MODELING THE IMPACTS OF HABITAT MANAGEMENT ON LARGEMOUTH BASS FISHERIES AT THE KISSIMMEE CHAIN OF LAKES, FLORIDA

By

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To my parents, without whose guidance and support I wouldn’t be where I am today

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LIST OF ABBREVIATIONS

CPH	Catch per hour
CV	Coefficient of variation
DEP	Florida Department of Environmental Protection
ft-NGVD1929	Elevation (feet); National Geodetic Vertical Datum
FWC	Florida Fish and Wildlife Conservation Commission
ha	Hectares
hrs	Hours
KCOL	Kissimmee Chain of Lakes
LMB	Largemouth bass
L	Liters
m	Meters
m^3	Cubic meters
mg	Milligrams
mm	Millimeters
PAC	Percent area coverage
Pt-Co	Color (Platinum-cobalt units)
SFWMD	South Florida Water Management District
Spp.	Species (plural)
TL	Total length
yr	Year

Abstract of Thesis Presented to the Graduate School
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The Kissimmee Chain of Lakes (KCOL) in South-Central Florida is one of Florida's largest lake systems and supports important resources for humans, fish and wildlife. Management of the KCOL requires attention to multiple interests from humans as well as fish and wildlife conservation needs, including management of prominent largemouth bass *Micropterus salmoides* fisheries. Human population growth necessitated regulation of KCOL lakes using water control structures to prevent flooding in surrounding areas. This regulation of water levels caused changes to aquatic plant communities, a situation further altered by the introduction of the invasive aquatic plant hydrilla *Hydrilla verticillata*. Periodic whole-lake drawdowns were implemented at Lakes Tohopekaliga and Kissimmee, the two largest lakes in the KCOL, since 1971 to mitigate habitat degradation resulting from the effects of stabilized water levels. Changes in aquatic plant coverage and water levels can influence largemouth bass recruitment (i.e. the number of fish that enter the adult population each year), and thus, these relationships are important to fishery managers.

My objectives for this study were to (1) compile and assess historical data at the Kissimmee Chain of Lakes (KCOL), Florida to evaluate factors influencing largemouth bass fisheries, (2) build a population model to approximate the relationships created by these factors and test its viability using historical catch and harvest creel estimates, (3) explore how management changes affecting habitat quality and quantity could potentially influence largemouth bass fisheries, and (4) identify key data gaps and needs for future field studies to reduce overall uncertainty. I utilized data from Lakes Tohopekaliga and Kissimmee as well as information from other previous relevant studies for this purpose. I determined that the model was reliable for predicting population responses at both lakes based on historical catch and harvest estimates. I simulated 50-year projections for metrics of adult largemouth bass abundance, recruitment, catch and harvest at Lakes Tohopekaliga and Kissimmee. Modeled management scenarios representing high hydrilla coverage produced the greatest increases for all metrics. A new water level regime planned at Lake Kissimmee was also predicted to produce modest increases for all largemouth bass metrics. Elimination of hydrilla at both lakes produced the greatest decreases of all scenarios considered. The results of this study can be used to evaluate a range of management policies for KCOL largemouth bass fisheries, and future work should be conducted to reduce key uncertainties about the system and reduce uncertainty of the model.

CHAPTER 1
INTRODUCTION

Objectives

My objectives for this study were to (1) compile and assess historical data at the Kissimmee Chain of Lakes (KCOL), Florida to evaluate factors influencing largemouth bass fisheries, (2) build a population model to approximate the relationships created by these factors and test its viability using historical catch and harvest creel estimates, (3) explore how management changes affecting habitat quality and quantity could potentially influence largemouth bass fisheries, and (4) identify key data gaps and needs for future field studies to reduce overall uncertainty. I utilized data from Lakes Tohopekaliga and Kissimmee as well as information from other previous relevant studies for this purpose.

Study Site

Florida's Kissimmee Chain of Lakes represents 19 lakes in Orange and Osceola Counties that constitute the headwaters of Lake Okeechobee and the Everglades via the Kissimmee River (Figure 1-1). Beginning in the late 19th century, human impacts to the KCOL including hydrologic regulation and land-use changes altered the lakes' water levels and trophic state. These changes modified intra- and inter-annual water levels, and influenced water chemistry (Dierberg et al. 1988; Williams 2001), aquatic plant community composition (Hoyer et al. 2008), and fish and wildlife communities (Moyer et al. 1995; Allen et al. 2003; Bonvechio and Bonvechio 2006).

The KCOL represents a crucial interface between human use of aquatic resources and their conservation. Humans utilize the KCOL for a multitude of uses including fishing, boating, waterfowl hunting and wildlife viewing, while also controlling its inflows and outflows to prevent flooding in increasingly urbanized areas. The KCOL boasts nationally-known largemouth bass *Micropterus salmoides* fisheries (Price 2009), in addition to fisheries for other species such as black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus* and redear sunfish *L.microlophus*. It also hosts a number of wildlife species of concern in both the United States and Florida, most notably the snail kite *Rhostramus sociabilis*, sandhill crane *Grus canadensis*, whooping crane *Grus americana* and American alligator *Alligator mississippiensis*. Resource managers at the KCOL must balance the competing needs of its multiple user groups in a way that protects aquatic resources.

The Kissimmee Chain of Lakes Long-Term Management Plan (KCOL LTMP) identifies targets for ecosystem attributes representing a multitude of lake uses and characteristics, one of these targets being recreational fisheries. The KCOL supports some of the most important largemouth bass fisheries in Florida. Maintaining these fisheries despite altered hydrology and associated impacts to littoral habitat is a primary management concern. To meet KCOL LTMP targets, it is necessary to understand the effects of potential future habitat changes and their mechanisms.

Managers at the KCOL must consider two major pieces of federal legislation at all times when implementing management actions. The Clean Water Act (Federal Water Pollution Control Amendments of 1972) directs the conservation of fishable and swimmable navigable waters in the United States. The Endangered Species Act (1973) prevents actions that threaten critically imperiled species with extinction. Both laws have specific applications at the KCOL.

Lake Tohopekaliga (~7,600 ha) and Lake Kissimmee (~14,000 ha) are the two largest lakes in the KCOL. Extensive monitoring data exist for these lakes which provide insight into the history of their largemouth bass fisheries. In an effort to synthesize and explain complex relationships between habitat and largemouth bass fisheries at the KCOL, I analyzed relationships between these data as well as those found in other relevant previous studies.

Largemouth Bass-Habitat Relationships

Abundance and structural complexity of aquatic plants can influence vertebrate and invertebrate populations in aquatic ecosystems leading to cascading effects on herbivorous and insectivorous invertebrates (Crowder and Cooper 1982), smaller insectivorous fishes (Crowder and Cooper 1982; Savino and Stein 1982; Valley and Bremigan 2002), and larger piscivorous fishes (Colle and Shireman 1980; Hoyer and Canfield 1996; Tate et al. 2003b). Large-scale changes in submersed aquatic plant coverage can have impacts across the entire fish community (Bettoli et al. 1993). Littoral plant abundance and composition can affect population abundance of largemouth bass prey species (e.g. bluegill) by increasing their forage bases (Crowder and Cooper 1982) as well as providing greater protection of juveniles from predation (Crowder and Cooper 1982; Savino and Stein 1982). Different prey species may select different aquatic plant types to avoid predation (Chick and McIvor 1997).

Similarly, aquatic plants influence population abundance and growth of largemouth bass (Hoyer and Canfield 1996; Tate et al. 2003b). Many juvenile fishes, including juvenile largemouth bass, use complex habitats as refuge from predation. Recruitment of largemouth bass (i.e., the number of fish that survive to age-1) may show a positive relationship to percent area covered by aquatic plants (Durocher et al. 1984), particularly in large Florida lakes such as those found in the KCOL (Hoyer and Canfield 1996; Tate et al. 2003b), though the nature of the relationship may vary. However, at high levels of aquatic plant coverage, adult largemouth bass condition can decrease due to reduced foraging efficiency (Colle and Shireman 1980). As habitat complexity also increases, predation success decreases (Savino and Stein 1982). Additionally, juvenile largemouth bass growth may slow under these conditions due to a delayed shift to piscivory in their diets (Bettoli et al. 1992), a behavior which is attributable to increased juvenile largemouth bass growth. However, Bonvechio and Bonvechio (2006) saw no direct evidence of such reductions in largemouth bass condition or growth at Lake Tohopekaliga from increasing hydrilla coverage between 0-83%. The effects of dense plant coverage on largemouth bass growth at large lake systems such as Lakes Tohopekaliga or Kissimmee remain unclear. Previous studies have suggested that moderate levels of aquatic plant coverage are ideal for promoting desired abundance and growth of largemouth bass (Wiley et al. 1984), possibly within a range of approximately 20-40% coverage (Bonvechio and Bonvechio 2006). Thus, largemouth bass population abundance is likely related to large-scale plant community changes at the KCOL.

Since the early 1990s, the dominant aquatic macrophyte in the KCOL has been the invasive submersed aquatic plant hydrilla *Hydrilla verticillata*. First introduced to Florida around 1960 and likely originating in Asia (Langeland 1996), hydrilla has the ability to spread rapidly in the absence of management to control the abundance and distribution of the species (Colle and Shireman 1980). Since its introduction in Florida, hydrilla has provided a challenge to lake managers as it has numerous effects on lake ecology and fisheries management goals. Increased hydrilla coverage may lead to increased largemouth bass recruitment or abundance in Florida (Moxley and Langford 1985; Tate et al. 2003b; Bonvechio and Bonvechio 2006). However, excessive hydrilla makes boating difficult and can even discourage angling in spite of constant or increased catch rate. Colle et al. (1987) found that angler effort for largemouth bass at Orange Lake, Florida decreased at hydrilla coverage levels greater than 80%. Hydrilla was previously controlled on a lake-wide scale at the KCOL by application of the herbicide fluridone, however, strains of fluridone-resistant hydrilla began appearing in Florida during the mid-2000s (Puri et al. 2006) and its use has since been discontinued at the KCOL (Puri et al. 2009). The development of fluridone resistance has complicated hydrilla management at the KCOL as many herbicides capable of targeting hydrilla may also have detrimental effects on desirable emergent aquatic plant populations. In recent years, however, treatments at Lakes Tohopekaliga and Cypress using the contact herbicide endothall appear to have been successful for both suppressing hydrilla expansion and minimizing unwanted effects on other species (Tim Coughlin, FWC, personal communication).

The Florida Fish and Wildlife Conservation Commission (FWC) has used extended water-level drawdown periods combined with mechanical removal of organic sediments as a management tool on the KCOL to eliminate dense emergent plant communities, tussocks (floating mats of dense plants), and muck caused by stabilized water levels (Moyer et al. 1987, 1988, 1992, 1993, 1995; Allen et al. 2003). Changes in largemouth bass population abundance and structure from these drawdowns can be inconsistent. Short-term changes may not always occur, but periodic drawdowns will likely continue to be necessary under the current flow regimes in some KCOL lakes to prevent excessive sediment accumulation over periods of decades.

Water level changes may also play a part in largemouth bass recruitment. Meals and Miranda (1991) found that abundance of centrarchid fishes (i.e., sunfishes, Centrarchidae) was positively related to water levels at two Mississippi reservoirs. Miranda et al. (1984) found young-of-year largemouth bass survival increased with water level increases at West Point Lake, Alabama-Georgia. Sammons et al. (1999) saw increased weekly survival of juvenile largemouth bass during increased water levels at Normandy Reservoir, Tennessee. These responses likely resulted from inundation of terrestrial habitat which provided additional habitat for young-of-year fish in reservoirs. However, due to the morphology of typical Florida lakes (i.e. shallow, gradual shoreline drop-off which creates an extended littoral zone, and lack of clear, abrupt shoreline boundaries), these relationships may be somewhat different at the KCOL. Bonvechio and Allen (2005) found that largemouth bass year-class strength was positively related to stage in three of four Florida lakes. Tate et al. (2003b) saw a negative relationship between estimated age-0 largemouth bass abundance and mean summer water levels at Orange Lake, Florida, but no significant relationship to water levels at Lake Lochloosa, Florida. Lake fluctuations often influence trophic state variables and aquatic plant abundance at Florida lakes, though the relationships are often highly variable based on a number of individual mechanisms (Hoyer et al. 2005). Increasing water levels may mediate the effects of submersed plant coverage on largemouth bass recruitment by reducing the area available for colonization due to decreased available light (Hoyer et al. 2005). Thus, fluctuations in water levels and associated impacts on aquatic plants will likely influence largemouth bass recruitment and fishing quality for anglers, though these relationships are not completely clear and their effects are often difficult to distinguish given varying aquatic plant coverage or other types of habitat variability.

Population Modeling

Resource managers and researchers often use models to explore the effects of environmental changes (e.g. habitat modifications, human use and harvest, etc.) on animal populations. All models are simplistic depictions of reality, and no model can capture all processes influencing natural systems. Thus, population models operate on assumptions (often derived from field-collected data) regarding the response of the population in question to changes in the modeled parameters. Some models evaluate a single change, such as habitat variability (Wiley et al. 1984; Crouse et al. 1987), whereas others evaluate a wide range of environmental and/or biological changes (Beamesderfer and North 1995; Forchhammer et al. 1998). They can explore the effects of random environmental changes or human-induced ones. Through modeling, scientists can inform their study designs and direct sampling effort to address targeted questions. They can use comparisons of modeled results and on-the-ground sampling to continually refine sampling designs as well as research questions.

Population models also allow researchers and managers to identify critical information needs in their research. Initial predicted responses can often prove to be inaccurate or even counterintuitive, and the process of model-building requires the modeler to identify the assumptions inherent in their model (Pine et al. 2009). The use of sensitivity analyses can identify the most crucial parameters with regard to model outputs. Subsequent field collections can then target those parameters to reduce their uncertainty. Through such mechanisms, population models can be improved and refined over time to more closely reflect the conditions present in the system being studied and allow for more accurate predictions.

The utility of population models spans across a wide range of fish and wildlife management needs. Birds (Mooij et al. 2005), amphibians (Keisecker et al. 2001; Pope 2008), reptiles (Crouse et al. 1987; Towns and Ferreira 2001) and mammals (Forchhammer et al. 1998) can all be modeled in various ways to explain the effects of environmental changes on their population dynamics. Hillborn and Walters (1992), Haddon (2001) and Walters and Martell (2004) all describe detailed methods used to model fish populations. Saltwater fish stocks are modeled in stock assessments to achieve goals such as optimum harvest strategies. In the United States, these assessments are required by law under the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (2006) to insure sustainability. Models for nongame fish species often fall under the auspices of the Endangered Species Act (1973) and can estimate population size as well as assess threats to the long-term viability of at-risk species (Coggins et al. 2006; Flowers 2008). These same types of models have the potential to determine stock responses for sport fish species to habitat variability and changes in fishing effort. For example, Beamesderfer and North (1995) tested the effects of fishing on largemouth bass and smallmouth bass *M. dolomieu* populations of widely varying productivity across North America. I created a population model to explore how changes in habitat would influence the largemouth bass fishery at the Kissimmee Chain of Lakes (KCOL), Florida.

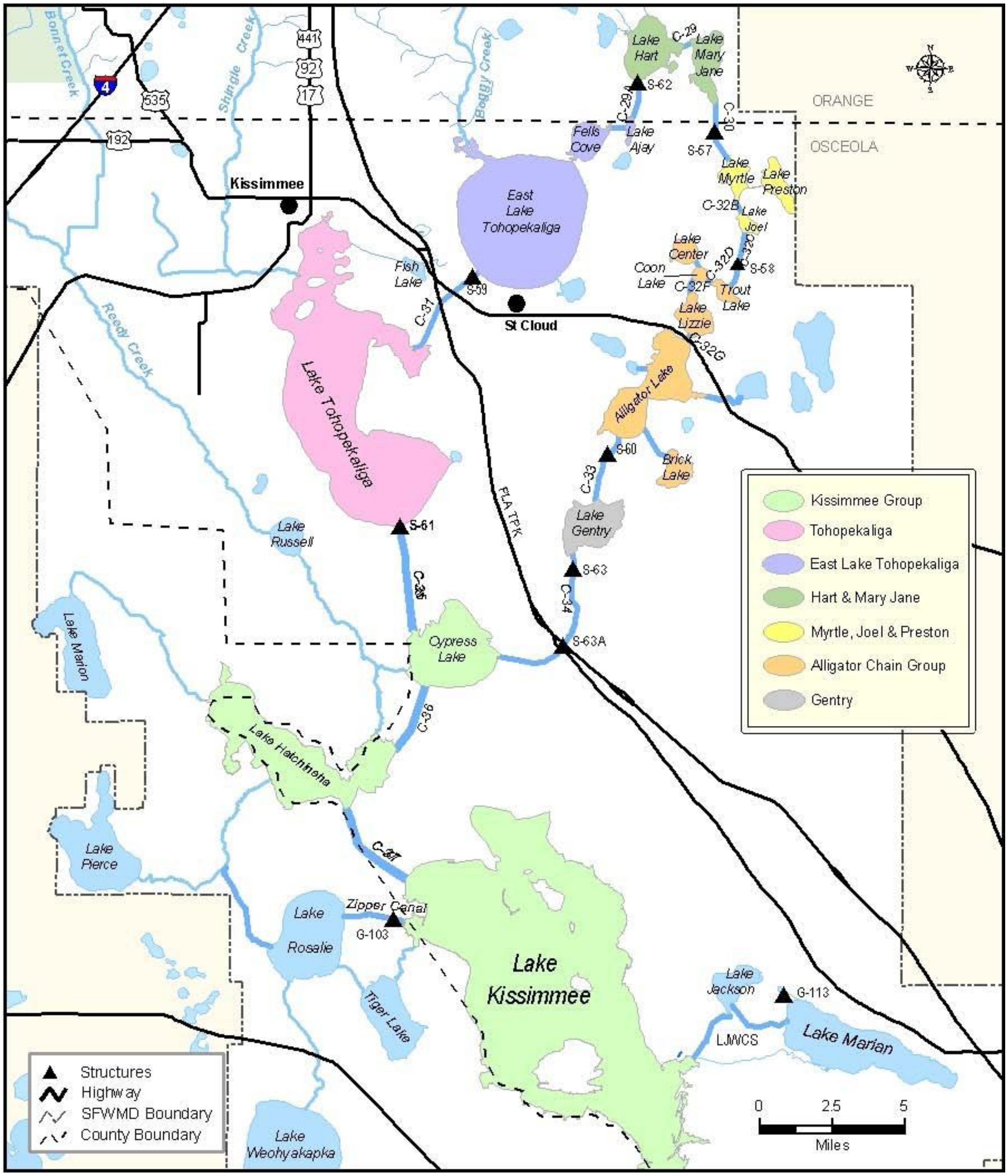

Figure 1-1. Kissimmee Chain of Lakes and associated water control structures. Map was obtained from the South Florida Water Management District.

CHAPTER 2
HISTORICAL KISSIMMEE CHAIN OF LAKES DATA ANALYSIS

Introduction

In this chapter I compiled data from the KCOL and evaluated empirical relationships between lake habitat conditions (i.e., water levels, aquatic plant abundance and composition) and largemouth bass populations. The results of this chapter served as the basis for the population model used in Chapter 3. This chapter addressed objective 1, and included assessing historical data at the KCOL and evaluating factors influencing largemouth bass fisheries. I evaluated relationships among the variables that were used to inform the population model, namely the effects of hydrilla, changes in water levels, changes in water quality, and drawdowns on largemouth bass recruitment. I also compared these relationships to previous studies at comparable systems to inform the structure of the population model in Chapter 3.

Methods

I compiled largemouth bass electrofishing catch per hour (CPH, fish/hr) data collected by Florida FWC personnel during the months of February, March and April at Lake Tohopekaliga from 1983-2008 and at Lake Kissimmee from 1985-2008 (Kevin McDaniel, FWC, unpublished data). The FWC did not sample in 1987 at Lake Tohopekaliga or 1996 at Lake Kissimmee during drawdowns, but did sample during the 2004 Tohopekaliga drawdown. Electrofishing samples for both lakes consisted of fixed site, 20-minute transects obtained at night until 2006, at which point 15-minute random sampling transects obtained during daylight hours were added. Only random transects were used after 2006. Length and weight of each largemouth bass captured were measured and recorded for each transect. I estimated largemouth bass CPH for each sampling transect, and then computed a mean CPH and standard error for each year at each lake. Some transects taken in non-standardized locations (e.g. areas with known high densities of fish) to supplement length-frequency analysis and were omitted from CPH analysis due to possible sampling bias.

I determined age-1 largemouth bass CPH by evaluating length frequency data. I grouped all fish caught in a given year at each lake into 1-cm size classes and plotted their frequency on a histogram. I determined the lengths between the first two modal points and established a minimum length for adult fish in each year (Devries and Frie 1996). After age-1 fish were separated from adult fish, I determined age-1 CPH mean and standard error for each year at each lake as previously described. I estimated mean total length (TL) of age-1 largemouth bass each year to explore growth of age-1 fish through time.

Florida FWC also provided nonuniform probability roving creel survey estimates for both lakes (Rob DeVries, FWC, personal communication). These creel surveys included angler effort (hours), catch and harvest (number of fish), and angler CPH estimates as well as their associated standard errors. The FWC conducted creel surveys on Lake Tohopekaliga in the fall of each year from 1970-2007 as well as spring of 1976, 1979, 1983 and 1990. The FWC conducted Lake Kissimmee surveys in winter from 1975-2007, spring from 1976-1992 and 2000-2007, summer from 1975-1999 and fall from 1975-1992. To maintain consistency in the data across years, I used only fall survey data from Lake Tohopekaliga and winter survey data from Lake Kissimmee because sampling of other seasons was not conducted in all of the study years.

I obtained monthly water stage records and water quality data from the South Florida Water Management District (SFWMD) at both lakes. Stage records were from January 1983 to March 2008 (David Anderson, SFWMD, personal communication). Data loggers recorded water levels at the S-61 gauge at Lake Tohopekaliga and the S-65 gauge at Lake Kissimmee. Records for each month included monthly minimum, mean, maximum and standard deviation for each month for stage (ft NGVD1929). I used these data to estimate annual minimum, mean and maximum stage at each lake in each year. Water quality records were available from 1981 to 2008 (Brad Jones, personal communication). I used data from stations B02 (open water, north end), B04 (open water, northeast end) and B09 (open water, south end) at Lake Tohopekaliga as they were the three stations with continuous data during my period of study. I used data from stations E02 (open water, northwest end) and E04 (open water, east central end) at Lake Kissimmee as they were the two stations with continuous data during the same period. Data included secchi depth (m), color (Pt-CO), chlorophyll-a (mg/m^3), total phosphorous (mg/L) and total nitrogen (mg/L). For both lakes I first found the annual mean of each measurement for each station and averaged these numbers to find the total annual mean of the entire lake.

I obtained Florida Department of Environmental Protection aquatic plant coverage estimates (Ed Harris, FDEP, personal communication; Mark Hoyer, Florida LAKEWATCH, personal communication) to explore trends in these species over time. I received copies of field sheets from annual FDEP surveys of Lake Tohopekaliga for 1991 and 1993-2007 and Lake Kissimmee for 1991 and 1993-2005 as well as electronic versions of DEP estimates from 1983-2003. The DEP staff took these surveys in

October of each year. Total acreage estimates were provided for hydrilla, water hyacinth *Eichhornia crassipes* and water lettuce *Pistia stratiotes* in all years. In some years, presence or absence of many other species was also included, with acreage estimates for some specific plant types in certain years. Total acreage estimates for all aquatic plant species were given for 1995 and 2003 at both lakes.

I evaluated trends between largemouth bass metrics (e.g, electrofishing CPH, angler CPH) and environmental factors (e.g., hydrilla coverage, water levels) using linear regressions. Age-1 largemouth bass electrofishing CPH was compared to hydrilla coverage in the previous fall (e.g., fall 1990 hydrilla vs. spring 1991 electrofishing CPH). Hydrilla estimates were similarly adjusted to the previous fall for angler CPH estimates observed at Lake Kissimmee (sampled in winter). Water stage minimum, mean and maximums were adjusted to the previous year when compared against age-1 largemouth bass electrofishing CPH. I compared age-1 electrofishing CPH estimates to angler CPH in the next two to five years in an attempt to find relationships between age-1 largemouth bass abundance estimates and angler catch rates in the future.

Results

Electrofishing

Largemouth bass electrofishing CPH varied substantially among years at both lakes. Total largemouth bass CPH at Lake Tohopekaliga ranged between 34 and 118 largemouth bass per hour (Figure 2-1a). Age-1 CPH ranged between 1 and 35 largemouth bass per hour (Figure 2-1b). Electrofishing catch rates of age-1 largemouth bass suggested the strongest year classes occurred in 1988, 1989, 2000 and 2003. Total largemouth bass CPH at Lake Kissimmee ranged between 32 and 112 largemouth bass per hour (Figure 2-1c). Catch rates of age-1 largemouth bass showed the strongest year class in 1998 with other relatively strong year classes in 1989, 1997 and 1999 (Figure 2-1d). Age-1 largemouth bass CPH ranged between 3 and 57 largemouth bass per hour.

Mean total length of age-1 largemouth bass also varied considerably at both lakes (Figure 2-2). Mean age-1 total lengths ranged from 130-200 mm at Lake Tohopekaliga and 118-196 mm at Lake Kissimmee. Mean total length of age-1 largemouth bass was not related to age-1 electrofishing CPH at either lake (r^2 = 0.061, P = 0.233 at Lake Tohopekaliga and r^2 = 0.059, P = 0.264 at Lake Kissimmee), suggesting that density-dependent growth may not have been a factor for age-0 fish at either lake.

Creel Surveys

Angler catch and effort also varied widely across years at both lakes. Total angler catch was highest at Lake Tohopekaliga in 2002 and at Lake Kissimmee in 1991 (Figure 2-3). Angler effort, catch and harvest at Lake Kissimmee all decreased by approximately 85-90% between 1989 and 2003, but have rebounded partially in recent years. Harvest as a percentage of total catch declined over the observed time period at both lakes. From 1983-1991, harvest averaged 51% of total catch at Lake Tohopekaliga and 80% at Lake Kissimmee. After 1991, harvest averaged 18% and 33% of total catch, respectively. These declines in percent of fish harvested are attributable to voluntary release of fish by anglers (Myers et al. 2008). However, total harvest of largemouth bass at Lake Tohopekaliga has remained similar through time due to increases in total fishing effort (Figure 2-3). Angler effort, catch and harvest at Lake Tohopekaliga approximately tripled between 1996 and 2001, a period of rapid fishing effort increases. Thus, although voluntary release of fish by anglers has increased, the fishing mortality on largemouth bass may still be substantial at this system.

Aquatic Macrophytes

Hydrilla areal coverage ranged from 7-77% (607-6,305 ha) at Lake Tohopekaliga between 1991 and 2007 (rapid expansion at both lakes occurred in the early 1990s) and 5-52% (650-7,386 ha) at Lake Kissimmee between 1991 and 2005 (Figure 2-4). Water hyacinth and water lettuce coverages were much lower; water hyacinth ranged from 1-162 ha and 4-178 ha, respectively, and water lettuce ranged from 2-30 ha and <1-142 ha, respectively. Aquatic plant species totaling over 200 ha areal coverage at Lakes Tohopekaliga and Kissimmee in either 1995 or 2003 were summarized in Tables 2-1 and 2-2. Hydrilla was the most abundant aquatic macrophyte at both lakes in both 1995 and 2003. However, hydrilla control efforts and changing environmental conditions through time made hydrilla coverage dynamic at both lakes and likely accounted for a large portion of total habitat variability across years.

Water Chemistry

Hydrilla coverage influenced water chemistry parameters at both lakes. Hydrilla coverage at Lake Kissimmee was positively related to mean secchi depth ($r^2 = 0.45$, $P < 0.01$, Figure 2-5). Lake Tohopekaliga displayed no significant relationship between hydrilla coverage and secchi depth ($r^2 = 0.16$, $P = 0.12$). Hydrilla also displayed a negative relationship with chlorophyll-a concentration at Lakes Tohopekaliga ($r^2 = 0.47$, $P < 0.01$) and Kissimmee ($r^2 = 0.42$, $P = 0.01$). Color was not related to hydrilla coverage at Lakes Tohopekaliga over the study period ($r^2 < 0.01$, $P = 0.97$) or Kissimmee ($r^2 = 0.02$, $P = 0.66$, Figure 2-5). There may, however, be some relationship at higher color values causing light limitation and influencing hydrilla growth. During

August/September 2004, three separate hurricanes passed directly over the KCOL; Hurricane Charley (August 13), Hurricane Frances (September 5) and Hurricane Jeanne (September 26) (Hoyer et al. 2008). As a result, the 2004 and 2005 color values at both lakes were the highest of the study period, and both years had noticeably lower levels of hydrilla coverage from previous years. It is possible that color lacks a significant effect on hydrilla coverage only until it reaches a level which inhibits light availability enough to prevent germination of hydrilla propagules.

Water Levels

Water levels were relatively stable at both lakes across years, except for drawdown years. Drawdowns in 1987 and 2004 at Lake Tohopekaliga and 1995-1996 at Lake Kissimmee caused the lowest water levels (Figure 2-6). Water levels rarely exceeded the maximum regulatory stage at either lake and only slightly exceeded it in those cases; the highest recorded stage at Lake Tohopekaliga was 55.7 ft-NGVD in October 2004 (maximum regulatory stage is 55.0 ft-NGVD) and at Lake Kissimmee was 53.1 ft-NGVD in August 2003 (maximum regulatory stage is 52.5 ft-NGVD). Lake stage also rarely dropped below minimum stage in non-drawdown years at either lake; the lowest non-drawdown stage recorded at Lake Tohopekaliga was 51.0 ft-NGVD in June 1990 (minimum regulatory stage is 52.0 ft-NGVD) and at Lake Kissimmee was 47.0 ft-NGVD in April 1987 (minimum regulatory stage is 49.0 ft-NGVD). Thus, across-year water level fluctuations similar to pre-regulation conditions have been rare at these systems.

Relationships between Largemouth Bass Metrics and Lake Conditions

The historical data yielded mixed results for predicting largemouth bass population metrics at each lake. Age-1 largemouth bass electrofishing CPH showed no relationship to hydrilla coverage levels in the previous fall at either Lake Tohopekaliga (r^2 = 0.02, P = 0.62) or Lake Kissimmee (r^2 = 0.02, P = 0.62). Age-1 CPH also showed no relationship to mean, minimum or maximum water stage at either lake, but water levels were very similar within each lake across years, except for drawdown years. I found no significant relationship between any water quality parameters and age-1 largemouth bass electrofishing CPH (all P > 0.32). Mean total length of age-1 largemouth bass was not related to hydrilla coverage at either lake (Tohopekaliga: r^2 = 0.03, P = 0.55; Kissimmee: r^2 = 0.02, P = 0.62), suggesting that hydrilla did not influence age-1 fish growth for the coverages evaluated.

However, hydrilla coverage influenced angler catch rates at Lake Tohopekaliga but not at Lake Kissimmee. Angler CPH was positively related to areal hydrilla coverage at Lake Tohopekaliga (r^2 = 0.43, P < 0.01), but there was no significant relationship at Lake Kissimmee (r^2 = 0.16, P = 0.16) (Figure 2-7). Hydrilla reached higher coverages at Lake Tohopekaliga than at Lake Kissimmee, and perhaps the lower coverage at Lake Kissimmee was not enough to elicit an angler CPH response. I found no relationship between angler effort and hydrilla coverage at either lake (Tohopekaliga: r^2 = 0.16, P = 0.14; Kissimmee: r^2 = 0.18, P = 0.13)

Largemouth bass population responses to the lake drawdowns were not consistent and generally showed only short-term effects. The 1987 Lake Tohopekaliga drawdown showed no significant differences in age-1 largemouth bass electrofishing CPH, mean total length (TL) of age-1 fish, total electrofishing CPH, or angler CPH (all P > 0.2). Moyer et al. (1995) did find significant differences in mean electrofishing CPUE between restored and control sites in 1988 and 1989. Moyer et al. (1995) also observed an increase in age-0 largemouth bass in 1988 followed by a decrease the following year, but, as noted, there were no significant differences in largemouth bass metrics between the two years pre- and post-drawdown. The 2004 Lake Tohopekaliga drawdown also showed no short-term changes in largemouth bass population metrics (all $P > 0.10$). However, recruitment and abundance did appear to increase after 2005 (Figure 2-1). Angler CPH remained relatively flat and appeared to be lower than in years just before the drawdown. Allen et al. (2003) found strong largemouth bass year classes (1997 and 1998) following the 1995-96 Lake Kissimmee drawdown as well as an increase in mean TL of age-1 fish from 143 mm to 186 mm. This increase in age-1 largemouth bass growth at Lake Kissimmee from the 1995-96 drawdown was not reflected in either of the drawdowns at Lake Tohopekaliga. In summary, my results showed that short term (1-4 years) benefits to largemouth bass recruitment can result from these projects, but there was very little noticeable impact after 5-6 years. This analysis did not evaluate the effects of drawdown and muck removal projects on lake habitat and fish metrics over long time scales (e.g., decades). This could be important if stabilized lake levels are not mitigated over periods of decades by drawdowns and muck removals, resulting in lake-wide littoral habitat loss.

Table 2-1. Aquatic macrophyte species present and coverage at Lake Tohopekaliga in 1995 and 2003. Species listed totaled over 200 hectares in 1995 and/or 2003. All values are in hectares. Data were obtained from the Florida Department of Environmental Protection.

Species	1995	2003
Ceratophyllum demersum	269	81
Filamentous algae	93	456
Hydrilla verticillata	4,553	4,796
Lemna/Spirodela spp.	295	283
Ludwigia octovalvis/preuviana	121	223
Nelumbo lutea	486	125
Nuphar luteum	441	318
Paspalidium geminatum	581	607
Pontederia cordata	571	718
Salvinia minima	496	364
Scirpus californicus/validus	83	217
Typha spp.	166	437
Utricularia foliosa	354	210
Utricularia gibba	167	251

Table 2-2. Aquatic macrophyte species present and coverage at Lake Kissimmee in 1995 and 2003. Species listed totaled over 200 hectares in 1995 and/or 2003. Data were obtained from the Florida Department of Environmental Protection.

Species	1995	2003
Ceratophyllum demersum	152	332
Hydrilla verticillata	7,386	2,630
Lemna/Spirodela spp.	304	453
Ludwigia octovalvis/preuviana	249	170
Nuphar luteum	799	332
Nymphaea odorata	639	146
Paspaladium geminatum	282	546
Potamogeton illinoensis	283	314
Salvinia minima	369	399
Typha spp.	354	277
Utricularia foliosa	451	229
Utricularia gibba	248	101
Vallisneria americana	119	318

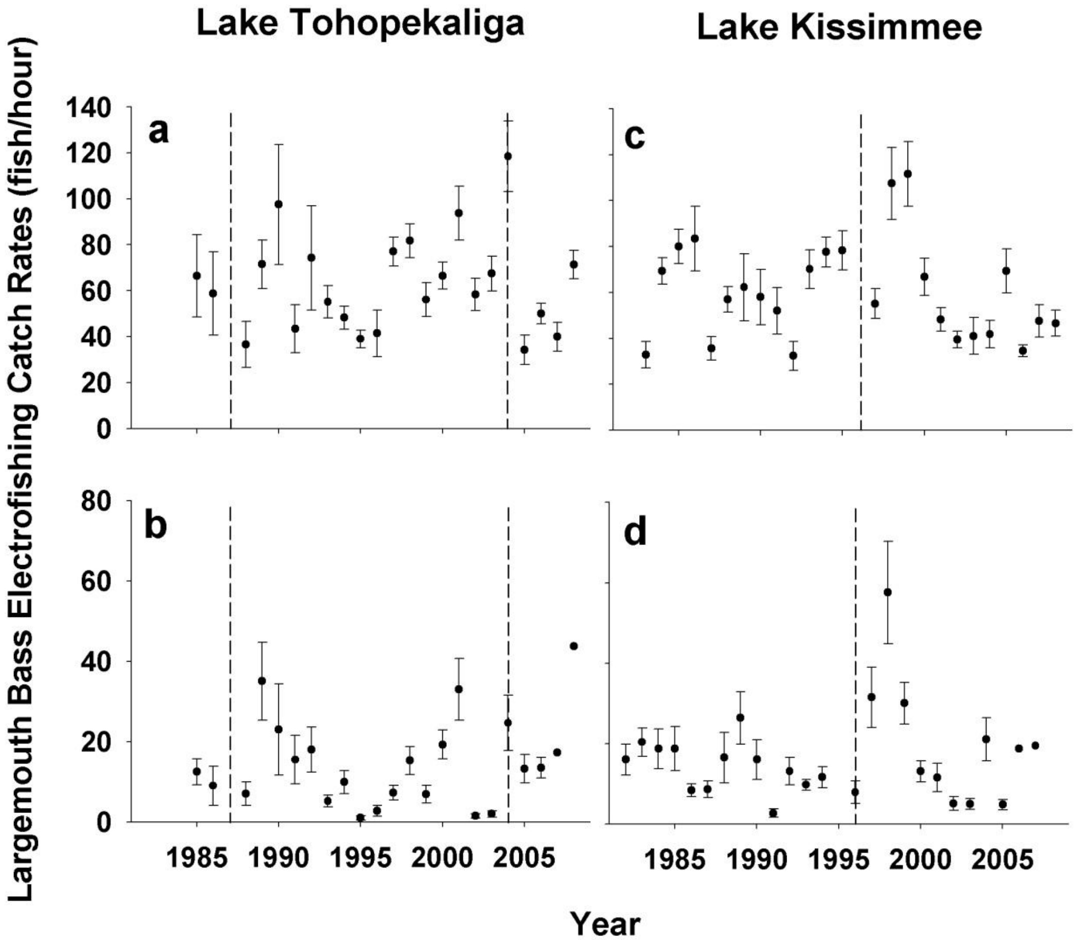

Figure 2-1. Mean electrofishing catch rates for all largemouth bass (LMB) and age-1 LMB (represented by year-class) at Lake Tohopekaliga (a and b) from 1985-2008 and Lake Kissimmee (c and d) from 1983-2008. Error bars represent ± one standard error. Dashed vertical lines represent drawdowns. Data were obtained from the Florida Fish and Wildlife Conservation Commission

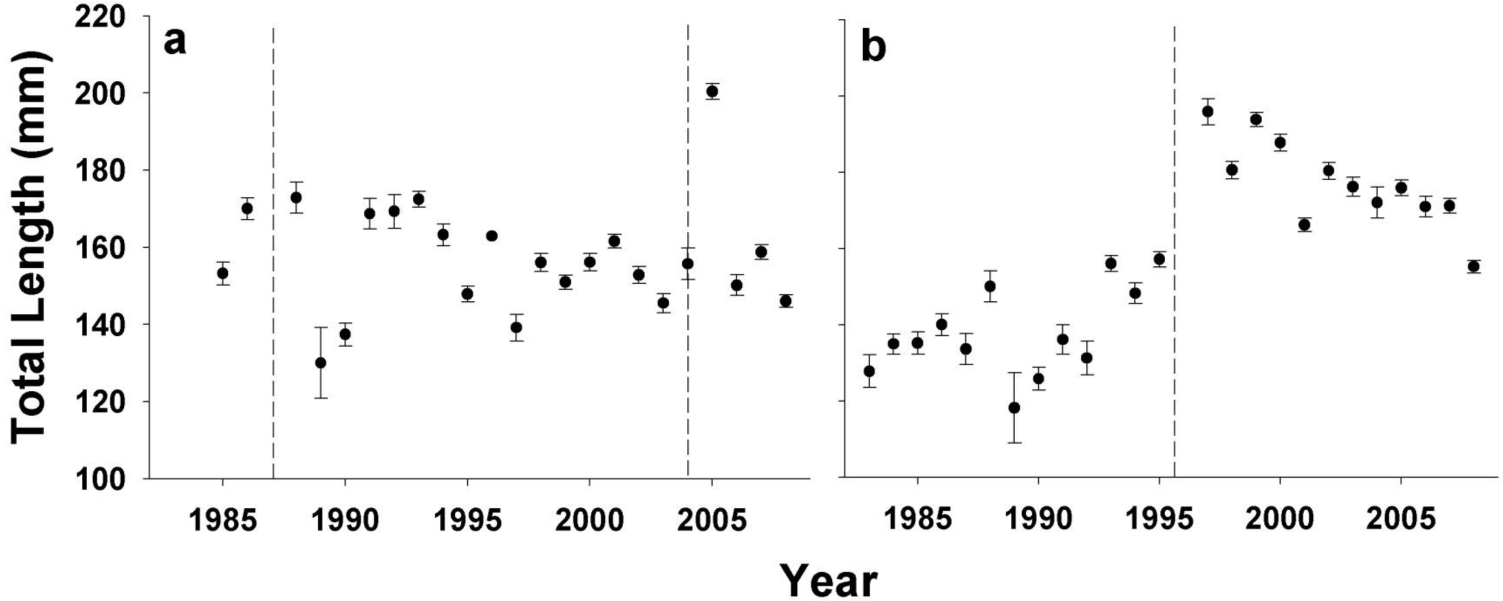

Figure 2-2. Mean total length and associated standard errors of age-1 largemouth bass at Lake Tohopekaliga (a) from 1985-2008 and Lake Kissimmee (b) from 1983-2008. Error bars represent ± one standard error. Dashed vertical lines represent facilitated drawdown periods. Data were obtained from the Florida Fish and Wildlife Conservation Commission.

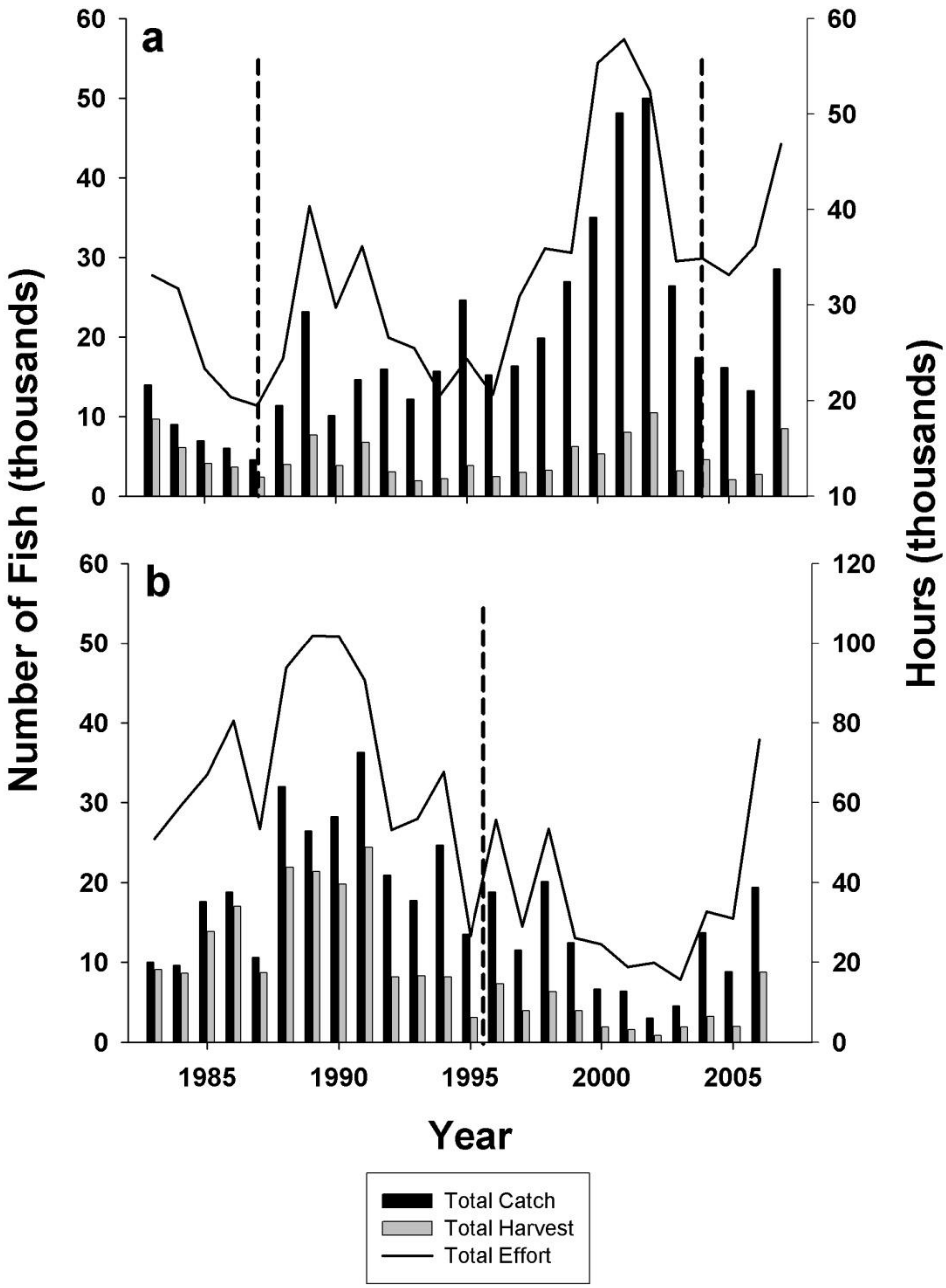

Figure 2-3. Total catch, total harvest and angler effort at Lake Tohopekaliga (a) from 1983-2007 (fall sampling period) and Lake Kissimmee (b) from 1983-2006 (winter sampling period). Dashed vertical lines represent facilitated drawdown periods. Data were obtained from the Florida Fish and Wildlife Conservation Commission.

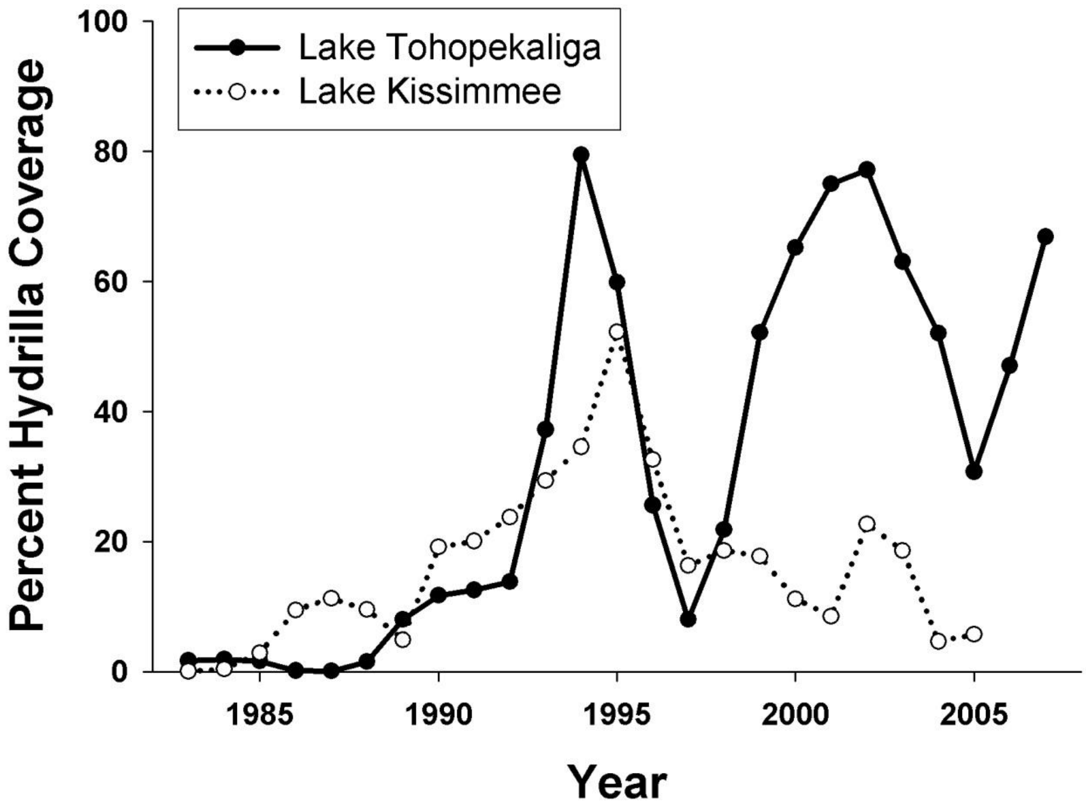

Figure 2-4. Percent of lake surface area covered in hydrilla at Lake Tohopekaliga from 1983-2007 and at Lake Kissimmee from 1983-2005. Data were obtained by the Florida Department of Environmental Protection.

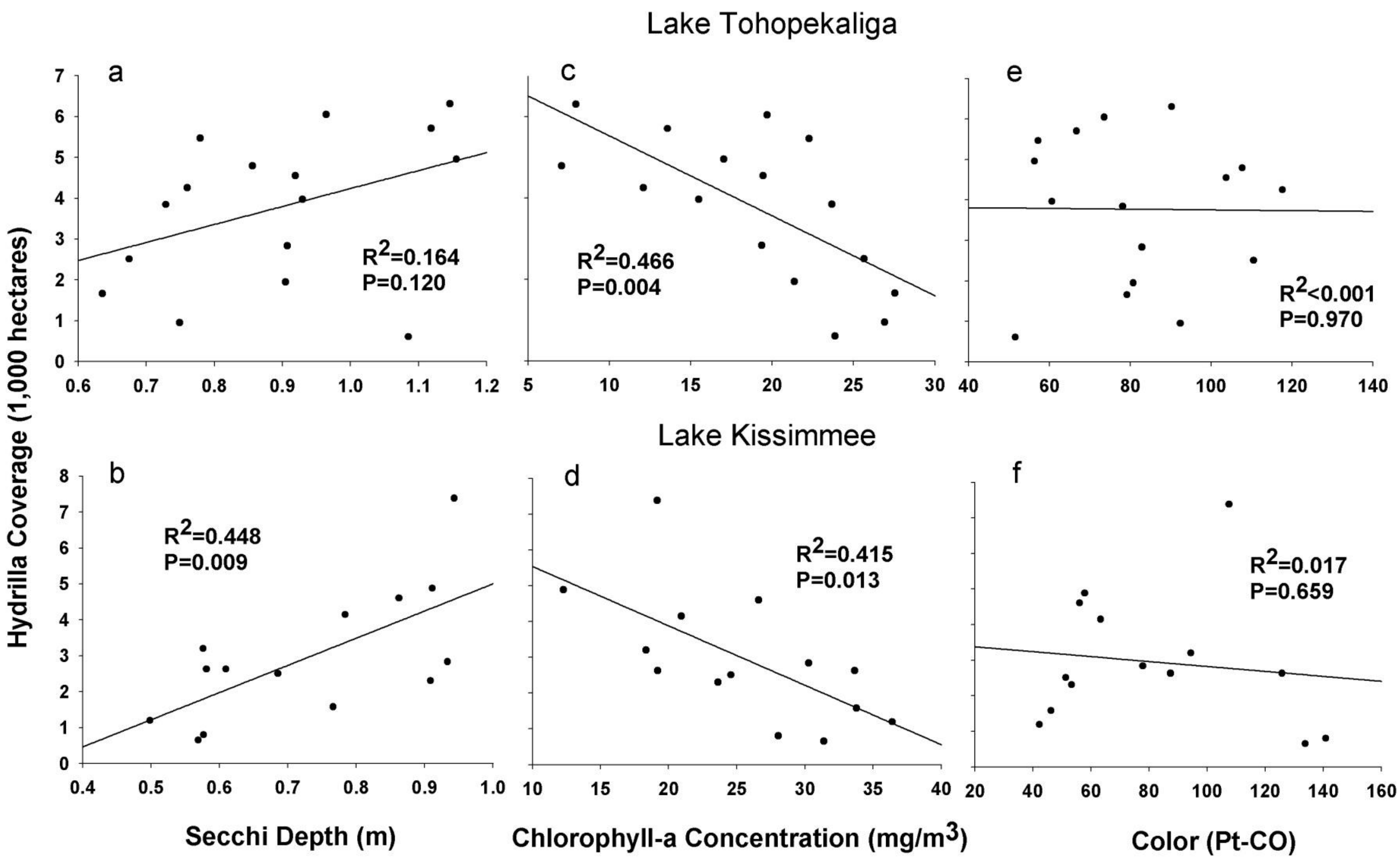

Figure 2-5. Regression analyses of three water chemistry parameters (secchi depth (a and b), chlorophyll-a concentration (c and d), and color (e and f)) versus areal hydrilla coverage (ha) at Lakes Tohopekaliga and Kissimmee from 1983-2007. Data were obtained from the South Florida Water Management district and the Florida Department of Environmental Protection.

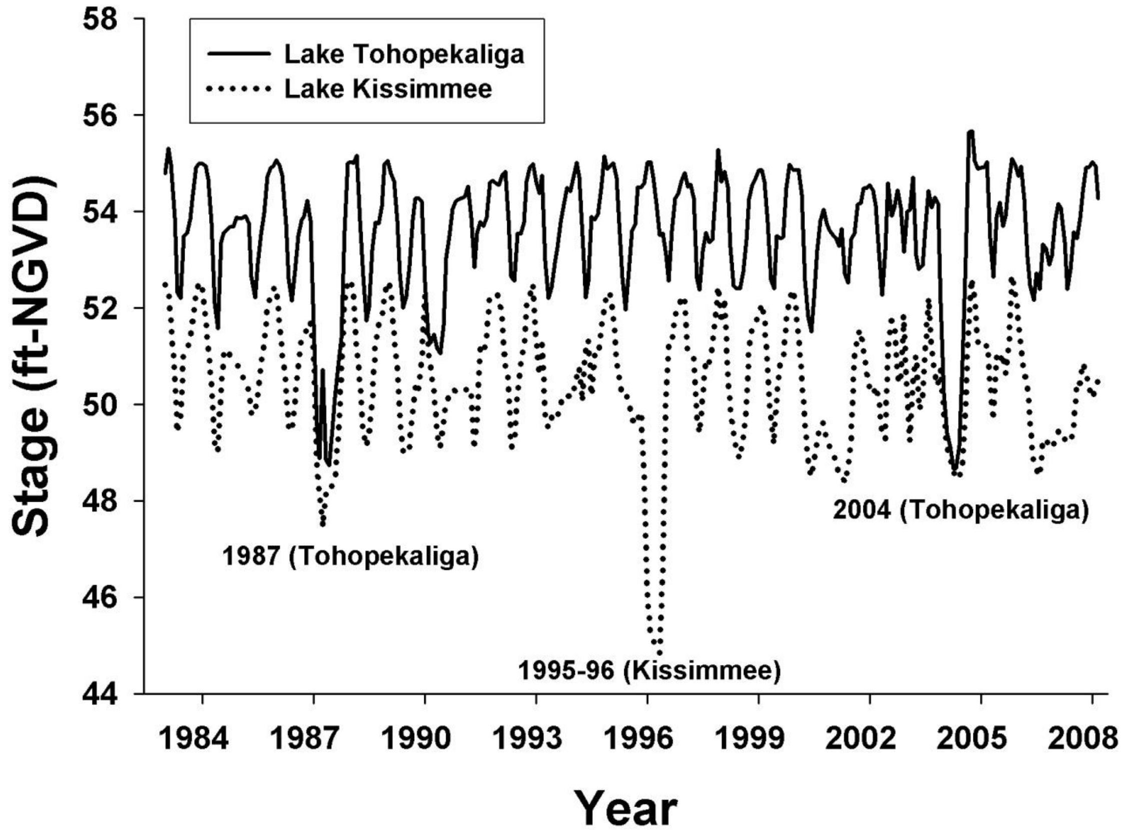

Figure 2-6. Mean monthly stage (ft-NGVD) at Lakes Tohopekaliga and Kissimmee from January 1983-March 2008. Labels indicate drawdown periods. Data were obtained from the South Florida Water Management District.

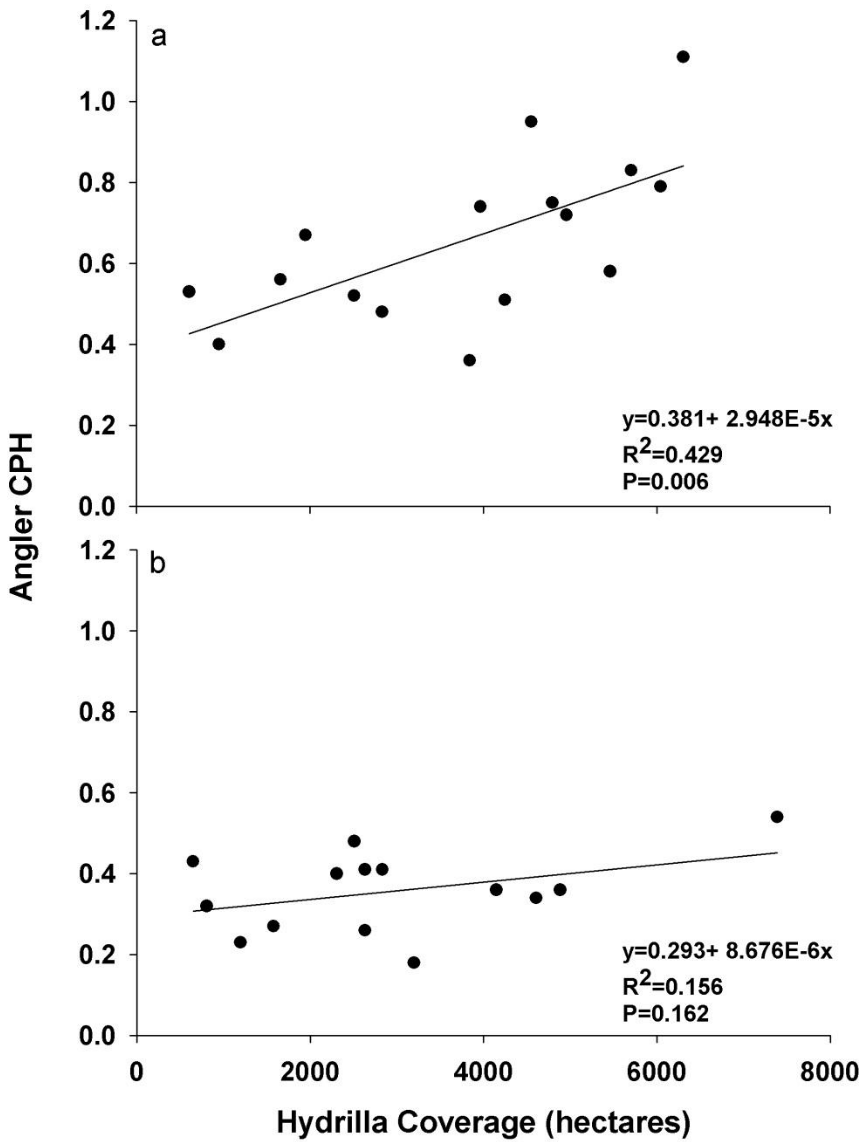

Figure 2-7. Hydrilla areal coverage (hectares) versus number of fish caught per angler hour (CPH) at Lakes Tohopekaliga (a, 1991-2007) and Kissimmee (b, 1991-2005). Linear regression equations are shown for each. Data were obtained from the Florida Department of Environmental Protection and the Florida Fish and Wildlife Conservation Commission.

Discussion

Electrofishing, Creel Surveys and Aquatic Macrophytes

The lack of relationships between age-1 largemouth bass electrofishing CPH and environmental variables, and creel survey data casts serious doubt whether age-1 CPH reflected the abundance, and thus recruitment, of largemouth bass at either lake. The high variability in hydrilla coverage combined with possible different capture efficiencies of age-1 and adult fish may have caused electrofishing estimates to misrepresent the population size of largemouth bass at both lakes. Electrofishing capture efficiency can vary greatly depending on plant coverage and other environmental factors (e.g. weather and fish size, Reynolds 1996; Bayley and Austin 2002). Years with high hydrilla coverage could have resulted in stable CPH rates due to fish in and around plants not being visible to biologists, even if overall abundance was higher. Alternatively, high coverage of hydrilla provides quality juvenile fish habitat throughout the lake. Stable CPH values in areas with plants could represent much higher lake-wide fish densities if fish are found throughout the macrophyte zones. Bonvechio et al. (2008) found that the two electrofishing sampling methods (fixed vs. standardized) referenced in the methods were not significantly different, so this was not likely a contributing factor to the patterns I observed.

Multiple studies have shown that largemouth bass recruitment increases with hydrilla coverage (Moxley and Langford 1985; Tate et al. 2003b) and/or other submersed aquatic macrophytes (Durocher et al. 1984), and the density of age-1 and older largemouth bass can decline with the removal or reduction of submersed aquatic vegetation (Bettoli et al. 1993). Both angler catch and effort increased with hydrilla coverage at Lake Tohopekaliga, suggesting that hydrilla ultimately may have increased abundance of adult largemouth bass. Bonvechio and Bonvechio (2006) also found a positive relationship between hydrilla coverage and electrofishing CPH at Lake Tohopekaliga. This presented several scenarios: first, that hydrilla had a positive effect on recruitment, similar to data seen in Tate et al. (2003b). Second, vulnerability of largemouth bass to angling may have increased significantly resulting in a greater portion of the fishery being caught and/or harvested in high hydrilla years. It is also possible that both scenarios contributed to some degree. There is another possibility that largemouth bass recruitment exhibits a non-linear relationship to hydrilla coverage, either showing little relationship until reaching a high enough level, or showing a strong relationship until reaching the carrying capacity of the system and an asymptotic recruitment ceiling. I believed the relationship seen in Tate et al. (2003b) was the most likely of these scenarios based on previous studies, and that the absence of relationships between hydrilla and age-1 electrofishing CPH and hydrilla coverage at my two study lakes was the result of sampling bias.

Some research shows that excessive hydrilla coverage may lead to decreased growth of adult largemouth bass. Colle and Shireman (1980) found decreased coefficients of condition for harvestable largemouth bass at >30% hydrilla coverage at Lakes Baldwin and Wales, Florida. Brown and Maceina (2002) found slower largemouth bass growth rates in a hydrilla infested arm of Lake Seminole, Georgia. This may be a function of decreased predation success for adult largemouth bass due to habitat complexity (Savino and Stein 1982). Bettoli et al. (1992) found that age-0 largemouth bass initiated piscivory at smaller sizes with decreasing submersed vegetation, leading to increased growth rates. Increased first-year growth of largemouth bass may contribute to increased adult standing stock (Gutreuter and Anderson 1985). I did not find, however, that mean age-1 TL was related to hydrilla coverage at Lake Tohopekaliga or Lake Kissimmee. There does appear to be a declining trend in age-1 TL following the 1995-1996 Lake Kissimmee drawdown (Figure 2-2), which may have been related to a declining trend in hydrilla (Figure 2-4), habitat changes resulting from the drawdown, or some other variable I did not account for. Bonvechio and Bonvechio (2006) also did not find any significant relationship between hydrilla coverage and largemouth bass growth at Lake Tohopekaliga from 1983 to 2002. Lakes Tohopekaliga and Kissimmee continue to enjoy outstanding reputations as trophy bass fisheries (Price 2009), indicating that growth decreases due to hydrilla coverage, if they exist, may not be a major concern for anglers or fishery managers at this time.

Unfortunately, I was unable to utilize aquatic plant species other than hydrilla for my analysis. Acreage estimates existed for only three species (hydrilla, water hyacinth and water lettuce) across all years of the study period, of which only hydrilla was abundant enough to likely have a discernable impact on fish habitat. Estimates of acreages for all plant species were only available in 1995 and 2003 at each lake. No estimates exist of total aquatic plant coverage on these lakes in any other years.

Because the underwater structure and complexity of aquatic plants differ across species, particularly between emergent and submersed species, I could not assume that any relationships between hydrilla and largemouth bass would hold true for all aquatic plants. Ideally, I would be able to isolate plant species by basic structural types across years; unfortunately the data available did not allow me to do so. However, in general hydrilla exhibits similar relationships with regard to largemouth bass reproduction and growth as other aquatic macrophytes (e.g. Wiley et al. 1984; Tate et al. 2003b; Bonvechio and Bonvechio 2006).

Water Levels

I found no significant largemouth bass population impacts related to water levels, however, water level fluctuations were much narrower than they would have naturally occurred due to regulation of the KCOL. Nevertheless, the current fluctuations (~1 m) represent a significant change in lake area due to the shallow depth of both lakes. For example, a rise in lake levels from 53 ft-NGVD to 54 ft-NGVD at Lake Tohopekaliga adds over 500 ha to the lake's area. Similarly, a rise from 51 ft-NGVD to 52 ft-NGVD at Lake Kissimmee adds nearly 1,200 ha to the lake's area. Identifying effects of future water level fluctuations on largemouth bass recruitment is a key need if the regulation schedule is changed at the KCOL.

It is difficult to isolate the effects of changes in water levels on largemouth bass recruitment at most Florida lakes due to confounding effects from high vegetation levels, particularly for examples similar to Lakes Tohopekaliga and Kissimmee with extremely variable levels of hydrilla coverage. Examples of mechanisms tying recruitment to water level changes exist (Miranda et al. 1984; Meals and Miranda 1991; Sammons et al. 1999), however, these studies dealt primarily with inundated terrestrial vegetation increasing habitat around reservoirs as water levels rose. In many Florida lakes, emergent, aquatic vegetation most often provides the additional habitat provided by rising water levels. The proportion of available habitat to lake area may be vastly different between these two distinct situations, as may be the width of the littoral zone due to shoreline gradients. Bonvechio and Allen (2005) attempted to isolate the effects of changing water levels on largemouth bass recruitment in Florida lakes. Their data likely provides the most similar impacts of certain water level changes on largemouth bass year-class strength at such lakes among all available studies.

Drawdowns

Moyer et al. (1995) and Allen et al. (2003) suggest that facilitated drawdowns may provide some benefits to largemouth bass populations, at least in the short term. My re-analysis of the 1987 Lake Tohopekaliga drawdown did not find any additional support for this conclusion, as I found no significant differences following the drawdown when exploring age-1 electrofishing CPH, mean age-1 TL, total electrofishing CPH or angler CPH. Additionally, I found no increase in age-1 CPH from the 2004 Lake Tohopekaliga drawdown. Overall, my analysis of the drawdown and muck removal projects at the KCOL indicates that benefits to largemouth bass populations can occur but tend to be short-term (e.g., within 2-4 years).

Similar to the nature of water level fluctuations described above, the relationships between lake drawdowns and largemouth bass recruitment may be difficult to distinguish from aquatic plant (specifically hydrilla) abundance. Drawdowns were used to mitigate the effects of lake succession (e.g. muck accumulation or tussock formation) which degraded habitat for desirable sportfish species. Additionally, drawdowns also reduced the volume of fluridone needed to apply whole-lake treatments in sufficient dilutions. Therefore, the positive effects of drawdowns (Moyer et al. 1995; Allen et al. 2003) on largemouth bass recruitment from improved emergent, littoral habitat in post-hydrilla invasion years may have been masked by a subsequent decrease in hydrilla coverage. Alternatively, because emergent, littoral aquatic plants provided a greater proportion of habitat in years before hydrilla invasion and expansion, post-drawdown effects on recruitment may have been more visible during that period. Regardless, drawdowns represent a significant habitat change when performed at KCOL lakes and appear to have affected largemouth bass populations in some instances. Exploring historical responses from previous drawdowns at the KCOL (Moyer et al. 1987; Moyer et al. 1988; Moyer et al. 1992; Moyer et al. 1993; Moyer et al. 1995; Allen et al. 2003) should provide the best estimate of their effects on largemouth bass recruitment.

Water Chemistry

The 2004 hurricanes (Hoyer et al. 2008) likely contributed to changes in water chemistry and plant communities in both lakes. Rainfall at Lake Tohopekaliga in these two months in 2004 was more than double the average level in the previous four years (92 cm vs. 38 cm, Hoyer et al. 2008). Excess runoff and erosion in the KCOL watershed may have caused a higher nutrient load than would have happened absent any hurricane impacts. Mean color (Pt-Co) increased at Lakes Tohopekaliga and Kissimmee from the 1996-2003 period to the 2004-2006 period. This color shift may have contributed to lowered hydrilla levels in 2004 and 2005 (Figure 2-4) at both lakes due to light limitations (Caffrey et al. 2007; Hoyer et al. 2008).

Secchi depth (as well as chlorophyll-a concentration, which often contributes to secchi depth) had an impact on aquatic macrophytes at the KCOL. I did not plan to model the effects of water chemistry and/or trophic state changes at the system, however, to isolate effects of other habitat change simulations. However, the potential for a major shift in trophic state in the future exists. Increasing trophic state may have little or no effect on largemouth bass abundance at Florida lakes due to their morphology (Keller and Chrisman 1990; Hoyer and Canfield 1996). As chlorophyll-a concentration increases beyond a certain point in a system, however, the lack of water clarity can prohibit germination of submersed and emergent aquatic macrophytes due to decreased light availability (Canfield et al. 1985). To make matters worse, the resulting lack of macrophytes can allow resuspension of particles from the lake substrate, further reducing clarity (Bachmann et al. 2005). This may result in a significant loss of habitat and a state of lowered largemouth bass abundance (Bachmann et al. 1999).

CHAPTER 3
LARGEMOUTH BASS POPULATION MODEL

Introduction

Here I utilized data compiled in Chapter 2 and constructed a computer model of the largemouth bass fisheries at Lakes Tohopekaliga and Kissimmee. This chapter addressed objectives 2: building a population model representing Lakes Tohopekaliga and Kissimmee and test its viability through comparison to historical data at both lakes and conduct sensitivity analyses, 3: exploring how management changes affecting habitat quality and quantity could potentially influence KCOL largemouth bass fisheries, and 4: identifying data gaps and future research needs for the largemouth bass fisheries at each lake to reduce overall model uncertainty.

Methods

Structure of the Model

I constructed an age-structured population model utilizing several factors that influence largemouth bass recruitment to explore the effects of various policy options on the largemouth bass fishery at the KCOL. I used previous studies and data from the KCOL whenever possible, but also used data from other lake systems in Florida to inform my model parameters. The model was age structured with a maximum age of 15 per methods in Beamesderfer and North (1995). I employed survival schedules, which were affected by natural, harvest and discard (i.e., catch and release) mortalities. The model used equilibrium recruitment to age-1 that was affected by multiple environmental parameters in each year. For the purpose of the model, I defined recruits as the number of fish which reached age-1 in the fishery each year. Parameters used in this model are summarized in Table 2-1 and described later in this chapter (*Parameters for the Model*).

Model structure

The model moved recruits through the population by age, and fish became vulnerable to fishing as they increased in length. The number of fish at each age a and year t ($N_{a,t}$) after year one was:

$$N_{a,t} = N_{a-1,t-1} * S_f \qquad \text{3-1}$$

where each cohort's population size was a function of its size in the previous year ($N_{a-1,t-1}$) and its survival rate in the fished condition (S_f), which included natural and fishing mortality. The number of fish at each age in year one ($N_{a,t=1}$) was:

$$N_{a,t=1} = {S_o}^{a-1} \qquad \text{3-2}$$

where S_o represented the natural survival rate. This age structure of an unfished condition allowed the model to establish a baseline population on which to apply equation 3-1 in subsequent years.

To account for natural and fishing mortalities, the survivorship function (S_f) included mortality due to harvest (U), mortality due to angler release ($U_o * D$) and natural mortality (M) per:

$$S_f = S_o(1 - U_t * V_{h\ a-1})(1 - (U_{ot} * V_{c\ a-1} - U_t * V_{h\ a-1})D) \qquad \text{3-3}$$

where S_o was equal to e^{-M}, representing fish survival from natural mortality. $V_{c\ a-1}$ and $V_{h\ a-1}$ represented the proportion of fish of that cohort in the previous year which were vulnerable to catch and harvest based on their length. The parameter U_o represented the fraction of the vulnerable population that was caught by anglers, and U was the fraction that was harvested by anglers. Minimum length limits could be simulated by setting V_c > V_h (described below). Discard mortality (D) was the mortality rate of fish which were caught and subsequently released back into the population. The use of U_o allowed the model to account for fish that were legal to harvest but voluntarily released by anglers. The last term ($(U_o * V_{c\ a-1} - U * V_{h\ a-1})D$) modeled deaths due to discard mortality for fish caught below the minimum length limit and those that were legal to harvest but were voluntarily released by anglers.

Recruitment (R_t) was the number of age-1 fish entering the population in a given year. This parameter is discussed in-depth in the following section. I defined adult population (N_t) as the number of fish age-2 and older present in a given year. Angler catch (C_t) was the number of largemouth bass caught (both harvested and released) by anglers in a given year:

$$C_t = \sum_{a=1}^{15} N_a V_{ca}\, U_{ot} \qquad \text{3-4}$$

where N_a represented the number of fish at a given age, V_{ca} represented the proportion of fish vulnerable to angling at a given age, and U_{ot} represented the proportion of vulnerable fish that were caught by anglers in a given year. The number of fish harvested (H_t) by anglers in a given year was:

$$H_t = \sum_{a=1}^{15} N_a V_{ha}\, U_t \qquad \text{3-5}$$

where V_{ha} represented the proportion of fish vulnerable to harvest at a given age (based on a legal minimum length limit) and U_t represented the total fishing mortality rate due to harvest in a given year.

Excessive hydrilla coverage can make boating difficult to the point that it discourages boating anglers from fishing. Colle et al. (1987) found that hydrilla coverages greater than 80% caused an 85% reduction in angler effort at Orange Lake, Florida. Therefore, for years (t) in which hydrilla coverage was greater than 80% in the model (hydrilla never exceeded 80% at either lake (Figure 2-4), therefore this function was applied to the management scenario simulations and did not affect the reliability analysis which used historical data), I accordingly reduced the values of H_t and C_t derived from formulas 3-4 and 3-5 by 85% to represent a reduction in angler effort.

Fish exhibit increased vulnerability to recreational angling as they increase in size. I used a logistic function to model the proportion of each cohort that was vulnerable to angler catch (V_c):

$$V_c = \frac{1}{1+e^{-\left(L_a - \frac{L50}{\sigma L\,50}\right)}} \qquad 3\text{-}6$$

where L_a was the mean length at age of each cohort in a given year, L_{50} was length at 50% vulnerability and σL_{50} was the approximate standard deviation around that length.

Size limits can change the vulnerability of fish to harvest independent of their vulnerability to catch. Fish may be highly vulnerable to catch yet not legal to harvest if the legal length limit is higher than the value for L_{50}. I estimated the proportion of each cohort that was vulnerable to angler harvest (V_h) as:

$$V_h = \frac{1}{1+e^{-\left(L_a - \frac{LL}{\sigma LL}\right)}} \qquad 3\text{-}7$$

where LL was the minimum legal length limit and σLL was the approximated standard deviation around that length limit.

I used a von Bertalanffy growth function to estimate the mean length of fish in each cohort (L_a) at a given age. This growth function was:

$$L_a = L_\infty(1 - e^{-K*(age - t_o)}) \qquad 3\text{-}8$$

utilizing the parameters L_∞ (asymptotic length), K (von Bertalanffy growth parameter), *age* (yrs) and t_o (theoretical age at which length=0).

Modeling recruitment

The model included three separate types of habitat factors that I expected to influence largemouth bass recruitment. The first was hydrilla, which as discussed in Chapter 2 can substantially influence largemouth bass recruitment. Secondly, changes in seasonal or annual water levels can increase available foraging and/or spawning habitat for largemouth bass and contribute to increases in recruitment (Miranda et al. 1984; Meals and Miranda 1991; Sammons et al. 1999; Bonvechio and Allen 2005). The third habitat factor included in the model concerned lake drawdowns. Six major drawdowns were implemented on the two study lakes since regulation began (1971, 1979, 1987 and 2004 at Tohopekaliga and 1977 and 1995-96 at Kissimmee), and these practices will likely continue to be a part of management at the KCOL in the future.

Recruitment to age-1 in each year in the model was influenced by each habitat condition (i.e. annual hydrilla coverage, water level changes, and drawdown occurrence). I set an equilibrium recruitment value (R_o) for each lake, then altered this value by applying multiplier functions representing the effects of the three habitat parameters (i.e., hydrilla, water level, and drawdowns). I did not believe that I could separate the contributions of changes in hydrilla coverage and changes in water levels since these can be interrelated (e.g., Tate et al. 2003b). Assuming no changes in water clarity, lowered water levels would allow additional hydrilla to colonize new areas due to increased light availability, and thus, these factors may be mitigating for one another. Therefore, I used the scaling parameters A_{yh} and A_{yw} , based on relationships in Tate et al. (2003b), to weight the effects of hydrilla coverage (Y_{hdev}) and water level changes (Y_{wdev}), respectively, on largemouth bass recruitment. I did not weight the effects of drawdowns on recruitment (Y_{ldev}) because the model treated drawdowns as distinct, separate events which I evaluated independent of the influence of the other recruitment factors. Recruitment in the model included the three habitat functions as:

$$R_t = R_o\left(Y_{hdev} * A_{yh} + Y_{wdev} * A_{yw}\right)Y_{ldev} \qquad \text{3-9}$$

where R_t was recruitment in year t. The three habitat parameters (Y_{hdev}, Y_{wdev} and Y_{ldev}) were allowed to vary stochastically based on expected inter-annual variation to simulate across-year changes in habitat conditions at the lakes. Thus, they were all random variables that were selected based on the mean and standard error of relationships described below. The value of Y_{hdev} was lognormally distributed with a mean of Y_h and a standard deviation of σY_h (hydrilla recruitment function), and Y_{wdev} was lognormally distributed with a mean of Y_w and a standard deviation of σY_w (water level recruitment function). The drawdown parameter Y_{ldev} was a binomial function of the probability of the drawdown returning a benefit in a given year (B_p) given the mean scale (B) and associated standard deviation (σB) of benefits that did occur. This binomial function allowed the model to first determine whether a benefit occurred in a given year (dependent upon the amount of time elapsed since the last drawdown), then estimated the relative value of that benefit if it did occur. Empirical relationships used as the basis for each of these recruitment parameters are described below.

Parameters for the Model

I summarized all input parameters for the model in Table 3-1. I attempted to use values observed at the KCOL, but where this was not possible I used values from other lake systems in Florida.

Recruitment

Hydrilla. Tate et al. (2003b) found relationships between hydrilla PAC and age-0 largemouth bass abundance at Orange and Lochloosa Lakes, Florida. They employed fixed electrofishing transects and found them to be more precise in detecting changes in abundance of both juvenile and adult largemouth bass than block net sites treated with rotenone (Tate et al. 2003a). I created a relative recruitment value for each data point from Tate et al. (2003b) by dividing each year's catch per hour of age-0 bass by each lake's median catch per hour of age-0 bass over the study period. I then fitted a nonlinear model to determine the relationship between relative recruitment strength (Y_h) and hydrilla PAC from Tate et al. (2003b) and found a function of:

$$Y_h = 0.39577e^{0.03445*PAC} \quad \text{3-10}$$

This relationship ($r^2 = 0.63$, $P < 0.01$) had a standard deviation (σY_h) of 3.259 and is depicted in Figure 3-3.

Water levels. I used data from another Florida study (T. Bonvechio, unpublished data, from Bonvechio and Allen 2005) to evaluate how water levels would influence largemouth bass recruitment. Bonvechio and Allen (2005) found that year-class strength was positively related to maximum fall water levels at Lake Bonny and Crooked Lake, Florida. I scaled the residuals by adding one for each year-class, such that an average year from the catch curve represented a one for a relative recruitment value. To quantify the percent change in fall water levels I divided each year's maximum fall water level by the average maximum fall water level over the study period at each lake. A regression on relative recruitment value (Y_w) and the percent change in fall water levels (WLC) from Bonvechio and Allen (2005) showed a relationship of:

$$Y_w = 0.3253(WLC) + 1 \qquad 3\text{-}11$$

This relationship ($r^2 = 0.59$, $P < 0.01$) had a standard deviation (σY_w) of 0.420 and is depicted in Figure 3-4.

Scaling parameters. I used information from Tate et al. (2003b) to model the relative influence of hydrilla coverage and maximum fall water level on recruitment. Tate et al. (2003b) found that hydrilla accounted for 47% and summer water levels accounted for 29% of variation in age-0 largemouth bass abundance at Orange Lake, FL. Hydrilla showed a positive relationship and summer water levels showed a negative relationship to age-0 abundance using the model:

$$\text{Mean CPH} = 182.9 + 0.166(\text{hydrilla}) - 2.96(\text{summer level}) \qquad 3\text{-}12$$

Because hydrilla accounted for approximately double the influence of water level changes on recruitment in Tate et al. (2003b), I conservatively weighted Y_{hdev} and Y_{wdev} using $A_{yh} = \frac{2}{3}$ and $A_{yw} = \frac{1}{3}$ for Equation 3-9. This procedure allowed recruitment in the model to vary as a function of hydrilla and water level conditions simultaneously.

Drawdowns. To determine the effects of drawdowns on recruitment, I analyzed data from Chapter 2 as well as Florida FWC reports (Moyer et al. 1987, Moyer et al. 1988, Moyer et al. 1992 and Moyer et al. 1993) for all of the six drawdowns at Lakes Tohopekaliga and Kissimmee. Some drawdowns performed at the KCOL provided a net recruitment benefit to largemouth bass in subsequent years, while others did not. I used the drawdown data to determine a) the probability that a recruitment benefit in a given year would occur, and b) the magnitude of benefits should they occur. I used the values in Table 3-2 showing the probability of a net recruitment benefit in years 1-4 following a drawdown to determine the value of B_p (final row of table) for those years. After year 5, I assumed no benefit to recruitment from drawdowns as I saw no evidence of benefits occurring after year 4 post-drawdown. While long-term benefits to recruitment are certainly possible, their likelihood appears to be low enough as to be negligible to the model output. I also determined the average scale (B) and associated standard deviation (σB) of each benefit that occurred based on the quantitative measurements summarized in Table 3-2. I found the average benefit scale was approximately 2.853 with a standard deviation of 0.730 for drawdowns that showed a positive effect on largemouth bass recruitment.

Mortality and survival

Based on Jensen's (1996) transformation of the von Bertalanffy K-parameter, I used the instantaneous natural mortality rate of M = 0.4551. This M resulted in a natural survival rate (S_o) of 0.63. This was similar to an estimate of M = 0.49 for largemouth bass across multiple lakes in the United States (Allen et al. 2008).

The fishing mortality rate was not known at either lake. I reconstructed a predicted annual harvest mortality rate (U), referenced for accuracy by Allen et al. (2008) which gave the current national average of 0.18. My estimate for annual total capture rate (U_o) was based on a study at Rodman Reservoir, Florida by Henry (2003) where approximately 40% of largemouth bass in the fishery were captured annually by anglers. I scaled these values of U and U_o in each year at both lakes using the creel survey data by scaling the reference value for total annual capture rate to that year's angler effort. I divided bass fishing effort (angler hours) in a given year by the median effort at that lake over the study period to find a relative effort value (>1 represented relatively high effort, <1 represented relatively low effort). I then multiplied this value by the reference value (U_o = 0.4; Henry 2003) to determine U_{ot}. Therefore, I made the assumption that a year experiencing an effort level equal to the median value would have a value of U_o = 0.40. I then determined the proportion of angler-caught fish that were harvested in each year based on creel estimates. To obtain a predicted value for U_t, I multiplied that year's proportion of captured fish that were harvested by that year's angler capture rate (U_{ot}). Figure 3-1 summarizes these values through the time series at both lakes. I used an estimate of $D = 0.1$ for all years based on a summary of largemouth bass discard mortality rates in Wilde and Pope (2008).

Voluntary release of largemouth bass showed an increasing trend over the past 20 years and release rates differed between Lakes Tohopekaliga and Kissimmee (Myers et al. 2008). I informed the current values of U and U_o for the purposes of model simulation from the average of their final four estimates at each lake from Figure 3-1 (2004-2007 at Lake Tohopekaliga and 2003-2006 at Lake Kissimmee). As these values were relatively variable from one year to another, simply using an estimate from the final year of the study period would not necessarily be representative of the lake in most years going forward. I made the assumption that total angler capture rate and fishing mortality rate will not significantly change from their current levels in the foreseeable future. Myers et al. (2008) stated that angler release rate increases were linear at Lakes Tohopekaliga and Kissimmee and therefore had the potential to continue increasing. My estimates of harvest proportion in Figure 3-1, however, suggest that this trend has reached an asymptote in recent years and is not likely to substantially increase.

Vulnerability

I approximated a length at 50% vulnerability (L_{50}) to catch of 300 mm and a standard deviation (L_{50}) of 10% of the parameter value based on the minimum quality length value for a proportional stock density index (Anderson and Neumann 1996). I used 356 mm as the legal length limit (LL) and an approximated standard deviation (σLL) as 10% of the length limit. This is the legal limit (14 inches) imposed on the KCOL largemouth bass fishery by the Florida Fish and Wildlife Conservation Commission. Figure 3-2 shows both of these vulnerability functions and their relationship to one another.

Growth, length and weight

I obtained von Bertalanffy growth parameters ($L\infty, K, t_o$) for the model from unpublished data used in a study of Lake Tohopekaliga (Bonvechio and Bonvechio 2006). I chose to use a relatively recent estimate for growth, as changes in lake habitat and trophic state over time may have altered growth in either lake. Nutrient levels (e.g. nitrogen, phosphorous and chlorophyll-a) showed a declining trend while secchi depth increased at Lake Tohopekaliga between 1983 and 2002 (Bonvechio and Bonvechio 2006). Among recent estimates, I used parameters from 2001, as that year had the largest sample size (n = 793) of largemouth bass among von Bertalanffy growth curves created for 2001-2003 and I believed this likely provided the most robust estimate of the three sets of parameters.

Performance of the Model Relative to Historic Trends

To test the model's ability to replicate historical trends, I employed historical data from Lakes Kissimmee and Tohopekaliga to use as inputs for the habitat variables. I compared catch and harvest outputs from the model to annual estimates at each lake from creel surveys performed by FWC.

I estimated R_o at each lake (Table 3-1) by removing the variability in the habitat parameters and minimizing the sum of squared errors between my estimated catch and the observed catch from the creel surveys. This exercise allowed use of an initial recruitment value that brought the model-predicted values of catch and harvest to the same scale as creel-estimated catch and harvest for comparison. The initial year of the model utilized an equilibrium population in the fished condition (as modeled by Equation 3-3). I then performed a Monte Carlo simulation for both harvest and catch at each lake, utilizing 1,000 iterations of the model employing average values for hydrilla coverage, maximum fall water levels and drawdowns that mimicked the observed data from 1983-2006. Each of these habitat variables contained uncertainty from their respective data sources based on the standard deviation of each relationship. I then assessed whether the observed data remained within the estimated 95% confidence intervals from the model output to gauge the model's feasibility.

I defined 1990 as t-0, allowing seven years (approximately one half of the age range in the model) as a burn-in period to allow the model to account for variation and come to equilibrium. Ideally, I would have used the entire age range (15 years) to burn the model in; however, this would have left me only ten years for comparison of the model outputs to observed data. As there was no stock-recruit relationship built into the model which depended on increased egg contribution from older (larger) fish, the relatively small remaining number of these older fish shouldn't contribute significant error to the model outputs. Therefore, I decided that having an increased range of years with which to judge the model's reliability took precedence over ensuring the model came to full equilibrium.

Simulated Policy Scenarios

I simulated multiple policy scenarios at both lakes to explore how potential habitat changes from management of hydrilla, changes in water levels, and varying intervals between drawdowns could influence the largemouth bass populations at each lake. I based each of these changes on potential shifts in these habitat variables from planned or likely policies for future management, or, in the case of hydrilla management, theoretical scenarios whereby managers could once again actively control large-scale hydrilla coverage (e.g. though herbicide applications).

I used the model to explore how largemouth bass recruitment, adult abundance, catch and harvest may respond to six potential management options related to hydrilla coverage, water levels, and drawdown frequency at Lake Tohopekaliga . Because managers would not likely achieve exact targets for hydrilla coverage or water stage in a given year, the annual values in each year of the simulations varied around a specific mean and standard deviation depending on the management scenario. The value for PAC (hydrilla) in each year (applied from equation 3-10) was lognormally deviated with a specific mean and standard deviation and a maximum of 100%. The value for WLC (maximum fall water level change) in each year (applied to equation 3-11) was normally deviated with means and standard deviations representing each scenario to simulate climactic variability. I used these habitat variables in six different combinations (baseline, high hydrilla, managed hydrilla, hydrilla eradication, eradication and fluctuations, eradication and drawdowns, Table 3-3). The baseline scenario assumed current hydrilla levels (mean and standard deviation of 1998-2007 values), water level fluctuations (mean and standard deviation of 1983-2007 values) and a 20-year drawdown interval, a likely estimate for drawdown intervals in the future (the last two drawdowns at Lake Tohopekaliga were 17 years apart). The high hydrilla scenario assumed no control of hydrilla and a higher than current level in the future. The managed hydrilla scenario assumed a future control method that will allow managers to maintain moderate (~20%) coverages. The hydrilla eradication scenario assumed a potential control method (e.g. grass carp *Ctenopharyngodon idella*) that eliminated hydrilla completely from the lake. The eradication and fluctuations scenario assumed elimination of hydrilla and a flow regime that allowed for additional fluctuations based on a potential future management regime at Lake Kissimmee (Lawrence Glenn, SFWMD, personal communication). This new flow regime is not likely to be implemented at Lake Tohopekaliga in the near future, as private holdings along the shoreline will prevent water levels that are higher than full pool, but I included it for informational purposes as a theoretical mitigation technique for hydrilla eradication. The eradication and drawdowns scenario simulated a five-year interval for drawdowns combined with hydrilla elimination. Again, it is unlikely that drawdowns will be implemented this frequently at Lake Tohopekaliga due to cost, but I included the scenario for informational purposes.

I used the same six scenarios at Lake Kissimmee as at Lake Tohopekaliga (above), along with a seventh scenario (fluctuations) utilizing baseline hydrilla and drawdown values but allowing for much larger fluctuations pursuant to future plans for flow regimes at the lake (Lawrence Glenn, SFWMD, personal communication). The seven management options at Lake Kissimmee are summarized in Table 3-4. The baseline scenario again assumed current hydrilla levels (mean and standard deviation of 1998-2005 values), water level fluctuations (mean and standard deviation of 1983-2007 values) and a 20-year drawdown interval, a likely estimate for drawdown intervals in the future (the last two drawdowns at Lake Kissimmee were 19 years apart). The hydrilla values I used were considerably lower at Lake Kissimmee than similarly-named scenarios at Lake Tohopekaliga. The maximum depth of submersed macrophyte colonization is affected primarily by light availability (Caffrey et al. 2007). Due to its larger size and resulting greater depth and lower light availability in many areas of the lake bed, hydrilla PAC tended to be lower in the past and will likely remain lower in the future at Lake Kissimmee than at Lake Tohopekaliga.

For each scenario, I performed Monte Carlo analyses utilizing 1,000 iterations of the model for all 50 years. I determined the mean value as well as upper and lower 95% confidence intervals for recruitment (number of age-1 fish), adult (age-2+) population size, predicted catch and predicted harvest. This approach provided both the equilibrium predictions (mean) and the uncertainty across years (confidence intervals) for each scenario, which accounted for effects of habitat variability across years.

Sensitivity Analysis

I performed a sensitivity analysis on a range of model parameters to determine their relative influence on model predictions of total largemouth bass population and total angler catch. I increased M, U_t, U_{ot}, D, L_{50}, LL, $L\infty$, K, t_o, Y_{hdev} and Y_{wdev} by 10% individually, while leaving all remaining parameters set at baseline values for Lake

Tohopekaliga. I then determined the percent change in total population and total angler catch between the altered parameter output and the baseline output. The choice to use a 10% change was an arbitrary one, as it simply allowed me to determine the elasticity of the model output based on changes in a given parameter.

Results

Performance of the Model Relative to Historical Trends

The model performed reasonably well for predicting past trends at both lakes. Observed estimates of catch and harvest from both lakes were within the 95% confidence intervals of the predicted values with few exceptions at Lake Tohopekaliga, where harvest was slightly above the 95% confidence interval in 2002 and slightly below it in 2006 (Figure 3-5). Catch was slightly below the 95% confidence intervals in 2005-2007 (Figure 3-5). Observed estimates were within the confidence intervals in all but one instance at Lake Kissimmee, where observed harvest slightly exceeded the upper 95% confidence limits in 1991 (Figure 3-6). The predicted mean values of both catch and harvest at Lake Kissimmee also showed very similar trends throughout the study period. These results suggested that the model was capable of producing largemouth bass population trends that were similar to the observed data at both lakes in most years.

Simulated Policy Scenarios

I used largemouth bass recruitment and total angler catch as response metrics to depict effects of each of the management scenarios on the largemouth bass populations at each lake. More detailed analyses of scenario simulations can be found in Appendix A describing effects on adult population, recruitment, angler catch and angler harvest. Effects across all four largemouth bass fishery metrics were relatively similar within each scenario.

Lake Tohopekaliga

Largemouth bass recruitment and angler catch demonstrated the greatest positive response to the high hydrilla scenario (Figures 3-7b and 3-8b). Under this scenario the model predicted a 119% increase in mean recruitment and a 64% increase in mean total angler catch compared to the baseline scenario. The baseline scenario (Figures 3-7a and 3-8a) represented the second-highest values for each metric. The other four scenarios (Figures 3-7c-f and 3-8c-f) appeared to be relatively similar to one another for each measurement and were all lower than the high hydrilla or baseline scenarios. The eradication scenario (Figures 3-7d and 3-8d) had the lowest potential of all scenarios. This scenario predicted 55% lower mean recruitment and 52% lower mean catch than the baseline scenario. Thus, maintaining the current-day management regime or increasing hydrilla coverage were the best predicted policies for the largemouth bass fishery at this system.

Lake Kissimmee

Similarly, largemouth bass recruitment and total angler catch at Lake Kissimmee demonstrated the greatest positive response to the high hydrilla scenario (Figures 3-9c and 3-10c), however, these values were not as clearly separated from the other scenarios as at Lake Tohopekaliga. The high hydrilla option predicted a 69% increase in mean recruitment and a 69% increase in mean total catch over the baseline scenario. However, at this system other management regimes (fluctuations, eradication and drawdowns, and eradication and fluctuations) also increased fishery metrics over the baseline scenario (Figures 3-9 and 3-10), suggesting that future management actions not including hydrilla presence and/or expansion could improve the largemouth bass fishery at this lake. The hydrilla eradication scenario displayed 17% lower mean recruitment and 18% lower mean total catch than the baseline scenario.

Sensitivity Analysis

The sensitivity analysis identified the model parameters most likely to influence the predicted values. Natural mortality (M), length at 50% vulnerability to catch (L_{50}), and asymptotic length ($L\infty$) all displayed a change greater than 10% sensitivity for total angler catch (Table 3-5) with a 10% increase in the baseline value, indicating that these parameters had a high level of elasticity their estimations required the most accuracy among all parameters to provide the most accurate model outputs. The value of L_{50} showed the greatest sensitivity, displaying an increase in catch approximately 18% higher than baseline levels with a 10% increase. This parameter only showed a 0.4% sensitivity to total largemouth bass population, however, because the vulnerability of largemouth bass to angling has a more direct impact on total catch given the relatively low fishing mortality rates in the model scenarios. All other parameters displayed changes below 10% sensitivity. Resource managers should insure that estimates of natural mortality and growth parameters be measured with precision in future analyses, as these will have the greatest influence model output.

Table 3-1. Parameters used in the simulation model and associated values.

Parameter	Description	Value	Source
Natural Mortality			
M	Instantaneous adult natural mortality (yr^{-1})	0.4551	Jensen (1996)
Fishing Mortality			
U	Annual harvest exploitation rate (Tohopekaliga)	0.107	FWC creel surveys
	Annual harvest exploitation rate (Kissimmee)	0.104	FWC creel surveys
U_o	Annual capture rate (Tohopekaliga)	0.466	FWC creel surveys
	Annual capture rate (Kissimmee)	0.290	FWC creel surveys
D	Discard mortality rate	0.1	Wilde and Pope (2008)
Vulnerability			
L_{50}	Length at 50% capture vulnerability (mm)	300	Anderson and Neumann (1996)
σL_{50}	Standard deviation of 50% capture vulnerability	30	
LL	Length at 50% harvest vulnerability (mm)	356	FWC Reg.
σLL	Standard deviation of 50% harvest vulnerability	35.6	
Growth			
L_∞	Asymptotic length (mm)	522.4	Bonvechio and Bonvechio (2006)
K	Von Bertalanffy growth parameter	0.3034	
t_o	Age at length=0 (yrs)	-0.1884	
Recruitment			
R_o	Equilibrium annual recruitment (Tohopekaliga)	75,044	Model fitting
	Equilibrium annual recruitment (Kissimmee)	91,037	Model fitting

Table 3-2. Summary of the influence of lake drawdowns on largemouth bass recruitment to age-1. Table indicates presence, absence and scale of net recruitment benefits to largemouth bass following drawdowns at Lakes Tohopekaliga and Kissimmee. In years where a quantitative benefit was measured, scale of the benefit is listed. Years where a benefit was only qualitatively observed in literature are noted with “Y.” Years where no significant benefit was observed are noted with “N.” Data were obtained from multiple Florida Fish and Wildlife Conservation Commission reports and raw data.

Drawdown	Year 1	Year 2	Year 3	Year 4
Tohopekaliga				
1971	Y	Y	Y	N
1979	3.0	3.0	N	N
1987	N	3.26	2.14	N
2004	N	N	N	N
Kissimmee				
1977	Y	Y	Y	N
1995-96	N	2.27	4.14	2.16
Summary				
# of Net Benefits	3	5	4	1
Prop. with Net Benefits	0.500	0.833	0.667	0.167

Table 3-3. Scenarios for model simulations at Lake Tohopekaliga. Values for hydrilla are in percent area covered (PAC) and values for water level deviations are the change (feet) from mean maximum fall water levels.

Scenario	Hydrilla (PAC)		Water level change (feet)		Drawdown interval (years)
	Mean	SD	Mean	SD	
Baseline	53	17.5	<0.01	<0.01	20
High hydrilla	75	10	<0.01	<0.01	20
Managed hydrilla	20	5	<0.01	<0.01	20
Hydrilla eradication	0	0	<0.01	<0.01	20
Eradication and fluctuations	0	0	1.0	0.2	20
Eradication and drawdowns	0	0	<0.01	<0.01	5

Table 3-4. Scenarios for model simulations at Lake Kissimmee. Values for hydrilla are in percent area covered (PAC) and values for water level deviations are the change (feet) from mean maximum fall water levels.

Scenario	Hydrilla (PAC)		Water level change (feet)		Drawdown interval (years)
	Mean	SD	Mean	SD	
Baseline	13	6.8	<0.01	<0.01	20
Fluctuations	13	6.8	1.0	0.2	20
High hydrilla	40	10	<0.01	<0.01	20
Managed hydrilla	7	5	<0.01	<0.01	20
Hydrilla eradication	0	0	<0.01	<0.01	20
Eradication and fluctuations	0	0	1.0	0.2	20
Eradication and drawdowns	0	0	<0.01	<0.01	5

Table 3-5. Sensitivity analysis testing how +10% changes in parameter values cause a percent change in total largemouth bass population and total angler catch at Lake Tohopekaliga relative to baseline estimates.

Parameter	Total Population		Angler Catch	
	Value	% Change	Value	% Change
Baseline	339,146	N/A	55,409	N/A
M	319,522	-5.8	46,349	-16.4
U_t	338,274	-0.3	55,104	-0.6
U_{ot}	338,544	-0.2	60,617	9.4
D	338,634	-0.2	55,139	-0.5
L_{50}	340,483	0.4	45,667	-17.6
LL	341,931	0.8	56,430	1.8
$L\infty$	334,977	-1.2	63,031	13.8
K	317,164	-6.5	51,950	-6.2
t_o	338,635	-0.2	56,630	2.2
Y_{hdev}	367,317	8.3	60,132	8.5
Y_{wdev}	344,890	1.7	56,226	1.5

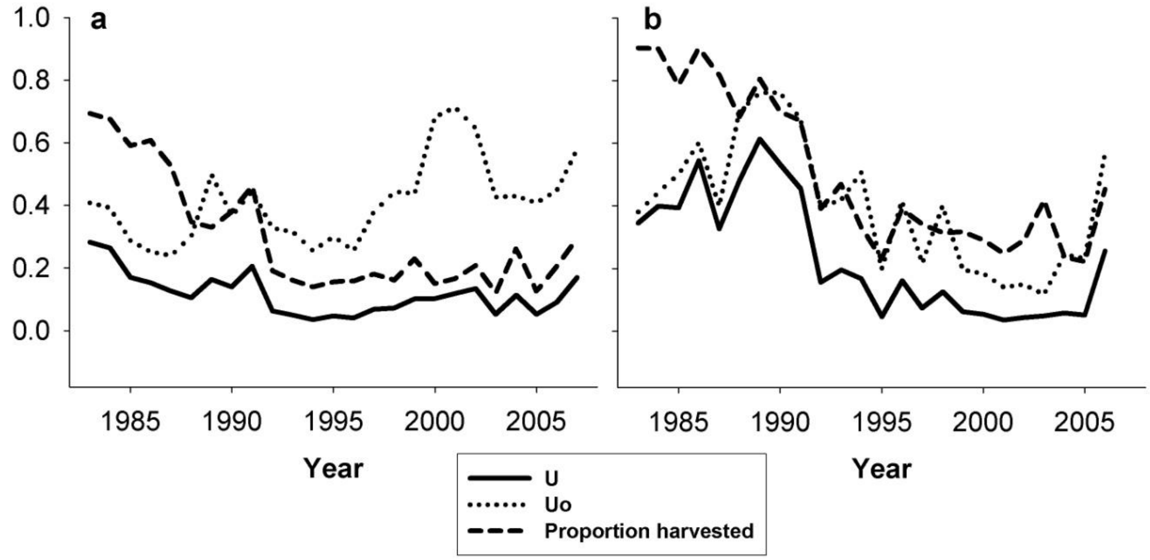

Figure 3-1. Predicted fishing mortality (U) and total catch (U_o) rates (recreated using a median reverence value and effort estimates) and proportion of angler-caught fish that were harvested at Lakes Tohopekaliga (a) and Kissimmee (b) from 1983-2007. Data are estimated from literature values of U and U_o combined with Florida Fish and Wildlife Conservation Commission creel survey results.

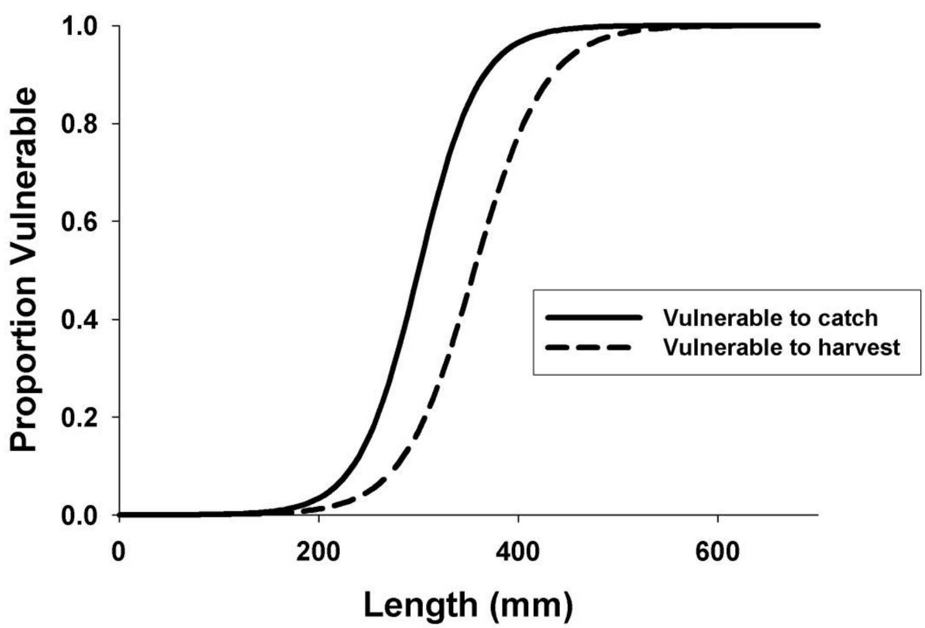

Figure 3-2. Predicted proportion of largemouth bass vulnerable to angler catch and harvest at given lengths.

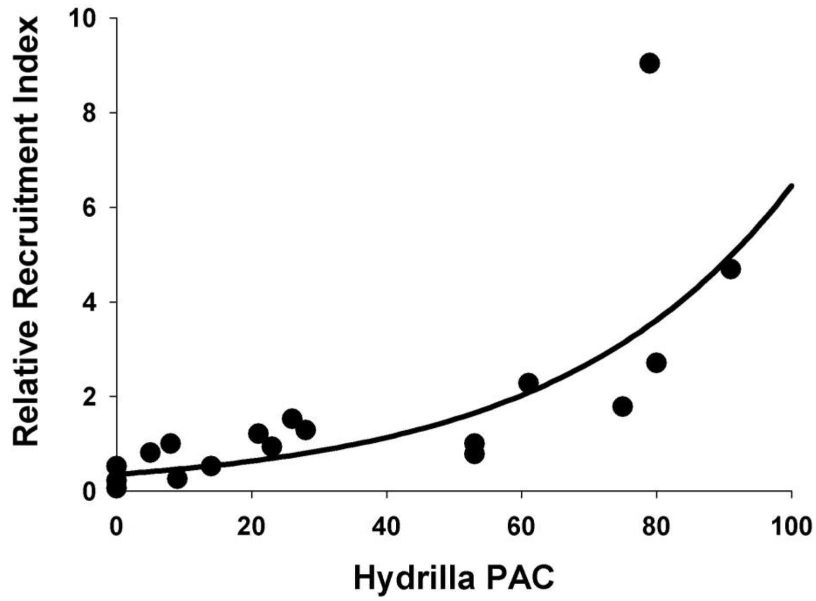

Figure 3-3. Least squares analysis of relative recruitment strength as a function of hydrilla abundance (PAC) at Orange and Lochloosa Lakes, Florida. Data were obtained from Tate et al. (2003).

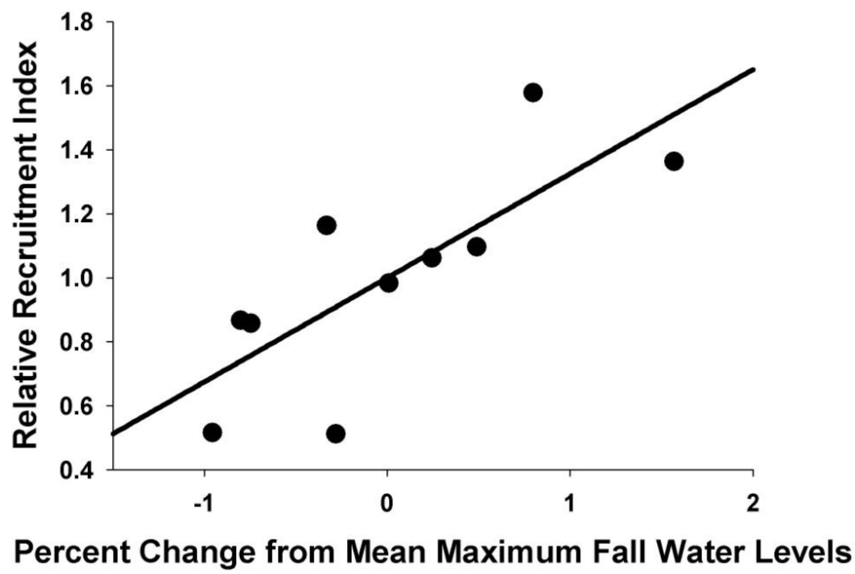

Figure 3-4. Regression of relative recruitment strength as a function of percent change in fall water levels at Lake Bonny and Crooked Lake, Florida. Data were obtained from unpublished data used in Bonvechio and Allen (2005).

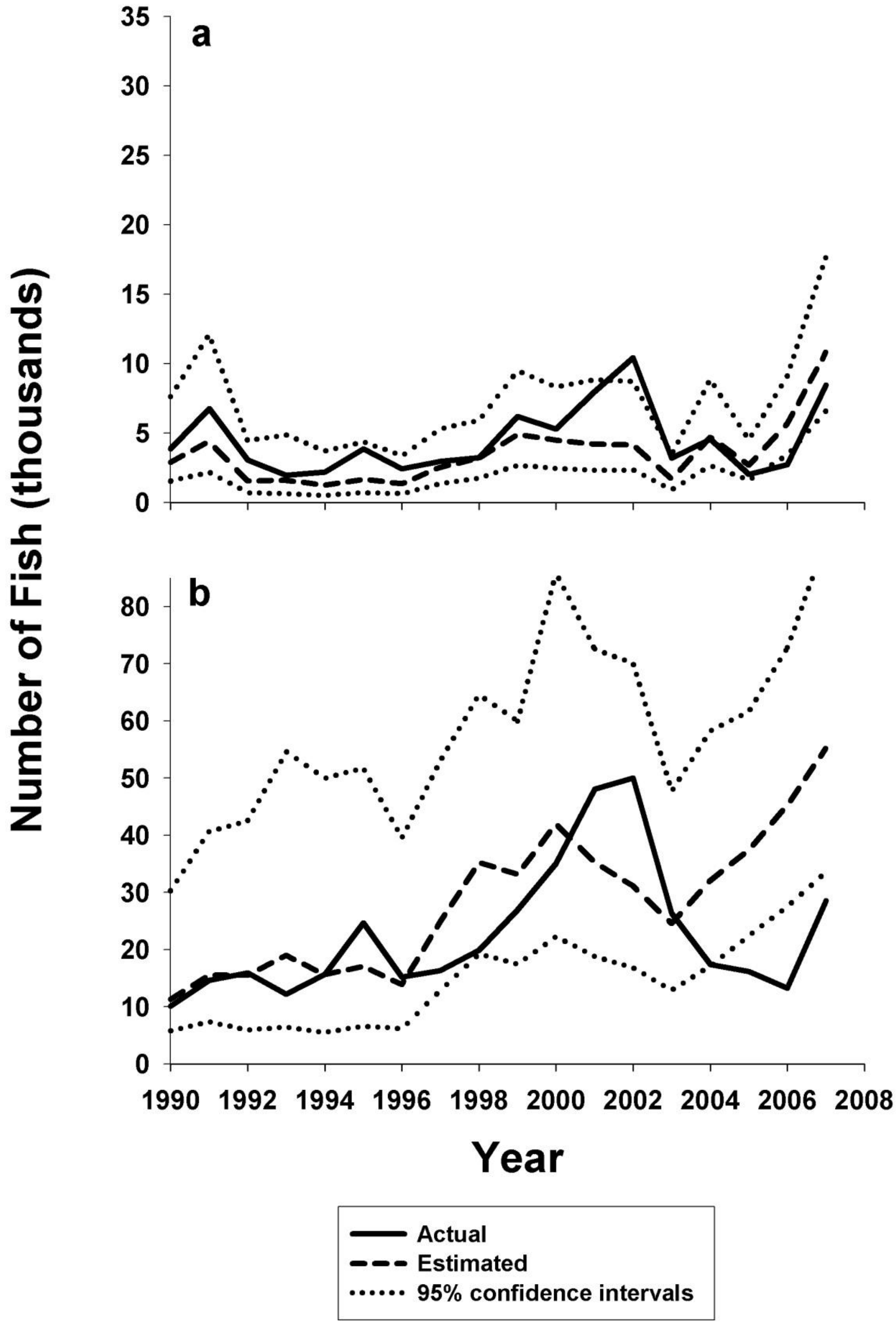

Figure 3-5. Observed and model-predicted (with 95% confidence intervals) harvest (a) and catch (b) at Lake Tohopekaliga from 1983-2008. The observed data represent FWC creel survey estimates. Predicted values and 95% confidence intervals are from model runs of 1,000 iterations.

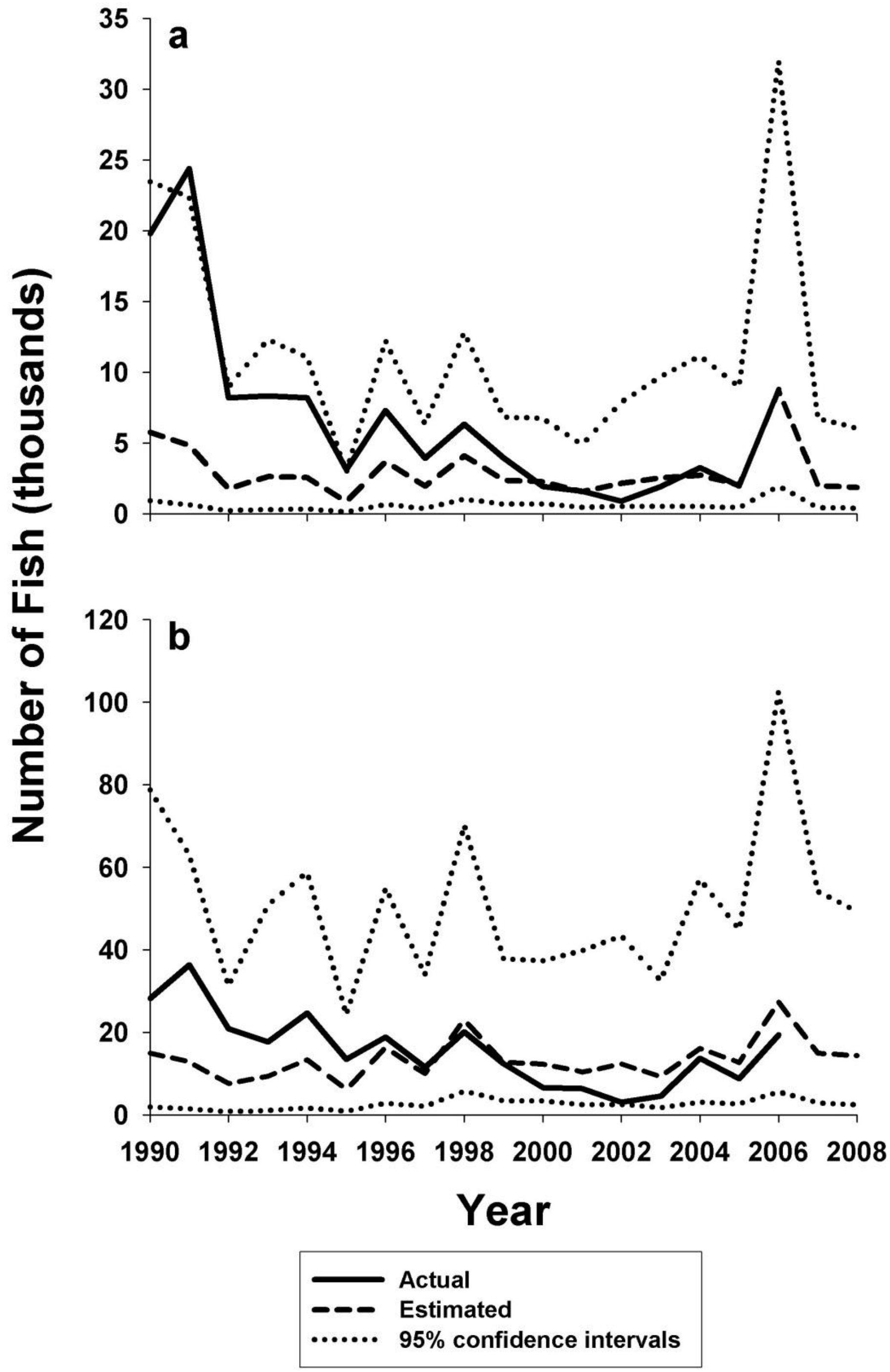

Figure 3-6. Observed and model-predicted (with 95% confidence intervals) harvest (a) and catch (b) at Lake Kissimmee from 1983-2008. The observed data represent FWC creel survey estimates. Predicted values and 95% confidence intervals are from model runs of 1,000 iterations.

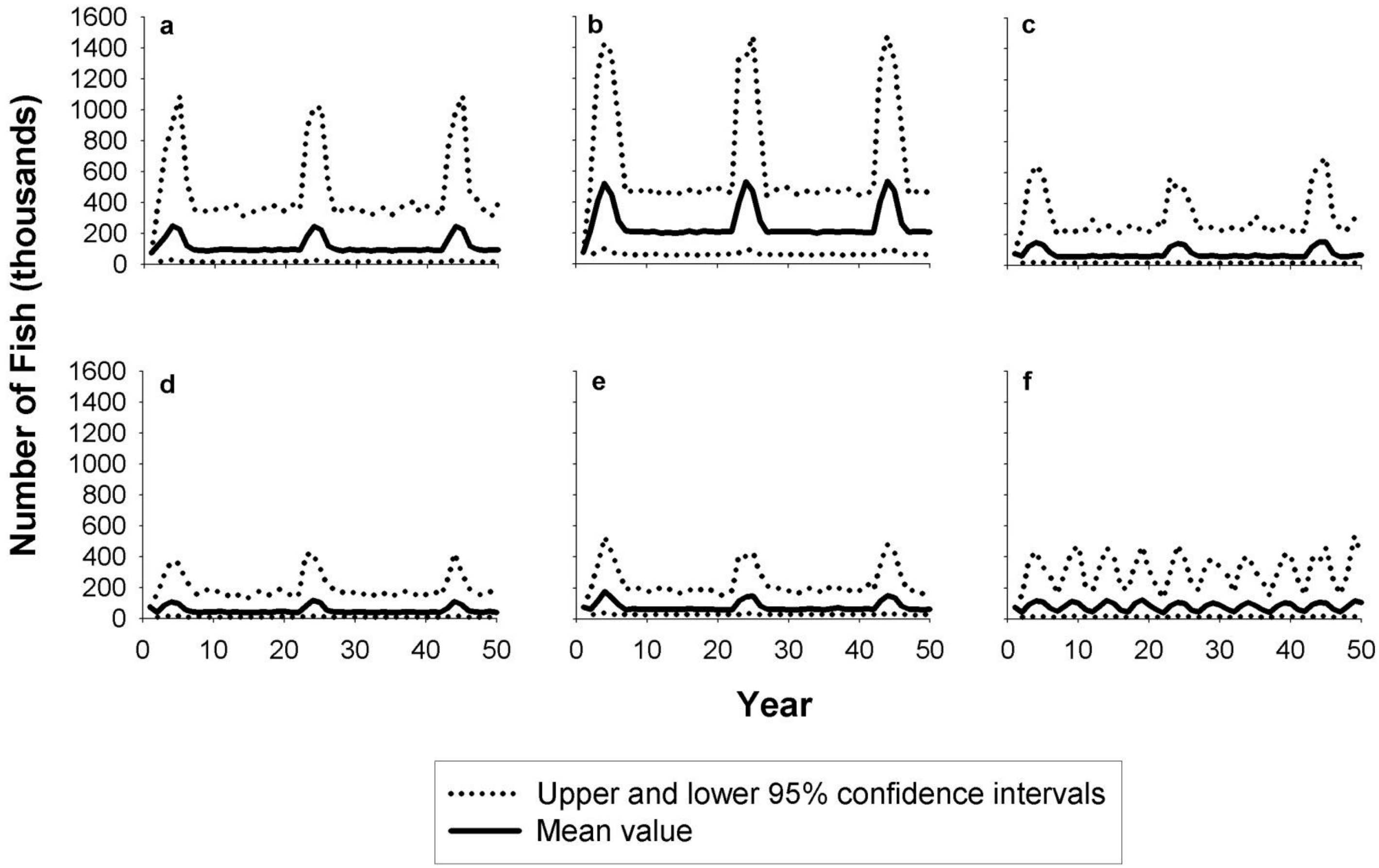

Figure 3-7. Model-predicted recruitment (age-1) of largemouth bass for six different management scenarios at Lake Tohopekaliga based on a Monte Carlo analysis utilizing 1,000 iterations over 50 years. Scenarios pictured are Baseline (a), High hydrilla (b), Managed hydrilla (c), Hydrilla eradication (d), Eradication and fluctuations (e), and Eradication and drawdowns (f). Solid lines represent mean values and dotted lines represent upper and lower 95% confidence intervals, respectively.

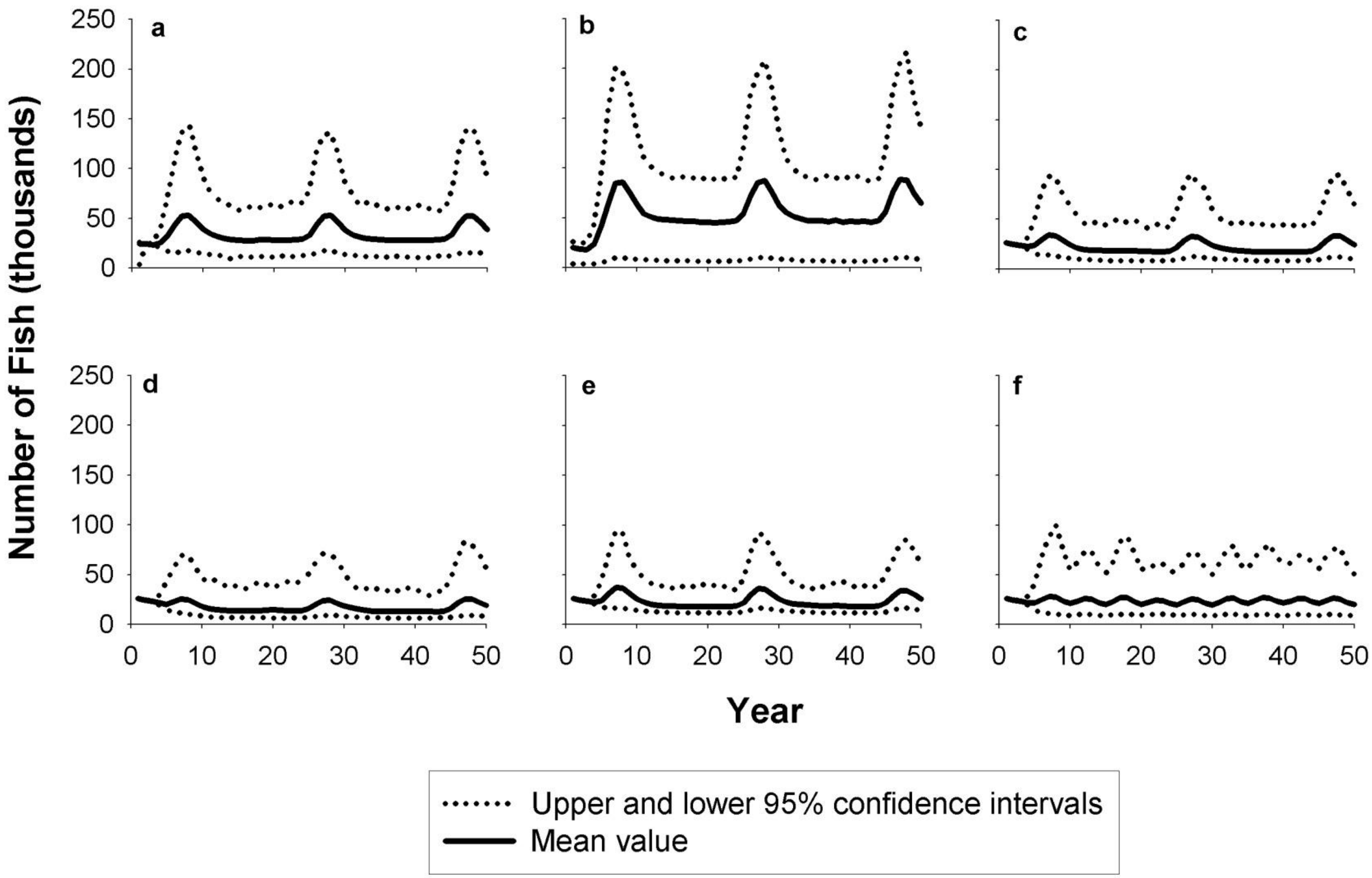

Figure 3-8. Model-predicted catch of largemouth bass for six different management scenarios at Lake Tohopekaliga based on a Monte Carlo analysis utilizing 1,000 iterations over 50 years. Scenarios pictured are Baseline (a), High hydrilla (b), Managed hydrilla (c), Hydrilla eradication (d), Eradication and fluctuations (e), and Eradication and drawdowns (f). Solid lines represent mean values and dotted lines represent upper and lower 95% confidence intervals, respectively.

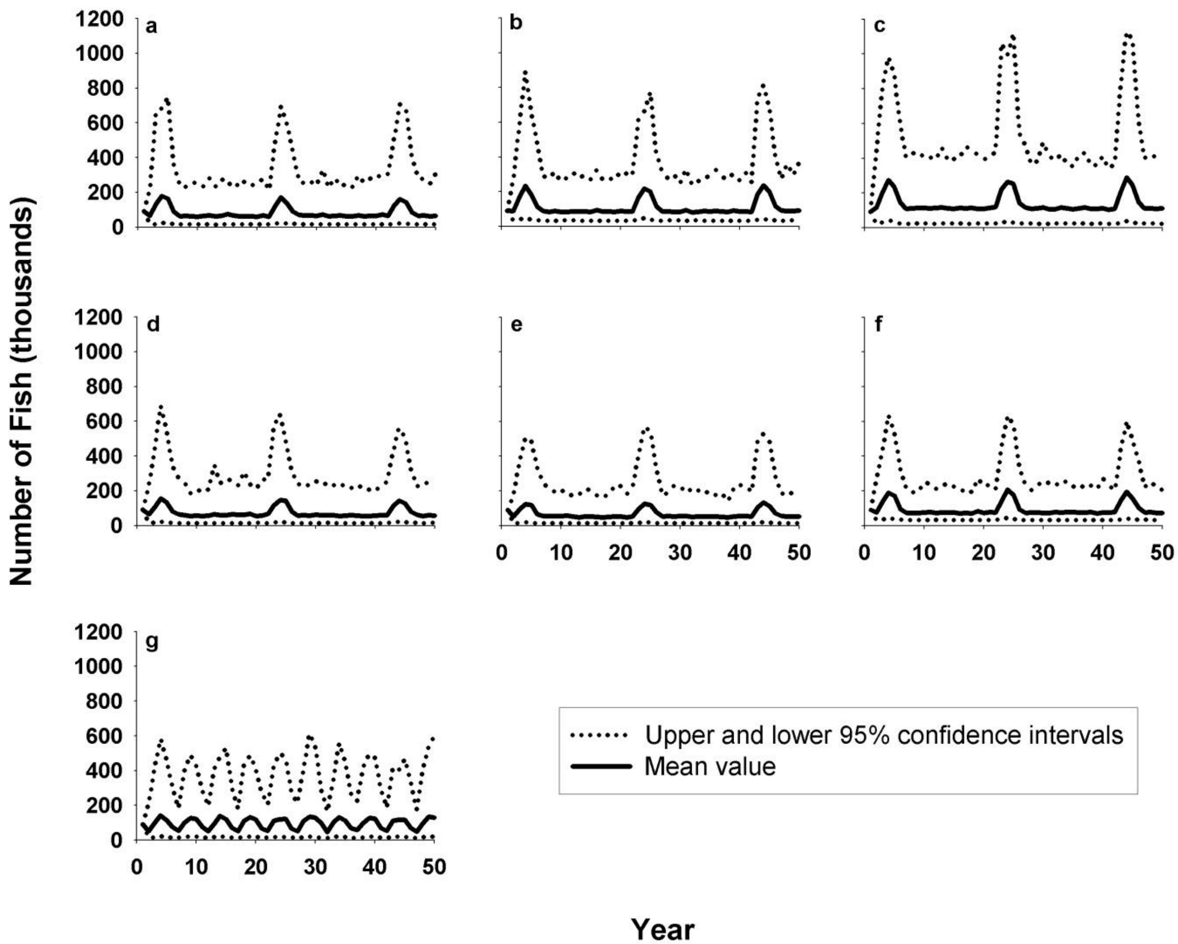

Figure 3-9. Model-predicted recruitment (age-1) of largemouth bass for seven different management scenarios at Lake Kissimmee based on a Monte Carlo analysis utilizing 1,000 iterations over 50 years. Scenarios pictured are Baseline (a), Fluctuations (b), High hydrilla (c), Managed hydrilla (d), Hydrilla eradication (e), Eradication and fluctuations (f), and Eradication and drawdowns (g). Solid lines represent mean values and dotted lines represent upper and lower 95% confidence intervals, respectively.

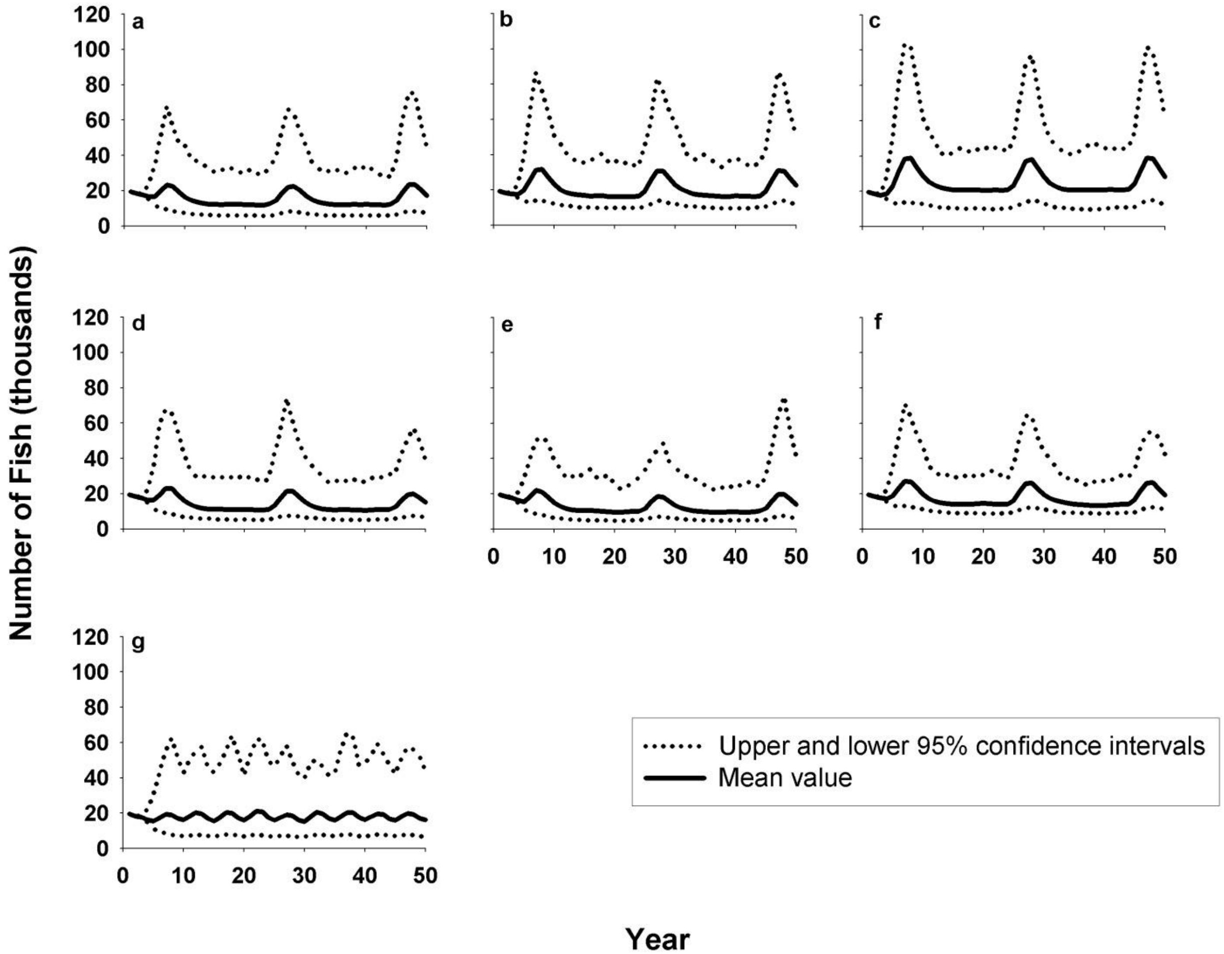

Figure 3-10. Model-predicted catch of largemouth bass for seven different management scenarios at Lake Kissimmee based on a Monte Carlo analysis utilizing 1,000 iterations over 50 years. Scenarios pictured are Baseline (a), Fluctuations (b), High hydrilla (c), Managed hydrilla (d), Hydrilla eradication (e), Eradication and fluctuations (f), and Eradication and drawdowns (g). Solid lines represent mean values and dotted lines represent upper and lower 95% confidence intervals, respectively.

Discussion

Model Performance versus Historical Data

Based on the model's response compared to historical catch and harvest estimates, using this population model appeared to be a viable option for exploring the effects of changes in hydrilla coverage, water level fluctuations and drawdowns on largemouth bass recruitment, adult population, catch and harvest at the KCOL. Outputs from the management scenarios were within the range of likely outcomes at Lakes Tohopekaliga and Kissimmee because the historical viability analysis showed the model predicted trends in catch and harvest in most years at both lakes. My estimates of equilibrium recruitment (R_o) resulted in estimates of approximately 42.8 fish/ha (ages 1-15) at Lake Tohopekaliga and approximately 15.5 fish/ha at Lake Kissimmee under the baseline scenarios. Hoyer and Canfield (1996) found a median of 173 largemouth bass/ha with a range of 14-5,916 across 56 Florida lakes with a surface area of <300 ha. At much larger lakes (e.g. KCOL lakes), a lower shoreline to lake area ratio would likely cause the value to be lower due to a smaller proportion of littoral habitat, but extensive hydrilla coverage outside of the littoral zone could mitigate this condition. Therefore, the model was predicting largemouth bass desnsity values that were within the range of Hoyer and Canfield's (1996) estimates. The model-predicted coefficient of variation (CV) in recruitment for baseline scenarios was about 40% at both lakes. This value fell within the range of values (11-189%) in a review of CV values for largemouth bass (Allen and Pine 2000), and was similar to the estimate of 59% found at Lake Kissimmee by Moyer et al. (1993).

Management Scenarios

Among the management options I explored for both lakes, the model predicted that the high hydrilla options would provide the greatest increases in largemouth bass abundance and angler catch metrics. The benefit from the high hydrilla scenario at Lake Kissimmee was lower than at Lake Tohopekaliga because much of Lake Kissimmee is not capable of hydrilla colonization due to its being a larger, deeper lake. While the current baseline scenario was the second-strongest scenario at Lake Tohopekaliga, it was third-weakest at Lake Kissimmee, suggesting that future management actions such as increased water level fluctuations could improve the fishery at this system.

Parameter Sensitivity

I found that natural mortality, length at 50% vulnerability and asymptotic length showed the most sensitivity to model outputs. My natural mortality rate was based on the review of Allen et al. (2008), and thus this estimate was informed by data. Future work should identify natural mortality rates for largemouth bass in Florida lakes. I believe that an accurate estimate of angling vulnerability at length for largemouth bass would reduce uncertainty in model predictions, as a change in angling vulnerability obviously directly impacts the number of fish caught. I also trusted my estimate of asymptotic length because I had several estimates directly from Lake Tohopekaliga. Future uses of this model, however, should use the most recent growth estimates available at either lake as von Bertalanffy growth parameters could shift over time.

Conclusions

Hydrilla likely has a strong effect on largemouth bass recruitment in large, Florida lakes, particularly at levels exceeding ~50% coverage. At Lake Tohopekaliga, high coverage of hydrilla is predicted to provide a much greater benefit to largemouth bass recruitment than any other management scenario I considered. Because options for adjusting water levels are limited at Lake Tohopekaliga, I suggest that the most beneficial scenario for largemouth bass is allowing hydrilla to expand to high coverages. However, resource managers must determine what an acceptable maximum coverage level is based on boating access needs, effects on other fisheries, potential declines in angler effort, aesthetics, and operation/safety of water control structure S-61 (excessive hydrilla can add stress to the structure and inhibit withdrawal rates).

At Lake Kissimmee, hydrilla levels are not likely to reach levels as high as at Lake Tohopekaliga. My results indicated that reduction/management of hydrilla is not necessary to improve the largemouth bass fishery at lake Kissimmee. The simulations suggested that the proposed water regulation schedule planned at Lake Kissimmee should provide a positive fishery benefit for largemouth bass at this system. However, monitoring of the fish population responses will be important, as there is still uncertainty in the impacts of water level fluctuations at this system due to a stabilized water history.

Drawdowns will likely still be necessary at both lakes to maintain littoral habitat and prevent rapid lake succession, but the required frequency could decline due to ongoing aquatic plant management efforts. The potential for a noticeable short-term benefit to largemouth bass may not be high enough to justify the cost (both expense of implementation and loss of public access) of drawdowns and muck removals. Thus, I do not suggest these drawdowns should be performed for any fishery-related reason other than habitat maintenance. As aquatic plants within the littoral zone eventually die off, organic sediment begins to accumulate and can eventually degrade largemouth bass habitat over time. Water stage and fluctuations, herbicide use, and other environmental variables will determine how often drawdowns should be necessary to prevent lake succession. An effective plant management regime that attempts to slow the accumulation of these organic sediments should allow for longer intervals between drawdowns.

CHAPTER 4
MODEL APPLICATION, CONSIDERATIONS, AND FUTURE STUDIES

The data compilation and model developed in this study can aid resource managers at the KCOL. This model can be used to explore future policies and evaluate fishery response times to stressors (e.g. aquatic plant loss). The model should also prove valuable for evaluating the relative value of a wide range of habitat management plans at the lakes. Finally, resource managers can use the model to explore how monitoring efforts could be tailored to reduce uncertainty in largemouth bass population responses in the future. Specifically, more field work is needed to identify electrofishing capture efficiency, adequate sample size and gears for monitoring, and fishing and natural mortality rates. Also, future monitoring should attempt to verify and/or refine the habitat-recruitment relationships used in the model.

Model Applications

There are a number of applications for which this model could be modified, both within the study system (KCOL) and outside of it. Within the KCOL, the model could be altered to account for changes in angler effort or harvest rate. The model could also estimate trophy catch to determine how changes in fishing or growth parameters could affect the fishery for notably large bass. A similar mathematical relationship to the hydrilla and water level recruitment functions could be explored for other habitat variables such as trophic state, and, if significant, could be applied in the same manner. The effects of other stochastic changes such as hurricanes on largemouth bass recruitment could be explored and these relationships applied in a similar nature to the binomial function used to model recruitment effects due to drawdowns.

Outside of the KCOL, the most obvious application for this model would be at similar Florida systems (e.g. Lake Istokpoga) which exhibit many of the same biological and limnological properties as Lakes Tohopekaliga and Kissimmee. This model could be applied to those systems with changes to the model structure to represent differences in growth, recruitment functions, angling effort, etc., and may give a relatively accurate representation of their largemouth bass populations. For systems outside of Florida where habitat similarity and largemouth bass growth and recruitment characteristics could drastically change, more significant adjustments to the model parameters would be necessary and new scientific literature or studies may be more informative to these parameters than those cited in this thesis. In some systems, there may be a more clearly defined stock-recruit relationship; as such, standard length-weight parameters and fecundity schedules could be used to model the effect of stock size on largemouth bass recruitment. Different genetic strains of largemouth bass (e.g. northern strain rather than Florida strain subspecies) would likely exhibit quite different life history characteristics than the Florida strain subspecies found at the KCOL. As is the case at Lakes Tohopekaliga and Kissimmee, any attempt to modify this model for use at other systems should be tested against historical data for reliability analysis if at all possible and supplemented by further experiments to further inform the model parameters and functions present at the system in question.

Considerations for Use of the Model

There are a number of limitations to acknowledge related to the structure and use of this model. From a broad view, it is most important to note that the predictions derived from the model are not expected to accurately portray the largemouth bass fishery at the KCOL in any given set of years. Instead, the value of the model is to explore the relative benefits of a range of potential management actions. Model parameters and functions should constantly be reevaluated and scrutinized to ensure the minimum amount of uncertainty possible. More specifically, I will also discuss some individual characteristics of the model that could potentially cause concern for the accuracy of its outputs.

Many of the parameters and relationships used in this model included natural variability resulting from field data. As with any natural system, it is impossible to account for every factor that drives the productivity of a single population or that of an entire ecosystem. The inputs used in this model are meant to represent a mean value based on the best available data, but will obviously vary around that mean in any given year.

Aquatic Macrophytes

I assumed that emergent plant communities would be relatively stable over time and did not predict any impacts from large-scale changes in these communities. The hydrilla eradication scenarios only predicted the impact of hydrilla absence in these systems and not of all aquatic macrophytes. Release of grass carp to eradicate hydrilla could substantially reduce coverage of other macrophytes (Leslie et al. 1983; Hanlon et al. 2000). Wiley et al. (1984) demonstrated a parabolic relationship between largemouth bass production and aquatic plant standing crop. Hoyer and Canfield (1996) predicted that, despite evidence to the contrary in lakes <300 ha, large lakes such as those in the KCOL would experience a bottleneck in largemouth bass recruitment in the absence of aquatic plants due to lower shoreline to lake area ratio limiting adequate cover from predation. Therefore, the hydrilla eradication scenarios would likely be more detrimental to the largemouth bass population than the model predicted if other submersed and emergent plants were eliminated. Similarly, any other large-scale changes in non-hydrilla aquatic macrophyte communities (e.g. exotic invasions, productivity shifts, changes in herbicide applications) could affect the largemouth bass populations.

I did not find any significant relationship between hydrilla coverage and largemouth bass reproduction in the data from Lakes Tohopekaliga and Kissimmee. I believe this resulted from changes in electrofishing capture efficiency, possibly leading to hyperdepletion where decreases in monitoring catch per unit effort indicate a greater decrease in abundance than actually exists for the true population (Hillborn and Walters 1992). Additionally, while entering electrofishing data from the original data sheets, I noticed multiple notations, particularly in the early period of hydrilla expansion, indicating that the location of fixed transects were occasionally moved to adjacent areas containing less hydrilla. This change could have caused additional underrepresentation of age-1 largemouth bass, as they would likely be utilizing the hydrilla-infested areas for cover from predation in a much greater proportion than open-water areas which were ultimately sampled. This may have also influenced the estimates of drawdown effects on recruitment in the final three drawdowns I explored at the KCOL. Thus, I used a clear relationship from Tate et al. (2003b) to model how I expected largemouth bass recruitment to change in response to hydrilla expansion or contraction. I believe this relationship would prove similar due to the comparable nature of the two lakes studied (Orange and Lochloloosa) to lakes in the KCOL. There is certainly a possibility, however, that the relationship between hydrilla coverage and largemouth bass recruitment at the KCOL is not as clearly-defined as Tate et al. (2003b) suggests for similar systems.

Drawdowns

I was unable to determine a rate at which largemouth bass habitat degrades when drawdowns are not performed for an extended period of time. Because the KCOL lakes were first regulated in the early 1960s and the first drawdowns occurred in the 1970s, I did not have a long-term record of how largemouth bass would respond to extended periods of stabilization of littoral areas. I explored this phenomenon at Lake Istokpoga, Florida, which did have a longer period of stabilization before the first drawdown. Unfortunately, data necessary to quantify the effects on either habitat or the largemouth bass fishery did not exist. Therefore, all model simulations assumed that drawdowns in some regular interval would continue to be necessary at the KCOL to maintain open water habitat and limit over-expansion of dense emergent macrophytes.

There is a possibility that this model overestimated the impact from drawdowns. Recent drawdown and muck removal projects at the KCOL (Lake Kissimmee 1995-96 and Lake Tohopekaliga 2004) did not appear to increase adult largemouth bass abundance in subsequent years (Allen et al. 2003). Because the data for drawdown effects came from a span of several decades, previous methodologies may have overestimated the gain in recruits following the drawdowns. Alternatively, the spread of hydrilla may have partially mitigated the loss of littoral habitat in degradation scenarios and caused recruitment to be more similar among pre- and post-drawdown years. If this was the case, my use of drawdown effects on recruitment as a distinct function may be flawed; the relative contribution of the littoral habitat improved and/or maintained due to a drawdown compared to that of hydrilla present in the system at the same time may need further exploration to increase the accuracy of this function. The more recent estimates of drawdown effects on largemouth bass recruitment may represent the present and future situation at the KCOL most accurately, as hydrilla is unlikely to be eradicated from the KCOL. However, even if the effects of drawdowns were overestimated, the model only predicted short-term (1-4 years) increases resulting from them. I do not have reason to believe that drawdowns provide any long-term (5+ years) benefits for largemouth bass outside of habitat maintenance and therefore the equilibrium values between drawdown periods in the simulations would be valid regardless of whether or not I overestimated the brief drawdown benefits.

Trophic State

I assumed no major changes in trophic state for either lake over the course of my simulations. Lake Tohopekaliga, however, experienced such a shift when a number of point-source inputs were removed in the late 1980s. The potential exists, particularly at Lake Tohopekaliga, for another shift to occur. The lake, which lies at the southern edge of suburban Orlando, could see greater levels of eutrophication from nonpoint-source pollution caused by increased urbanization. Any significant changes to trophic state at either lake could have major impacts on both the largemouth bass population and its associated habitat. Hoyer and Canfield (1996) found that adult largemouth bass abundance and standing crop were positively related to trophic state at 56 Florida lakes. Bachmann et al. (1996) saw no change in largemouth bass abundance with changes in trophic state but did find that largemouth bass biomass as a percentage of total fish biomass declined with increasing trophic state. A shift to an alternative stable state (Scheffer 1998) similar to one seen at Lake Apopka, Florida (Bachmann et al. 1999;

Lowe et al. 2001; Bachmann et al. 2005; Schelske et al. 2005) has the potential to drastically reduce largemouth bass largemouth bass populations at the KCOL.

Fishing Mortality, Angler Effort, and Largemouth Bass Growth

The model varied fishing mortality based on values from the literature and creel survey catches, but I did not vary these rates (U and U_o) in my simulations of future scenarios. Future studies should measure fishing mortality rates at these systems. I believe voluntary release of fish may be at a plateau, and is currently at a high enough level at both lakes given the low discard mortality estimate (10%) that further increases in voluntary release should be relatively negligible to the largemouth bass population. Angler effort likely will change at both lakes in the future and could influence fishery responses. However, considering high voluntary release and low discard mortality rates, large increases in effort would be necessary to cause substantial impact on the largemouth bass population.

A major component of the KCOL largemouth bass fishery is the ability for anglers to catch “trophy” fish. This model did not specifically predict trophy catch, but trophy fish numbers should resemble trends for total adult abundance unless growth or mortality rates change substantially with changes in habitat. Thus, model-predicted trophy fish catches would identify the high hydrilla option at both lakes and the fluctuation scenario at Lake Kissimmee to maximize trophy catches, assuming no major changes in mortality or growth. This assumption does include the expectation that fishing mortality due to harvest is similar across the legal size structure. If trophy fish are harvested at a significantly higher rate due to angler preference for harvesting larger fish, predictions of catch, harvest, and population size structure could be affected.

If excessively high levels of hydrilla do actually reduce both juvenile (Bettoli et al. 1992) and adult (Colle and Shireman 1980; Brown and Maceina 2002) largemouth bass growth, these impacts should be accounted for in the model. A shift in the size structure of the largemouth bass population would potentially impact the vulnerability of the population to angling mortality. Changes in juvenile growth may also impact survival of largemouth bass to adulthood (Gutreuter and Anderson 1985).

Future Studies and Conclusions

Because the three recruitment functions I used directly impact the number of individual fish entering the model in a given year, it is important to ensure that these functions are similar to what actually occurs at the KCOL. Opportunities exist to explore and refine the relationships between largemouth bass recruitment and habitat used in this model. Long-term monitoring programs conducted by the Florida FWC and Florida LAKEWATCH are collecting long-term data that could help reduce uncertainty. However, given the apparent inability of electrofishing CPH to monitor largemouth bass recruitment, fish age sampling will be required to monitor year classes as they move through the fishery. This would provide a way to validate or invalidate electrofishing CPH trends and identify how changes in habitat influence largemouth bass recruitment. Because the monitoring programs across Florida utilize electrofishing as the primary sampling technique for largemouth bass abundance, electrofishing catchability as a function of hydrilla coverage and other major habitat changes should be explored. Because of this potential bias, future experiments may need to utilize alternative sampling methods (e.g. age structure combined with use of creel survey data) to increase confidence in largemouth bass recruitment and abundance trends.

There are other opportunities to conduct whole-lake experiments for the KCOL largemouth bass fisheries. The implementation of a new water level schedule at Lake Kissimmee presents an opportunity to test the relationship between fall (or other seasonal) water levels and largemouth bass recruitment at these systems. Monitoring of largemouth bass recruitment with electrofishing, creel surveys, and age structure data before, during and after its implementation could provide new insight into how fluctuating water levels impact recruitment in the future and will influence the sport fishery. Lake Tohopekaliga, Lake Kissimmee, or other lakes in the KCOL could also host experimental tests for changes in largemouth bass recruitment with varying hydrilla coverage. Hydrilla levels in these lakes are constantly changing, both due to management actions and natural conditions. Any drawdowns performed in the future should allow for sampling designs to test for specific responses in largemouth bass recruitment and population age structure.

Growth of largemouth bass (e.g. estimation of von Bertalanffy growth parameters) at the KCOL should be measured at regular intervals to maintain accurate inputs for the model. Additionally, the relationship between largemouth bass growth and hydrilla abundance should be further explored; if there is a significant relationship, the model would need to include a function affecting growth, and, by extension, vulnerability of largemouth bass to angling mortality with changing hydrilla coverage levels. More accurate estimates of largemouth bass mortality, both natural and angling-related, should be obtained, possibly through tagging studies. The length of largemouth bass at 50% vulnerability to angling should be evaluated closer to assure accuracy of catch and harvest estimates from the model. in summary, this largemouth bass population model represented a set of recruitment-habitat relationships as well as growth and vulnerability parameters which may be similar to those currently present at Lakes Tohopekaliga and Kissimmee based on my synthesis of available literature and data. This model should not, however, be assumed to be an accurate representation of the system as all population models inherently contain error. Future studies should be conducted to better inform the model relationships and parameters. Despite preconceived notions from modelers about the systems they are attempting to recreate, models are often incorrect and counterintuitive (Pine et al. 2009). The inaccuracy of models can allow scientists to better understand flaws in their general structure, however, and allow this structure to be improved for more accurate predictions in the future. As the relationships and parameters in this model are tested and improved over time, its accuracy should accordingly increase.

APPENDIX
PERCENT CHANGE OF MODEL SCENARIOS FROM BASELINE SCENARIOS

Table A-1. Simulated mean and upper/lower 95% confidence interval changes from baseline values for five different scenarios at Lake Tohopekaliga. Values represent percent difference compared to corresponding baseline value, e.g. mean vs. mean, lower 95% vs. lower 95%).

Scenario	Adult abundance			Recruitment		
	Mean	Lower 95%	Upper 95%	Mean	Lower 95%	Upper 95%
High hydrilla	115	198	54	119	234	37
Managed hydrilla	-38	-35	-27	-37	-22	-32
Eradication	-54	-50	-46	-55	-37	-56
Eradication and fluctuations	-36	-9	-38	-35	44	-49
Eradication and drawdowns	-30	-34	-12	-28	-30	-26
	Catch			Harvest		
	Mean	Lower 95%	Upper 95%	Mean	Lower 95%	Upper 95%
High hydrilla	64	-42	47	66	-40	52
Managed hydrilla	-37	-26	-29	-36	-24	-25
Eradication	-52	-44	-42	-53	-43	-44
Eradication and fluctuations	-35	2	-37	-34	4	-35
Eradication and drawdowns	-27	-23	-10	-27	-21	-7

Table A-2. Simulated mean and upper/lower 95% confidence interval changes from baseline values for six different scenarios at Lake Kissimmee. Values represent percent difference compared to corresponding baseline value, e.g. mean vs. mean, lower 95% vs. lower 95%).

Scenario	Adult abundance			Recruitment		
	Mean	Lower 95%	Upper 95%	Mean	Lower 95%	Upper 95%
Fluctuations	35	72	9	34	69	14
High hydrilla	70	72	36	69	72	40
Managed hydrilla	-8	-7	-9	-8	-7	-6
Eradication	-20	-15	-24	-17	-15	-13
Eradication and fluctuations	15	57	-8	16	53	0
Eradication and drawdowns	24	13	25	25	17	34
	Catch			Harvest		
	Mean	Lower 95%	Upper 95%	Mean	Lower 95%	Upper 95%
Fluctuations	36	69	17	36	117	12
High hydrilla	69	74	40	72	51	57
Managed hydrilla	-10	-9	-8	-9	-6	-11
Eradication	-18	-16	-16	-19	-11	-24
Eradication and fluctuations	15	53	-7	17	104	-13
Eradication and drawdowns	30	15	42	31	1	25

LIST OF REFERENCES

Allen, M. S. and W. E. Pine, III. 2000. Detecting fish population responses to a minimum length limit: effects of variable recruitment and duration of evaluation. North American Journal of Fisheries Management 20:672-682.

Allen, M. S., K. I. Tugend and M. J. Mann. 2003. Largemouth bass abundance and angler catch rates following a habitat enhancement project at Lake Kissimmee, Florida. North American Journal of Fisheries Management 23:845-855.

Allen, M. S., C. J. Walters and R. Myers. 2008. Temporal trends in largemouth bass mortality with fishery implications. North America Journal of Fisheries Management 28:418-427.

Anderson, R. O. and Neumann, R. M. 1996. Length, weight and associated structural indices. Pages 447-482 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Bachmann, R. W., M. V. Hoyer and D. E. Canfield, Jr. 1999. The restoration of Lake Apopka in relation to alternative stable states. Hydrobiologia 394:219-232.

Bachmann, R. W., M. V. Hoyer, S. B. Vinzon and D. E. Canfield, Jr. 2005. Limnology and Oceanography 50:629-635.

Bachmann, R. W., B. L. Jones, D. D. Fox, M. Hoyer, L. E. Bull and D. E. Canfield, Jr. 1996. Relations between trophic state indicators and fish in Florida (USA) lakes. Canadian Journal of Fisheries and Aquatic Sciences 53:842-855.

Bayley, P. B. and D. J. Austin. 2002. Capture efficiency of a boat electrofisher. Transactions of the American Fisheries Society 131:435-452

Beamesderfer, R. C. P. and J. A. North. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15:688-704.

Bettoli, P. W., M. J. Maceina, R. L. Noble and R. K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. North American Journal of Fisheries Management 12:509-516.

Bettoli, P. W., M. J. Maceina, R. L. Noble and R. K. Betsill. 1993. Response of a reservoir fish community to aquatic vegetation removal. North American Journal of Fisheries Management 13:110-124.

Bonvechio, T. F. and M. S. Allen. 2005. Relations between hydrological variables and year-class strength of sportfish in eight Florida waterbodies. Hydrobiologia 532:193-207.

Bonvechio, K. I., M. S. Allen, T. F. Bonvechio and T. P. Coughlin. 2008. Comparison of largemouth bass assessment metrics between standardized and historical sampling designs at six Florida lakes. North American Journal of Fisheries Management 28:1132-1137.

Bonvechio, K. I. and T. F. Bonvechio. 2006. Relationship between habitat and sport fish populations over a 20-year period at West Lake Tohopekaliga, Florida. North American Journal of Fisheries Management 26:124-133.

Brown, S. J. and M. J. Maceina. 2002. The influence of disparate levels of submersed aquatic vegetation on largemouth bass population characteristics in a Georgia reservoir. Journal of Aquatic Plant Management 40:28-35.

Canfield, D. E., Jr., K. A. Langeland, S. B. Linda and W. T. Haller. 1985. Relations between water transparency and maximum depth of macrophytes colonization in lakes. Journal of Aquatic Plant Management 23:25-28.

Caffrey, A. J., M. V. Hoyer and D. E. Canfield, Jr. 2007. Factors affecting the maximum depth of colonization by submersed macrophytes in Florida lakes. Lake and Reservoir Management 23:287-297.

Chick, J. H. and McIvor, C. C. 1997. Habitat selection by three littoral zone fishes: effects of predation pressure, macrophyte density and macrophytes type. Ecology of Freshwater Fish 6:27-35.

Coggins, L. G., Jr., W. E. Pine, III, C. J. Walters, D. R. Van Haverbeke, D. Ward and H. C. Johnstone. 2006. Abundance trends and status of the Little Colorado River Population of Humpback Chub. North American Journal of Fisheries Management 26:233-245.

Colle, D. E. and J. V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Transactions of the American Fisheries Society 109:521-531.

Colle, D. E., J. V. Shireman, W. T. Haller, J. C. Joyce and D. E. Canfield. 1987. Influence of hydrilla on harvestable sportfish populations, angler use, and angler expenditures at Orange Lake, Florida. North American Journal of Fisheries Management 7:410-417.

Crouse, D. T., L. B. Crowder and H. Caswell. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology 68:1412-1423.

Crowder, L. B. and W. E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Devries, D. R. and R. V. Frie. 1996. Determination of age and growth. Pages 438-512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Dierberg, F. E., V. P. Williams and W. H. Schneider. 1988. Lake and Reservoir Management 4:101-111.

Durocher, P. P., W. C. Provine and J. E. Kraai. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. North American Journal of Fisheries Management 4:84-88.

Endangered Species Act of 1973. United States Code. 35:1531

Federal Water Pollution Control Amendments of 1972. United States Code. 33:1251

Flowers, J. 2008. Age-structured population model for evaluating gulf sturgeon recovery on the Apalachicola River, Florida. Masters thesis. University of Florida, Gainesville.

Forchhammer, M. C., N. C. Stenseth, E. Post and R. Langvatn. 1998. Population dynamics of Norwegian red deer: density-dependence and climatic variation. Proceedings of the Royal Society of London 265:341-350.

Gutreuter, S. J. and R. O. Anderson. 1985. Importance of body size to the recruitment process in largemouth bass populations. Transactions of the American Fisheries Society 114:317-327.

Haddon, M. 2001. Modelling and quantitative methods in fisheries. Chapman and Hall, New York.

Hanlon, S. G., M. V. Hoyer, C. E. Cichra and D. E. Canfield, Jr. 2000. Evaluation of macrophyte control in 38 Florida lakes using triploid grass carp. Journal of Aquatic Plant Management 38:48-54.

Henry, K. R. 2003. Evaluation of largemouth bass exploitation and potential harvest restrictions at Rodman Reservoir, Florida. Masters thesis. University of Florida, Gainesville.

Hillborn, R. and Walters, C. J. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Hoyer, M. V. and D. E. Canfield, Jr. 1996. Largemouth bass abundance and aquatic vegetation in Florida lakes: an empirical analysis. Journal of Aquatic Plant Management 34:23-32.

Hoyer, M. V. R. W. Bachmann and D. E. Canfield, Jr. 2008. Lake management (muck removal) and hurricane impacts to the trophic state of Lake Tohopekaliga, Florida. Lake and Reservoir Management 24:57-68.

Hoyer, M. V., C. A. Horsburgh, D. E. Canfield, Jr. and R. W. Bachmann. 2005. Lake level and trophic state variables among a population of shallow Florida lakes and within individual lakes. Canadian Journal of Fisheries and Aquatic Sciences 62:2760-2769.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53:820-822.

Keisecker, J. M., A. R. Blaustein and L. K. Belden. 2001. Complex causes of amphibian population declines. Nature 410:681-684.

Langeland, K. A. 1996. *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". Castanea 61:293-304.

Leslie, A. J., Jr., L. E. Nall and J. M. Van Dyke. 1983. Effects of vegetation control by grass carp on selected water-quality variables in four Florida lakes. Transactions of the American Fisheries Society 112:777-787.

Lowe, E. F., L. E. Battoe, M. F. Coveney, C. L. Schelske, K. E. Havens, E. R. Marzolf and K. R. Reddy. 2001. The restoration of Lake Apopka in relation to alternative stable states: an alternative view to that of Bachmann et al. (1999). Hydrobiologia 448:11-18.

Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006. U.S. Statutes at Large. 109:3575-3665.

Meals, K. O. and L. E. Miranda. 1991. Variability in abundance of age-0 centrachids among littoral habitats of flood control reservoirs in Missisippi. North American Journal of Fisheries Management 11:298-304.

Miranda, L. E., W. L. Shelton and T. D. Bryce. 1984. Effects of water level manipulation on abundance, mortality and growth of young-of-year largemouth bass in West Point Reservoir, Alabama-Georgia. North American Journal of Fisheries Management 4:314-320.

Mooij, W. M., R. E. Bennetts, W. M. Kitchens and D. L. DeAngelis. 2005. Exploring the effect of drought extent and interval on the Florida snail kite: interplay between spatial and temporal scales. Ecological Modelling 149:25-39.

Moxley, D. J. and F. H. Langford. 1985. Beneficial effects of hydrilla on two eutrophic lakes in Central Florida. Proceedings of the Annual Conference of the Southeastearn Association of Fish and Wildlife Agencies 36:280-286.

Moyer, E. J., M. W. Hulon, R. S. Butler, D. C. Arwood, C. Michael and C. A. Harris. 1987. Completion Report for Kissimmee Chain of Lakes Studies. Study I. Lake Tohopekaliga Investigations. Florida Game and Freshwater Fish Commission, Tallahassee.

Moyer, E. J., M. W. Hulon, R. S. Butler, D. C. Arwood, C. Michael and C. A. Harris. 1988. 1983-1988 Completion Report for Kissimmee Chain of Lakes Studies. Study II. Lake Kissimmee Investigations. Florida Game and Freshwater Fish Commission, Tallahassee.

Moyer, E. J., M. W. Hulon, J. Buntz, R. W. Hujik, J. J. Sweatman, C. S. Michael, D. C. Arwood and A. C. Jasent. 1992. 1987-1992 Completion Report for Kissimmee Chain of Lakes Studies. Study I. Lake Tohopekaliga Investigations. Florida Game and Freshwater Fish Commission, Tallahassee.

Moyer, E. J., M. W. Hulon, J. Buntz, R. W. Hujik, J. J. Sweatman, C. S. Michael, D. C. Arwood and A. C. Jasent. 1993. 1988-1993 Completion Report for Kissimmee Chain of Lakes Studies. Study II. Lake Kissimmee Investigations. Florida Game and Freshwater Fish Commission, Tallahassee.

Moyer, E. J., M. W. Hulon, J. W. Sweatman, R. S. Butler and V. P. Williams. 1995. Fishery responses to habitat restoration in Lake Tohopekaliga, Florida. North American Journal of Fisheries Management 15:591-595.

Myers, R., J. Taylor, M. Allen and T. Bonvechio. 2008. Temporal trends in voluntary release of largemouth bass. North American Journal of Fisheries Management 28:428-433.

Pine. W. E., III, S. J. D. Martell, C. J. Walters and J. F. Kitchell. 2009. Counterintuitive responses of fish populations to management actions: some common causes and implications for predictions based on ecosystem modeling. Fisheries 34:165-180.

Pope, K. L. 2008. Assessing changes in amphibian population dynamics following experimental manipulations of introduced fish. Conservation Biology 22:1572-1581.

Price, S. 2009. Top 10 bass getaways. Bassmaster Magazine. (July/August):28.

Puri, A., W. T. Haller and M. D. Netherland. 2009. Cross-resistance in fluridone-resistant hydrilla to other bleaching herbicides. Weed Science 57:482-488.

Puri, A., G. E. MacDonald, W. T. Haller and M. Singh. 2006. Phytoene and β-carotene response of fluridone-susceptible and -resistant hydrilla (Hydrilla verticillata) biotypes to fluridone. Weed Science 54:995-999.

Reynolds, J. B. 1996. Electrofishing. Pages 221-253 *in* B. R. Murphy and R. W. Willis, Editors. Fisheries Techniques, 2nd Edition. American Fisheries Society, Bethesda, Maryland.

Sammons, S. M., L. G. Dorsey and P. W. Bettoli. 1999. Effects of reservoir hydrology on reproduction by largemouth bass and spotted bass in Normandy Reservoir, Tennessee. North American Journal of Fisheries Management 19:78-88.

Savino, J. F. and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society 111:255-266.

Scheffer, M. 1998. Ecology of Shallow Lakes. Chapman and Hall.

Schelske, C. L., E. F. Lowe, L. E. Battoe, M. Brenner, M. F. Coveney and W. F. Kenney. 2005. Abrupt biological response to hydrologic and land-use changes in Lake Apopka, USA. Ambio 34:192-198.

Tate, W. B., M. S. Allen, R. A. Myers and J. R. Estes. 2003a. Comparison of electrofishing and rotenone for sampling largemouth bass in vegetated areas of two Florida lakes. North American Journal of Fisheries Management 23:181-188.

Tate, W. B., M. S. Allen, R. A. Myers, E. J. Nagid and J. R. Estes. 2003b. Relation of age-0 largemouth bass abundance to hydrilla coverage and water level at Lochloosa and Orange Lakes, Florida. North American Journal of Fisheries Management 23:251-257.

Towns, D. R. and S. M. Ferreira. 2001. Conservation of New Zealand lizards (Lacertilia: Scincidae) by translocation of small populations. Biological Conservation 98:211-222.

Valley, R. D. and M. T. Bremigan. 2002. Effects of macrophytes bed architecture on largemouth bass foraging: implications of exotic macrophytes invasions. Transactions of the American Fisheries Society 131:234-244.

Walters, C. J. and S. J. D. Martell. 2004. Fisheries ecology and management. Princeton University Press, Princeton, New Jersey.

Wilde, G. R. and K. L. Pope. 2008. A simple model for predicting survival of angler-caught and released largemouth bass. Transactions of the American Fisheries Society 137:834-840.

Wiley, M. J., R. W. Gorden, S. W. Waite and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North American Journal of Fisheries Management 4:111-119.

Williams, V. P. 2001. Effects of point-source removal on lake water quality: a case history of Lake Tohopekaliga, Florida. Journal of Lake and Reservoir Management 17:315-329.

BIOGRAPHICAL SKETCH

Patrick Michael O'Rouke was born in Atlanta, Georgia in 1982 to Michael and Mary Lou O'Rouke and spent the first 18 years of his life as a fifth-generation resident of Gwinnett County in his native town of Sugar Hill. One of his earliest memories is of catching his first fish (a bluegill) at Vogel State Park in the North Georgia mountains. He spent countless hours in the woods behind his house playing in the creek and capturing whatever critters he could manage to get his hands on. He played a number of organized sports from an early age, fostering an obsession that continues to this day. He was raised in Level Creek United Methodist Church, where the majority of his relatives were members and many of his ancestors are buried. He remains an active member of the Methodist Church today, currently attending Gainesville First United Methodist Church.

During the spring of his senior year at North Gwinnett High School, Patrick realized there wasn't much of a market for 6'0", 210 lb. offensive linemen in college football and instead opted to end his football career and enroll at the University of Georgia as a typical freshman. He chose a major that he hoped would allow him to turn one of his favorite hobbies (fishing) into a career. Four and a half years (and 56 football games as well as a trip to Omaha, Nebraska for the College World Series) later he graduated with a Bachelor of Science in Forest Resources degree in fisheries and aquaculture and a minor in agribusiness. During his time at UGA, he was a member of Pi Kappa Phi fraternity and served as its Vice President in 2002-2003. He also served as a Student Ambassador for the Warnell School of Forest Resources from 2002-2004. In December 2004, he was dragged kicking and screaming from Athens to move on to the next stage of his life.

Following graduation, Patrick attended the Wendelstedt Umpire School during the first five weeks of 2005 in an attempt to become a professional baseball umpire. When he began searching for “real” jobs, he made two promises to himself: he would never take a job in a big city, and he would never move up north. Shortly thereafter, he accepted a position as the Everett C. Hames Policy Fellow with the American Sportfishing Association (ASA) in Alexandria, Virginia (a suburb of Washington, D.C. located just inside the capital beltway). Patrick’s fellowship at ASA coincided with the 109th Congress where he worked on a number of issues that were extremely relevant to the field of fisheries management, including the reauthorization of the Wallop-Breaux Act, the reauthorization of the Magnuson-Stevens Act, and the creation of the National Fish Habitat Action Plan. He was afforded the opportunity to work with Members of Congress, federal agency administrators, state agency administrators, non-governmental organization personnel, and countless members of the sportfishing industry (he managed to pick up a fair amount of free fishing tackle along the way, of course). His immediate boss and mentor, Gordon Robertson, always made sure Patrick got the chance to meet the right people, attend the right meetings, or gain new experiences. Two of his favorite memories from his time in the nation’s capital include placing second in a Congressional bass fishing tournament on a team that included Congressman (and former University of Nebraska football coach) Tom Osborne and being present at the signing of the 2006 Magnuson-Stevens Act.

During his second year at ASA, Patrick decided that to advance his career as he wanted, a masters degree was going to be necessary. He began exploring his options for graduate school and when soliciting opinions from trusted advisors, Dr. Mike Allen’s name always seemed to come up. Patrick thought highly of Dr. Allen's research focus, but he had always told himself that he would never, under any circumstances, attend the University of Florida. After a series of conversations with Dr. Allen during the fall, Patrick moved to Gainesville in January 2007 to begin work as a technician in the Allen lab. He started classes at UF a year later, an event which ultimately culminated in the production of this thesis.

Following graduation from UF, Patrick hopes to work as a fish biologist within the southeastern United States. He also plans to continue umpiring, a second job/hobby he began while in high school and currently holds at the high school and collegiate baseball levels. He will no doubt find free time in between to obsess over the Georgia Bulldogs and Atlanta Braves and squeeze in as many fishing trips as possible. Finally, Patrick has learned that he should probably never say "never" again.