix caroliniana*	50
Elderberry	*Sambucus canadensis*	15
Wax myrtle	*Myrica cerifera*	15
Hardwood Mixture		
Red maple	*Acer rubrum*	30
Loblolly-bay	*Gordonia lasianthus*	15
Sweetbay	*Magnolia virginiana*	15

Table 10. Location, area (m^2), and maximum depth (m) of eel-grass beds in Lake Apopka, Florida, in 2004.

GPS Locations	Area (m^2) Reported by the SJRWMD in 1999 (unpublished data[a])	Area (m^2) Measured in 2004	Maximum Depth of Plant Bed (m)
Twenty three sites where eel-grass beds were sampled on 1 October 2004			
X:-81.66268 Y:28.59395	1465.0	None sighted	—
X:-81.66999 Y:28.60700	1277.3	(one plant) 1.0	0.9
X:-81.65463 Y:28.59138	885.3	None sighted	—
X:-81.67006 Y:28.60724	517.9	Included[b]	0.9
X:-81.65359 Y:28.68176	510.9	None sighted	—
X:-81.67829 Y:28.61896	494.4	278.9	0.9
X:-81.67803 Y:28.61925	355.7	29.2	0.9
X:-81.60593 Y:28.56912	333.0	2.6	0.9
X:-81.67317 Y:28.61035	310.5	536.0	1.4
X:-81.54957 Y:28.62397	308.0	8.3	0.5
X:-81.65332 Y:28.68184	281.9	None sighted	—
X:-81.68426 Y:28.66171	240.8	None sighted	—
X:-81.67196 Y:28.60970	237.4	Included[b]	1.4
X:-81.66989 Y:28.60720	201.8	Included[b]	0.9
X:-81.67787 Y:28.62014	199.5	1.8	0.9
X:-81.65359 Y:28.68210	174.0	None sighted	—
X:-81.60584 Y:28.56924	165.2	Included[b]	0.9
X:-81.69429 Y:28.64223	93.5	None sighted	—
X:-81.68031 Y:28.62056	55.5	10.5	0.9
X:-81.68025 Y:28.62054	54.5	Included[b]	0.9
X:-81.66973 Y:28.60674	41.6	Included[b]	0.9
X:-81.58700 Y:28.57731	27.0	None sighted	—
X:-81.68030 Y:28.62049	12.1	21.0	0.9
Total	8242.7	889.3	
Six sites where eel-grass beds were observed while electrofishing in June – August 2004[c]			
X:-81.64903 Y:28.58658	—	1.8	0.9
X:-81.64948 Y:28.58717	—	1.8	0.9
X:-81.64950 Y:28.58781	—	1.8	0.9
X:-81.67127 Y:28.60920	—	1.8	0.9
X:-81.67183 Y:28.60972	—	1.8	0.9
X:-81.66442 Y:28.59677	—	1.8	0.9
Total		10.8	

[a]The data shown here for 23 sampling sites are a subset of the unpublished data set obtained from the SJRWMD. The total area for all the eel-grass beds in the data set is 11032.1 m^2, which includes only the area of the plant beds in the major part of the lake and not the area of those in the gourd neck area, Marsh Flow-Way, or canals.

[b] The SJRWMD reported beds that were near each other as separate beds, identified with separate GPS coordinates. At some of the sites reported by the SJRWMD to have multiple beds, only one bed was found, or in some instances the boundry separating multiple beds was not distinguishable. In these instances, the total area (m^2) of closely spaced bed locations was recorded only once at the GPS coordinates of one bed. The area (m^2) of any nearby beds was annotated as included.

[c]The six eel-grass beds observed while electrofishing were nearly identical in area and maximum depth.

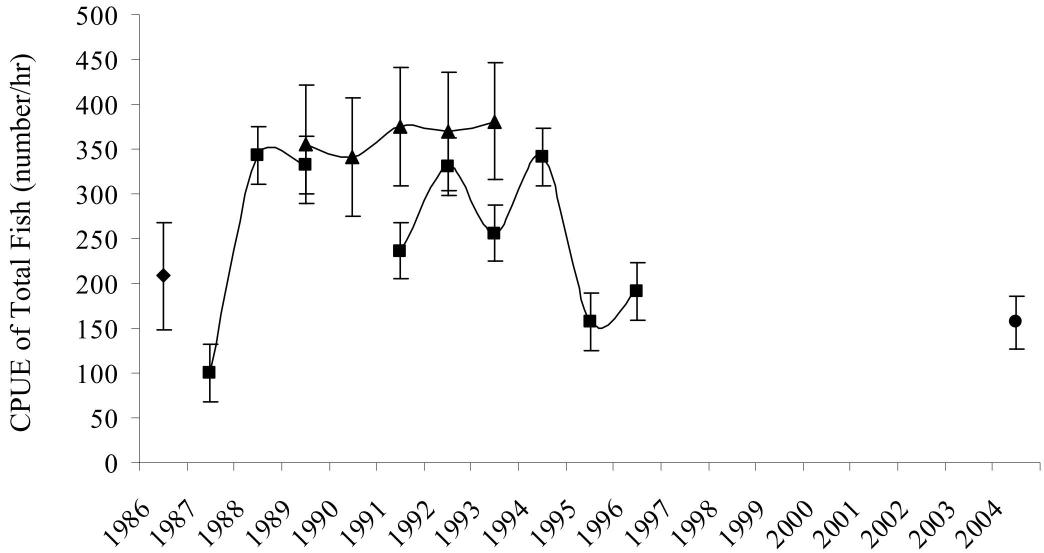

Figure 2. Mean electrofishing catch per unit effort estimates of total fish abundance (number/hr) for Lake Apopka, Florida, sampled by Canfield and Hoyer (1992) (♦), Hoyer (UF, unpublished data) (■), Johnson and Crumpton (1998) (▲), and this study (●). Data were not available for Johnson and Crumpton (1998) for 1996 – 1997.

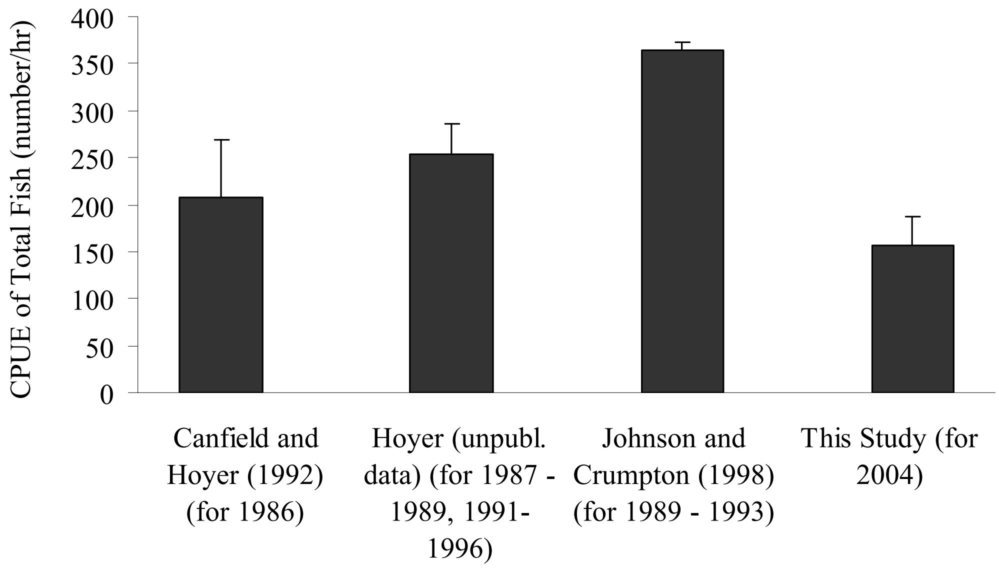

Figure 3. Mean electrofishing catch per unit effort estimates of total fish abundance (number/hr) for the combined data of different studies for Lake Apopka, Florida.

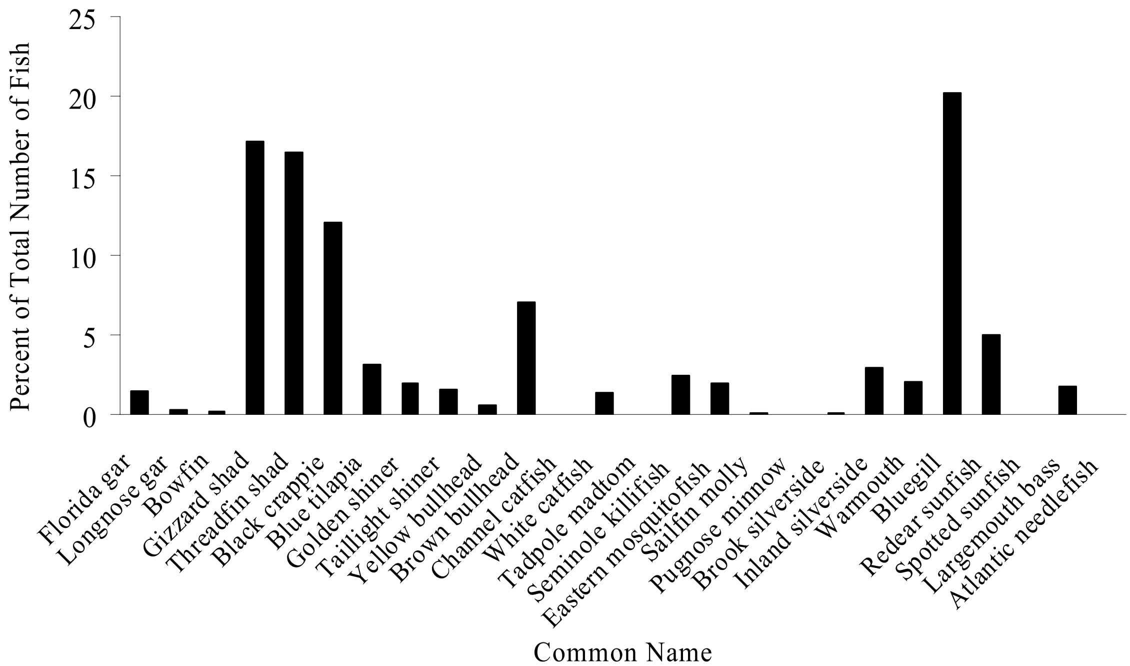

Figure 4. Individual fish species percent of total number collected by electrofishing for Lake Apopka, Florida, by Johnson and Crumpton (1998) for 1989 – 1993.

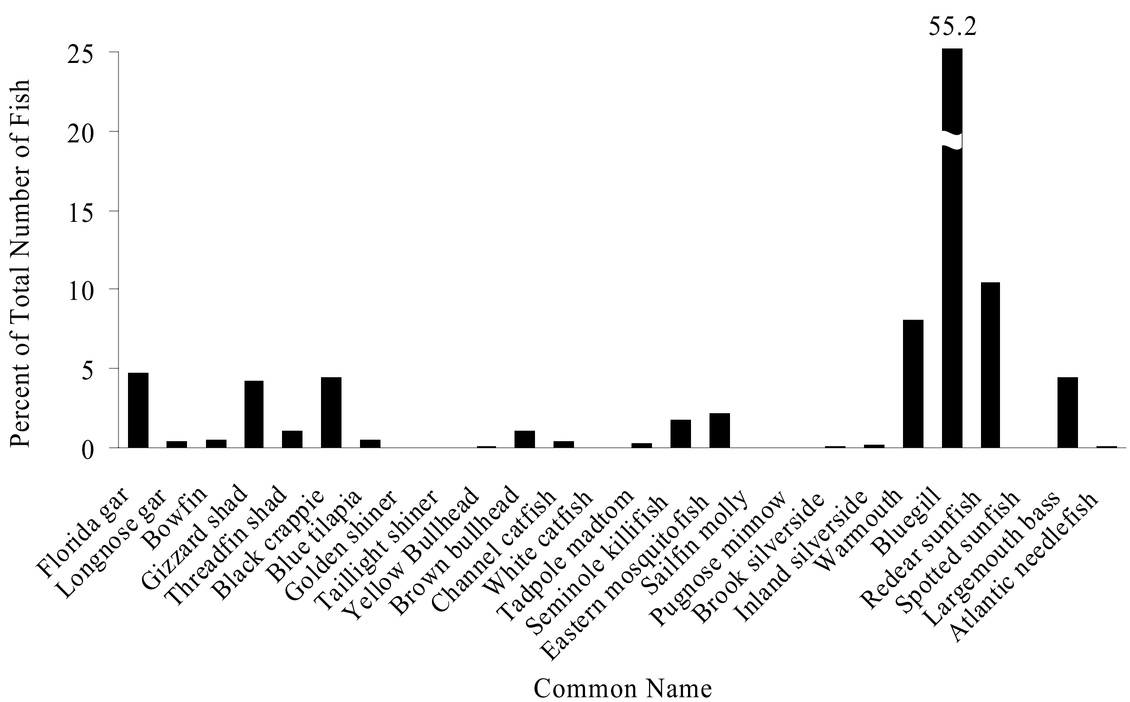

Figure 5. Individual fish species percent of total number collected by electrofishing for Lake Apopka, Florida, in June – August 2004.

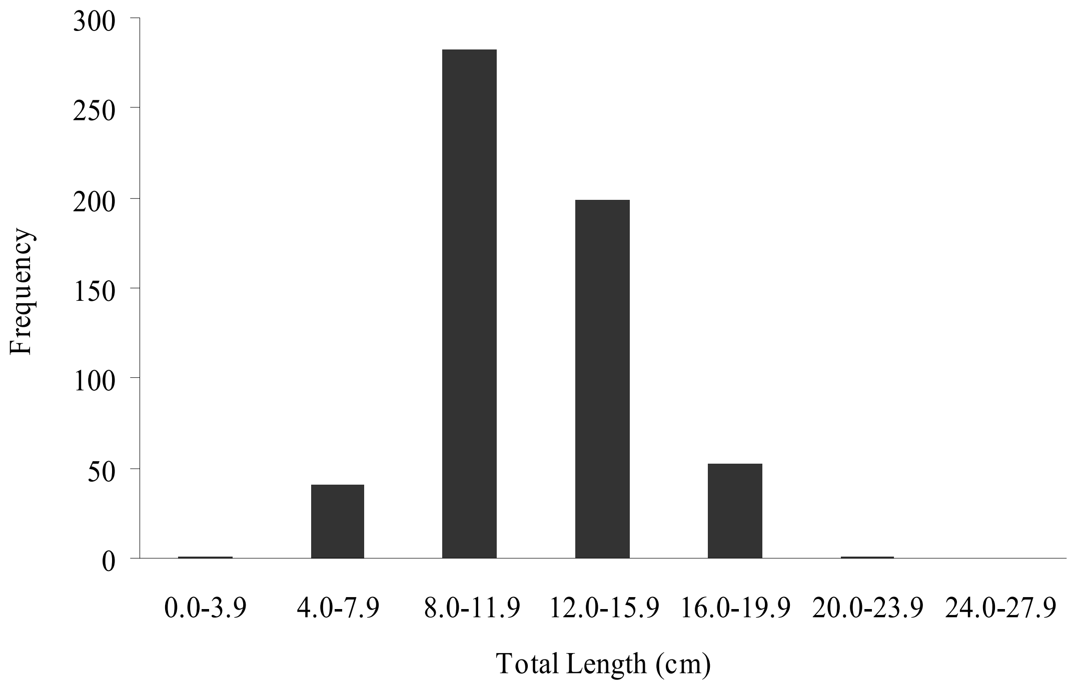

Figure 6. Length frequency distribution of bluegill collected by electrofishing for Lake Apopka, Florida, in June – August 2004.

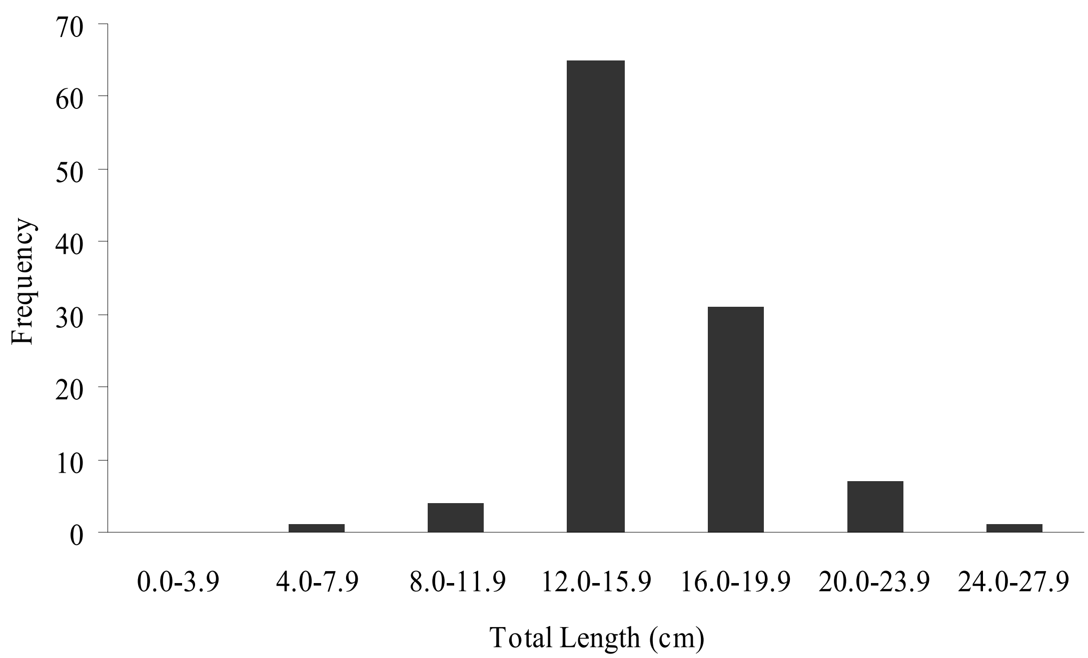

Figure 7. Length frequency distribution of redear sunfish collected by electrofishing for Lake Apopka, Florida, in June – August 2004.

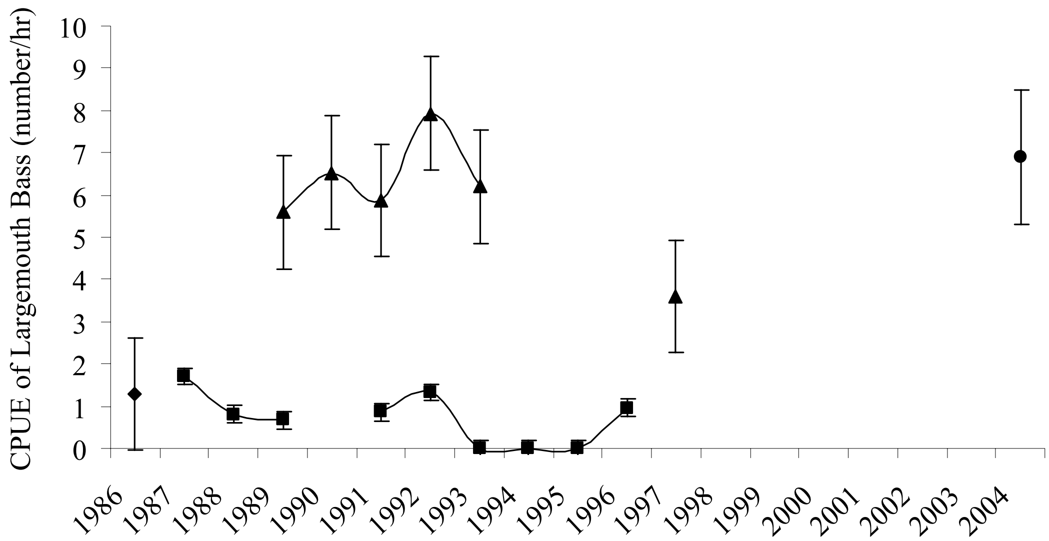

Figure 8. Mean electrofishing catch per unit effort estimates of largemouth bass abundance (number/hr) for Lake Apopka, Florida, sampled by Canfield and Hoyer (1992) (♦), Hoyer (UF, unpublished data) (■), Johnson and Crumpton (1998) (▲), and this study (●).

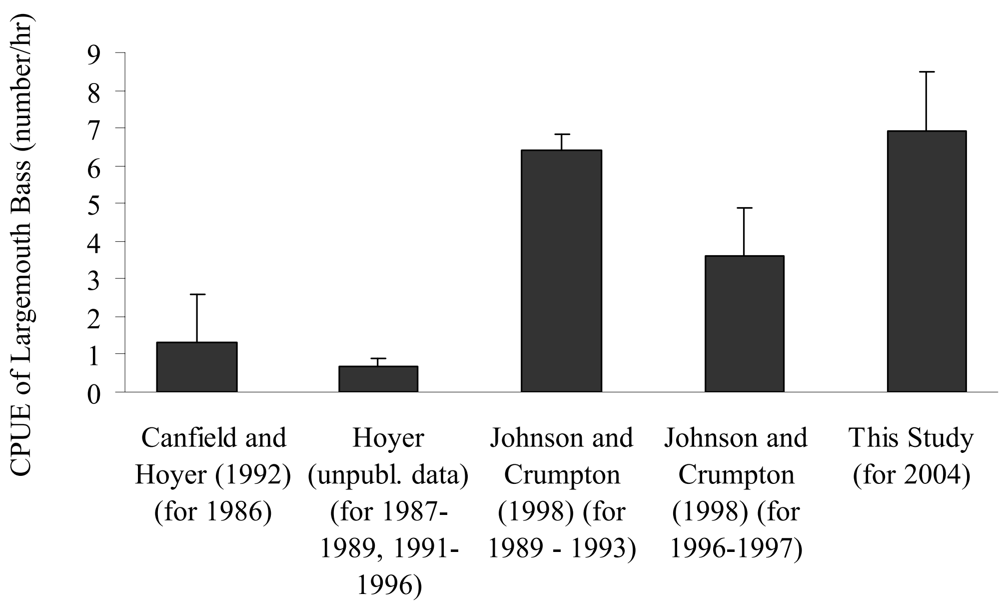

Figure 9. Mean electrofishing catch per unit effort estimates of largemouth bass abundance (number/hr) for the data sets of combined years from different studies for Lake Apopka, Florida.

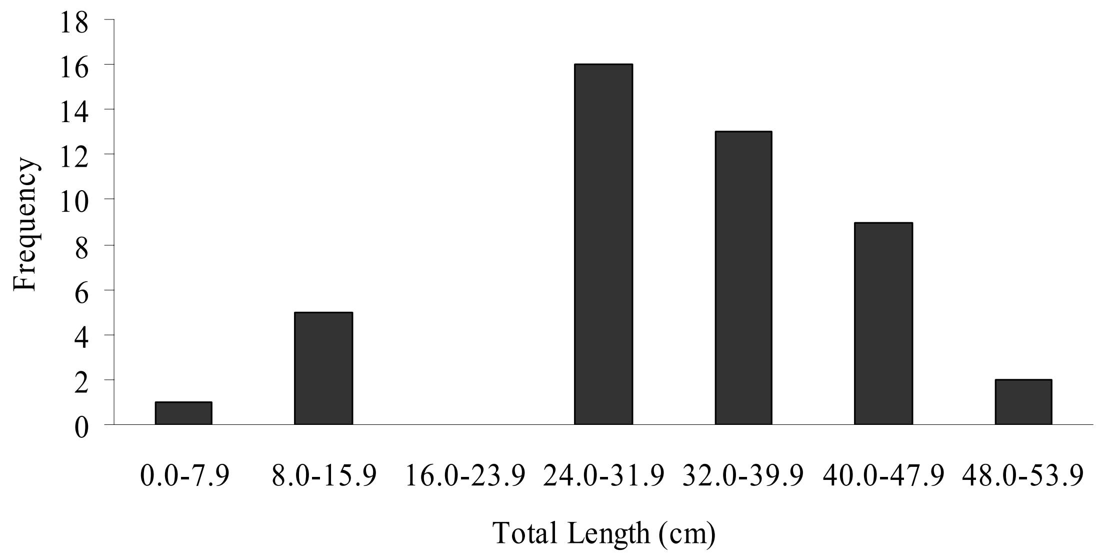

Figure 10. Length frequency distribution of largemouth bass collected by electrofishing for Lake Apopka, Florida, in June – August 2004.

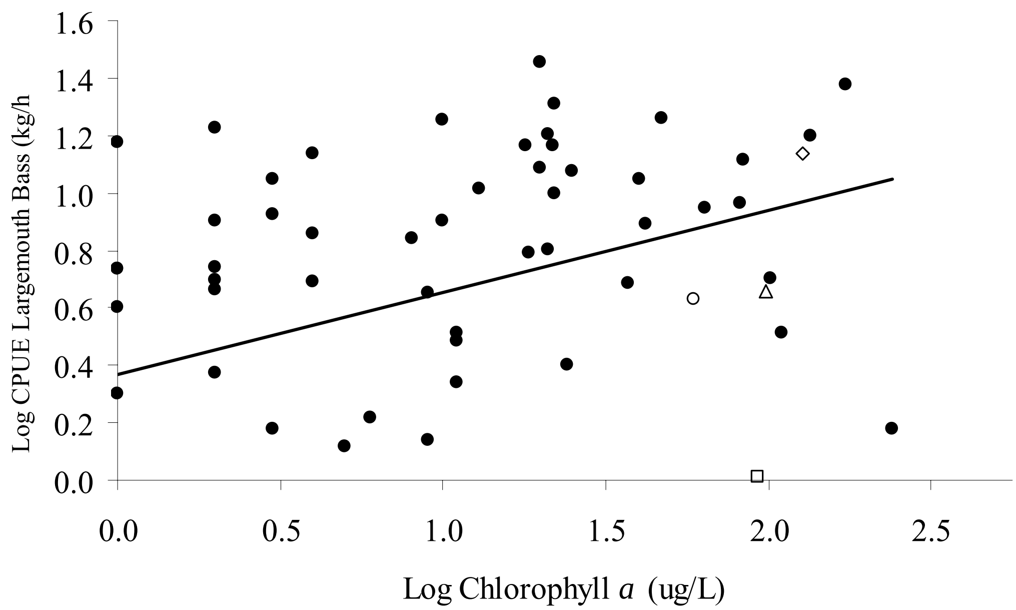

Figure 11. Electrofishing catch per unit effort of largemouth bass (kg/hr) versus total chlorophyll *a* (µg/L) for 60 Florida lakes sampled by Canfield and Hoyer (1992) and Lake Apopka, Florida, sampled by Canfield and Hoyer (1992) (◊), Hoyer (UF, unpublished data) (□), Johnson and Crumpton (1998) (Δ), and this study (○). A regression line is included.

LAKE MANAGEMENT RECOMMENDATIONS

Restoration efforts have not yet been successful in increasing the largemouth bass population or expanding the area occupied by aquatic vegetation in Lake Apopka. It is up to lake managers to come up with ideas to improve the largemouth bass fishery so that anglers can enjoy recreational fishing in the lake. A drawdown was proposed by the USEPA as part of its environmental impact statement in 1978 as a way to improve the largemouth bass fishery (USEPA 1979). Downdraw has been a successful tool by increasing the water clarity and littoral vegetation in several Florida lakes including Lakes Tohopekaliga, Trafford, Hancock, and Griffin (USEPA 1979). However, a drawdown was not recommended by the SJRWMD for Lake Apopka for several reasons including the high cost (of at least \$20 million) and increased nutrient flow to downstream lakes (Lowe et al. 1992). Additionally, there were concerns over the quantity of water to be pumped, the amount of unconsolidated muck, the type of vegetation that would grow, and the restrictive time schedule (USEPA 1979).

Conditions in Lake Apopka have changed since 1979. Over \$100,000,000 in Federal and State funds was spent to buy out farms, to reduce or eliminate nutrient-rich pumpage back into the lake, and to construct a marsh flow-way, to remove phosphorus-rich particles from the lake water (Conrow et al. 1993, Hoge et al. 2003). Mean phosphorus levels dropped from over 200 μg/L, in 1979, to about 100 μg/L, in 2004. The Lake County Water Authority also recently proposed building an alum treatment plant for Lake Apopka that would help reduce phosphorus levels even more. In light of these improvements, it would be a good idea to reconsider drawdown. The concern over increased nutrient flow to downstream lakes is no longer as big of an issue in 2004, as it was in 1979, because nutrient levels are lower now, than they were before.

Since a drawdown was not approved and may never be approved, the next step for lake managers is to look for other viable alternative strategies that could potentially improve the largemouth bass fishery in Lake Apopka. Other alternative ideas have been proposed that could potentially improve the habitat for largemouth bass in Lake Apopka, but have not been acted upon by the state agencies. For example, artificial reefs could be placed along the shoreline as habitat for largemouth bass and other littoral fish (Canfield et al. 2000). Canfield et al. (2000) also suggested allowing hydrilla, a fast-growing exotic submersed aquatic plant, to grow behind the protective barriers to provide habitat for largemouth bass. If at least 50% coverage (PVI) of submersed aquatic vegetation occurred, it would be enough for the water to start to clear in those local areas and provide additional benefits (Canfield and Hoyer 1992).

Hydrilla is an exotic aquatic plant that has invaded many lakes. It will often outcompete native aquatic macrophyte species and expand to fill in an entire water body, and interfere with navigation and other uses of a water body (Hoyer et al. 2005). Control of hydrilla across lakes has been unsuccessful (Hoyer et al. 2005). It spreads from one water body to another when fragments and tubers, left attached to vehicles, trailers, or propellers, are transported from one water body to another. It also spreads when fragments and tubers, from one water body, drift into another attached water body. It costs a tremendous amount of money, to purchase herbicides and equipment, and to provide manpower to control it. Allowing hydrilla to grow anywhere in Florida lakes, such as suggested by Canfield et al. (2000), is controversial. However, Lake Apopka historically had about 80% aquatic macrophyte coverage (PVI). So it should not be a big issue if hydrilla were to expand into the open area of this lake.

Recent studies have stated that in certain situations, native aquatic macrophytes will grow in close association with hydrilla. For example, Rybicki and Carter (2002) found populations of eel-grass, Eurasian water milfoil (*Myriophyllum spicatum*), and coontail growing within hydrilla and along the edges, in portions of the Potomac River recovering from poor water transparency and high turbidity. Smart (1992), in experimental plots, that were monitored for a duration of one year, showed that Illinois pondweed, eel-grass, and hydrilla, that were planted in randomly assigned plots, could grow together for one year, as long as Illinois pondweed and eel-grass were planted before or at the same time as hydrilla. Illinois pondweed and hydrilla grew in the canopy and eelgrass grew in the understory.

Smart (1992) stated that eel-grass is considered to be a later successional species than hydrilla. In the long run, eel-grass should theoretically be able to recolonize areas that were formerly dominated by hydrilla. There is evidence in Florida lakes that native aquatic macrophyte species recolonized areas that were dominated by hydrilla for several years. For example, Lake Okahumpka, Florida, was dominated by hydrilla for several years, in the late 1990s and early 2000s (Mark Hoyer, research manager, UF, personal communication). A regular maintenance control program, in the early 2000s, using contact herbicides, put hydrilla into submission. Native submersed aquatic macrophyte species (e.g., Illinois pondweed and eel-grass) recolonized areas previously dominated by hydrilla.

Hydrilla is already present in small quantities in Lake Apopka. Erich Marzolf (environmental scientist, SJRWMD, Palatka, FL, personal communication) stated that contact herbicide is applied regularly by the SJRWMD to keep it from expanding. Eel-grass and hydrilla beds were observed near each other during this study at Lake Apopka in 2004. Eel-grass plants were also observed growing within hydrilla beds and along the edges.

Evidence from Lake Okahumpka, Florida (a hypereutrophic lake similar to Lake Apopka), and from Lake Apopka itself, suggests that if hydrilla were allowed to grow in small quantities (≤ 15% PVI) around the periphery of Lake Apopka, to provide habitat for largemouth bass, that no more than the already existing maintenance control program using contact herbicides would be required to keep hydrilla in check, and that native submersed aquatic macrophyte species (e.g., Illinois pondweed and eel-grass) could coexist with hydrilla.

Erich Marzolf also raised concerns about not being able to control hydrilla and it spreading to downstream lakes, if it were allowed to grow. Hydrilla is already in the lakes that are downstream of Lake Apopka. Maintenance control of hydrilla, with contact herbicides, is already needed as well, in those lakes. Lakes Beauclair and Dora, the nearest downstream lakes from Lake Apopka, are separated from Lake Apopka by the Apopka-Beauclair Canal that is about 48 km long, and about 10 m average width. Should hydrilla be allowed to grow in limited areas in Lake Apopka, the likelihood of invasion by hydrilla, by fragments and tubers drifting to those downstream lakes would be reduced to minimal risk because the Apopka-Beauclair Canal is a long and narrow canal. Additional expenditures might be needed to control hydrilla in Lake Apopka and in downstream lakes, if hydrilla were allowed to grow in limited areas in Lake Apopka. It might be appropriate for lake managers to perform a cost assessment to balance the income from a largemouth bass fishery to the surrounding community against the additional expenditures needed to control hydrilla.

Hypereutrophic lakes function differently than other lakes. Authors have suggested in recent years that hydrilla can benefit hypereutrophic lakes such as Lake Apopka where both light attenuation and deep sediments prevent native vegetation from colonizing major parts of the lake (Moxley and Langford 1982, Canfield and Hoyer 1992, Porak et al. 1999, Hoyer et al. 2005) by providing habitat, food resources, and refugia for fish and wildlife (Aggus and Elliot 1975, Durocher et al. 1984, Dibble and Kilgore 1994, Dibble et al. 1996, Porak et al. 1999). Canfield et al. (2000) suggested that the combination of light attenuation and wind resuspension of sediments in Lake Apopka should prevent hydrilla from filling in the open area of the lake in the same way that native plants are now being prevented from colonizing that area. In a hydrilla workshop (Hoyer et al. 2005), it was recommended for hypereutrophic lakes like Lake Apopka that a regular control program such as the program now in affect in Lake Apopka, using contact herbicides to control hydrilla, in keeping with the management objectives aimed at improving the sports fishery, may represent a more practical and viable alternative than completely eliminating hydrilla.

There is controversy between aquatic weed specialists, that recommend not letting hydrilla grow in any Florida lakes, and fishermen and UF biologists that say that a small amount (≤15% coverage (PVI)) of hydrilla should improve the largemouth bass fishery.

Perhaps allowing hydrilla to grow in limited areas in Lake Apopka should be considered again, despite the debate.

A key lake management action should be to balance the needs of anglers with other members of the community that enjoy looking at or boating in an open lake (Canfield et al. 2000). If the entire lake were to be completely covered with aquatic macrophytes, largemouth bass anglers would enjoy fishing there, but the general public would likely perceive the profuse growth of aquatic macrophytes as an aquatic weed problem. If lake managers allowed the lake to have about 15% coverage (PVI) of rooted aquatic vegetation, they could make anglers happy by improving the sport fishing and also keep other members of the community happy by keeping most of the lake open (Canfield et al. 2000).

If the expansion of hydrilla is not to be allowed, then another alternative to mitigate the loss of largemouth bass would be stocking. Management efforts have been conducted at Lake Apopka for several decades to improve the environmental conditions in the lake (Conrow et al. 1993, Hoge et al. 2003). In lieu of the recent improvements, it is a good time to stock largemouth bass into Lake Apopka.

Previous stocking by the FFWCC in 1990, using small fry, did not result in adequate survival to produce a fishery (Johnson and Crumpton 1998). Because that stocking was not successful in producing a fishery, the FFWCC could use fingerlings or advance fingerlings. The use of advanced fingerlings to stock Lake Talquin, Florida, has been more successful than stocking projects at Lake Apopka, which used smaller fish (Dr. Daniel E. Canfield, Jr., professor, UF, personal communication).

Stocking larger ($\geq$ 24 cm) wild largemouth bass into Lake Griffin enhanced the economic activity in the surrounding community (Canfield et al. 2005). If fingerlings or advanced fingerlings were stocked into Lake Apopka, and fishermen caught them, anglers would come back. It could improve the economic viability of the largemouth bass fishery in Lake Apopka. Of course, it would be more viable to stock largemouth bass into Lake Apopka once protected, vegetated areas were established. The additional plants would also make it easier for anglers to locate the fish.

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BIOGRAPHICAL SKETCH

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