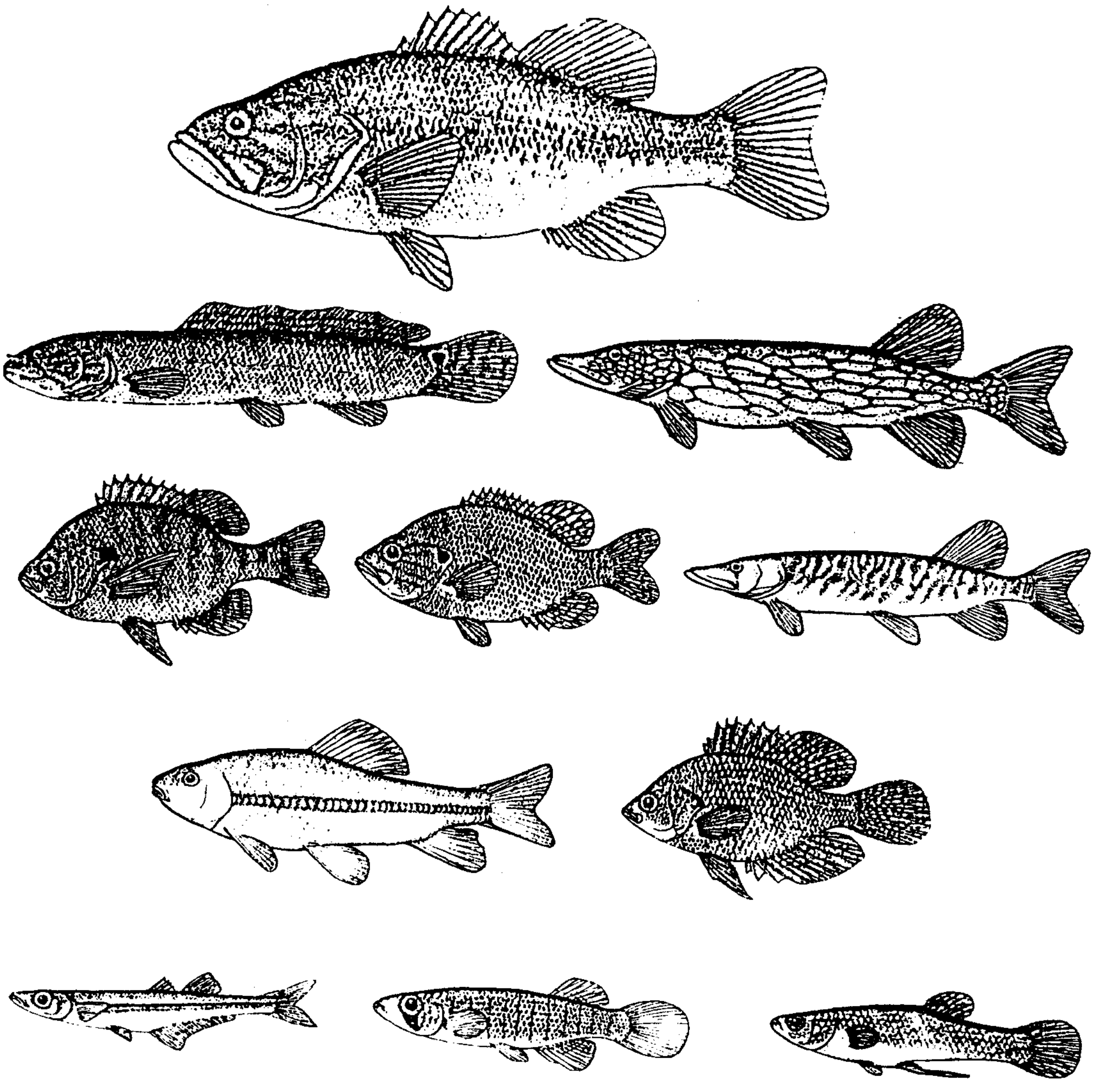
FISH COMMUNITY STRUCTURE
IN SOME NATURALLY ACID FLORIDA LAKES



Final Project Report - Research Work Order No. 73

Prepared by

Cecil A. Jennings, Daniel E. Canfield, Jr., and Douglas E. Colle
Department of Fisheries and Aquaculture
University of Florida, Gainesville, Florida 32611

June 1990

FISH COMMUNITY STRUCTURE IN SOME NATURALLY ACID FLORIDA LAKES

By

CECIL ANDRE JENNINGS

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

MAY 1990

ACKNOWLEDGEMENTS

There are many individuals, among them faculty, staff and fellow graduate students who provided guidance, assistance, and comradery during my four years at the University of Florida. I am extremely grateful to them and extend many thanks.

Financial support from several sources made my tenure at the University of Florida possible. Thanks are extended to the sponsors and administrators of the Graduate Minority Fellowship Program and the Delores A. Auzenne Fellowship for Graduate Education for financial support through the first three years and fourth year, respectively. Thanks are also extended to the Florida Department of Environmental Regulation and the U.S. Fish and Wildlife Service, both of whom provided financial support for my research.

I am extending special thanks to the members of my graduate advisor committee. Drs. Wiley Kitchens, Dan Canfield, Carter Gilbert, Frank Nordlie, and Jerome Shireman always had the time to listen, offer encouragement, advice, comments, criticisms, and congratulations, as needed. I am very grateful to Wiley, my graduate advisor, for providing an environment at the Florida Cooperative Fish and Wildlife

Research Unit which exposed me to learning opportunities not available in the classroom. My other committee members also provided similar opportunities, and for that I am grateful.

The field and laboratory portions of this study were labor intensive and required many hands to complete. In the early stages of the field work, Judy (Lamia) Ludlow and Doug Colle helped with finding, evaluating, and sampling prospective study lakes. Doug also provided technical advice for assessing age, growth and reproductive success. Additionally, his timely advice on data management made the volumes of data collected during the study less formidable. Assistance provided by Ken Romie, Steve Fisher, and Dennis Crumby were crucial to the successful completion of the electrofishing, gillnetting, and limnological sampling. Mark Hoyer directed the block-net and rotenone sampling, and provided technical advise regarding aging techniques. Christie Horsburgh, Mark Jennings, Cary Pickands, Rick Spratt, and Ron Van Fleet provided assistance in all phases of the field work. Christie was especially helpful with computer data entry and verification. Mary Rutter analyzed the water samples, sometimes with little or no advance warning that they were forthcoming. Truman Perry, caretaker of the Ordway Preserve, provided assistance in finding the lakes on the preserve, and was always willing to lend a hand as needed. Without the assistance rendered by these individuals, the successful completion of this project would

almost have been an impossible feat. I am very appreciative of their efforts and offer them many thanks.

I would also like to express my gratitude to the following individuals for assistance and advice which contributed to the successful completion of my work. Dr. Chuck Cichra of the Department of Fisheries and Aquaculture offered the use of his microcomputer and modem and for downloading data files from the NERDC mainframe. Chuck also provided technical advice on many subjects, including fisheries statistics, age and growth, and SAS software. Pam Latham, Dr. Tom Smith, Dr. Carole McIvor, and Steven Linda helped me through the maze of multivariate statistics. Pam also helped me get started with SAS programming, and Carole provided critical reviews of an early draft of this manuscript. Leonard Pearlstine and John Richardson rendered assistance with microcomputers. I usually provided the questions; Leonard and John usually provided the answers. I am thankful to all these individuals for their assistance.

There are many individuals whose contributions to my graduate education are less tangible, but no less deserving of gratitude and acknowledgement. These individuals include faculty, staff, and students closely associated with the Coop Unit. They were usually the first to listen, counsel, encourage, critique, and assist, often without my asking. They include Dr. H. Franklin Percival, Barbara Fesler, and Petra Wood. Dr. W. Reid Goforth of the Cooperative Research

Unit Center, Washington, D. C., and Sebrina Street, formerly of the Student Records Office, School of Forest Resources and Conservation, also functioned in much the same fashion. I am also grateful to Sebrina for her skills in deciphering the seemingly complex regulations governing the formation of graduate advisory committees, preliminary exams, and the ever-changing status of assistantship appointment letters and fee waivers.

Finally, I would like to express deep appreciation to my family for their continued encouragement and moral support. They always told me I could if I wanted to, regardless of the undertaking. I owe a great debt of gratitude to my wife, Brenda, whose love, companionship and moral support keep me going through the hardest times. She was always there for me, beginning with the stresses of coursework and preliminary exams, through the many late nights electrofishing and three-day sampling trips to the panhandle, to the countless hours spent preparing this dissertation. Her belief in my abilities carried me through the times when I was less sure. For this I will always be grateful.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ii

LIST OF TABLES ix

LIST OF FIGURES xii

ABSTRACT xv

CHAPTERS

I INTRODUCTION 1
  Overview 1
  Nomenclature 1
  Anthropogenic Acidification 2
    Biotic Response to Acidification . . 3
    Non-Fish Biota 4
    Fish 8
    Mechanisms for Fish Population Losses . 10
    Direct mortality 10
    Reproductive and recruitment failure . 11
  Naturally Acid Waters 12

II ABUNDANCE, BIOMASS, GROWTH, AND CONDITION OF SELECTED FISH SPECIES IN SOME NATURALLY ACID FLORIDA LAKES 15

  Introduction 15

  Methods 16
    Lake Selection 16
    Fish Sampling 19
    Age, Growth and Condition 23
    Limnological Sampling 24
    Aquatic Macrophyte Sampling . . . 27
    Fish Stocking 27
    Data Analysis 28

  Results 28
    Lake Morphometry and Water Chemistry . 28
    Macrophytes 32
    Fish Abundance--Electrofishing . . 34
    Fish Abundance and Biomass--Gillnetting 59

Page

Total Fish Abundance and Biomass--Block-netting 59
Condition Factors 67
Age and Growth of Largemouth Bass . . 73
Fish Stocking 80

Discussion 82
Study Site 82
Fish Abundance--Electrofishing . . 83
Fish Abundance and Biomass--Gillnetting 88
Fish Abundance and Biomass--Block-netting 89
Condition Factors 91
Age and Growth of Largemouth Bass . . 94
Fish Stocking 98

Conclusions 98

III FISH SPECIES DIVERSITY AND ASSEMBLAGE PATTERNS IN 12 NATURALLY ACID FLORIDA LAKES 100

Introduction 100

Methods 102
Community Analysis 102
Reproduction 103
Data Analysis 104

Results 106
Fish Species Diversity 106
Fish Assemblage Patterns 112
Environmental Water Chemistry . . . 122
Reproduction 127

Discussions 133
Species Diversity 133
Fish Assemblage Patterns 136
Environmental Water Chemistry . . . 140
Reproduction 141

Conclusions 143

IV SUMMARY AND CONCLUSIONS 145

Project Summary. 145
Conclusions 151
Future Research Needs 157
Florida 158
Other affected areas. . . . 159

Page

APPENDIX 161

LITERATURE CITED 163

BIOGRAPHICAL SKETCH 178

LIST OF TABLES

Page

2-1. Location, surface area and mean depth of study lakes 20

2-2. Means, standard errors, and sample size of limnological parameters measured in the study lakes 29

2-3. Abundance of aquatic macrophytes measured in the study lakes 33

2-4. Total number of fish $\geq$ 150 mm TL captured, by species, with electrofishing gear from the study lakes 35

2-5. Density and biomass estimates (in parenthesis) and 95% confidence intervals, by species, for fish $\geq$ 150 mm TL sampled during the mark-recapture procedure used on the study lakes 50

2-6. Density and biomass estimates for largemouth bass $\geq$ 150 mm TL sampled during the mark-recapture procedure, and total abundance estimates including young-of-the-year collected during rotenone samples from the study lakes 53

2-7. Mean density and biomass of fish collected per experimental gillnet from the study lakes . 60

2-8. Total density and biomass estimates of fish collected per hectare from the study lakes with rotenone and block-nets 64

2-9. Mean condition factors (K_{TL}) for subadult fish collected from the study lakes with electrofishing gear (standard errors in parenthesis) 68

2-10. Mean condition factors (K_{TL}) for adult fish collected from the study lakes with electrofishing gear (standard errors in parenthsis) 69

Page

2-11. Mean back calculated length at Age I and months to adult recruitment (i.e., $\geq$ 250 mm TL) for largemouth bass collected from the study lakes . 77

2-12. Mean daily growth rates (mm TL/day) tagged largemouth bass collected from the study lakes . 81

2-13. Mean daily growth rates (mm TL/day) of largemouth bass, by size group, collected from the study lakes and other Florida lakes . 96

3-1. Fish species occurrence in the study lakes based on electrofishing, experimental gillnets, and rotenone sampling. Open circles represent actual occurrence and dashed line represent species distribution across pH levels . . . 107

3-2. Species richness (number of species/lake) and Shannon-Weaver index (H') of species diversity for the study lakes 109

3-3. Species composition of the four fish assemblage patterns as indicated by cluster analysis . . 119

3-4. Results of discriminant function analysis of water chemistry data showing group means of individual variables 123

3-5. Results of discriminant function analysis of water chemistry data, listing multivariate statistics and F approximations 124

3-6. Results of canonical discriminant analysis, listing canonical correlation, eigenvalues, and total canonical structure of the three canonical variates derived from the analysis . 125

3-7. Documented (D) and undocumented (ND) occurrence of young-of-the-year fish collected by electrofishing, experimental gillnets, and rotenone sampling for all species in each lake . 128

3-8. Minimum pH values in the 12 study lakes in which adults and young-of the-year were collected. . 130

Page

4.1. Summary of the major parameters measured for fish populations in the study lakes and the environmental factor(s) implicated as strongly influencing each parameter . . . 149

A-1. The physiographic districts and subdivisions where the 12 study lake are located . . . 162

LIST OF FIGURES

Page

2-1. Location of the three geographic regions considered to be sensitive to further acidification 18

2-2. Relative abundance of fish species collected with electrofishing gear from Gobbler Lake, Florida . 37

2-3. Relative abundance of fish species collected with electrofishing gear from Lawbreaker Lake, Florida 38

2-4. Relative abundance of fish species collected with electrofishing gear from Lake Barco, Florida . 39

2-5. Relative abundance of fish species collected with electrofishing gear from Crooked Lake, Florida . 40

2-6. Relative abundance of fish species collected with electrofishing gear from Deep Lake, Florida. . 41

2-7. Relative abundance of fish species collected with electrofishing gear from Lake McCloud, Florida . 42

2-8. Relative abundance of fish species collected with electrofishing gear from Turkey Pen Pond, Florida 43

2-9. Relative abundance of fish species collected with electrofishing gear from Lofton Ponds, Florida . 44

2-10. Relative abundance of fish species collected with electrofishing gear from Lake Tomahawk, Florida 45

2-11. Relative abundance of fish species collected with electrofishing gear from Brock Lake, Florida 46

2-12. Relative abundance of fish species collected with electrofishing gear from Lake Suggs, Florida 47

Page

2-13. Relative abundance of fish species collected with electrofishing gear from Moore Lake, Florida 48

2-14. Mark-recapture estimates and 95% upper limits of adult ($\geq$ 250 mm TL) and subadult (150-249 mm TL) largemouth bass densities in the 10 study lakes where the species occurred 56

2-15. Relationship between mean density and biomass of fish collected per experimental gillnet from the study lakes and lake pH 61

2-16. Relationship between mean density and biomass of fish collected per experimental gillnet from the study lakes and lake total alkalinity . . . 62

2-17. Relationship between mean density and biomass of fish collected per experimental gillnet from the study lakes and lake chlorophyll a concentrations 63

2-18. Relationship between total density and biomass estimates of fish collected per hectare from the study lakes with rotenone and block-nets and lake pH 65

2-19. Relationship between total density and biomass estimates of fish collected per hectare from the study lakes with rotenone and block-nets and lake total alkalinity 66

2-20. Relationship between mean condition factors (K_{TL}) for adult largemouth bass collected from the study lakes with electrofishing gear and the width of lake littoral zone 74

2-21. Relationship between mean condition factors (K_{TL}) for adult largemouth bass collected from the study lakes with electrofishing gear and lake total nitrogen concentrations 75

2-22. Relationship between mean back calculated length at Age I for largemouth bass collected from the study lakes and lake pH and total alkalinity 78

2-23. Relationship between months to adult recruitment (i.e., $\geq$ 250 mm TL) for largemouth bass and lake pH and total alkalinity . . . 79

Page

3-1. Fish species richness (number of species per lake) in relation to mean lake pH for the 12 study lakes 110

3-2a. Fish species richness (number of species per lake) in relation to lake area for the 12 study lakes 111

3-2b. Fish species richness (number of species per lake) in relation to lake area for 11 study lakes, excluding Lake Suggs 111

3-3. Fish species richness (number of species per lake) in relation to lake total alkalinity for the 12 study lakes. 113

3-4. Fish species richness (number of species per lake) in relation to lake total nitrogen for the 12 study lakes. 114

3-5. Shannon-Weaver index (H') of fish species diversity in relation to lake pH and total alkalinity in the nine study lakes sampled with block-nets and rotenone. 115

3-6. Shannon-Weaver index (H') of fish species diversity in relation to the areal coverage of aquatic vegetation in the nine study lakes sampled with block-nets and rotenone . . . 116

3-7. Cluster dendrogram showing similarities in fish assemblage patterns based on the presence/absence data matrix of the 33 species collected from the 12 study lakes. . . . 117

3-8. Graphical representation of the distribution of the four lake groups along the first and second canonical variates derived from lake water chemistry data 126

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

FISH COMMUNITY STRUCTURE IN SOME NATURALLY ACID LAKES

By

Cecil Andre Jennings

May 1990

Chairperson: Wiley M. Kitchens
Major Department: Forest Resources and Conservation
(Fisheries and Aquaculture)

This study investigated the status of fish communities in 12 naturally acid Florida lakes. The small, shallow lakes were located in the Ocala National Forest, the Trail Ridge, and panhandle Florida; regions where lakes have low acid neutralizing capacities and are considered sensitive to further acidification from anthropogenic sources.

Fifteen species from seven families were captured during mark-recapture sampling. Warmouth (*Lepomis gulosus*) was the only cosmopolitan species in the study. Bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*), collected from 11 and 10 lakes, respectively, were also widely distributed species. Total fish abundance and biomass were not related to lake pH or total alkalinity.

Condition factors for fish in this study were comparable to published values. Condition factors of the sportfishes bluegill and largemouth bass were not related to lake pH or total alkalinity. Daily growth rates of Age I and older largemouth bass in all but one study lake were equivalent to literature values for Florida systems with pH values > 5. Back-calculated length at Age I and months to adult recruitment were below published values for the species.

Fish species richness and the Shannon-Weaver index (H') of species diversity were not related to lake pH, but were significantly correlated with total nitrogen concentrations and to the areal coverage of aquatic macrophytes, respectively.

Classification analysis suggested four fish assemblages, with each having consistent patterns of species composition. The four assemblages patterns ranged from species poor to species rich, with a shared core-group of species. Discriminant analyses of the limnological data indicated that the differences among lake groups were not significant. Fish assemblage patterns appear to be influenced more by lake isolation (i.e., degree of connectedness) than by lake pH.

Fish reproduction in the study lakes seems not to be affected by lake pH. At least sixteen fish species successfully reproduced in the acid conditions (i.e., 4.1 -

5.7) found in the study lakes. Many of these species, including the sportfishes largemouth bass and bluegill reproduced well below previously reported minimum values for the species.

CHAPTER 1
INTRODUCTION

Overview

The research findings presented in this dissertation are organized into two main chapters. Introductory and summary chapters are also included. The introductory chapter contains notes on the nomenclature used in the manuscript, a brief literature review of the causes and consequences of anthropogenic acidification, and general project objectives. In chapter two, consideration is given to measures of fish populations such as relative abundance, density, biomass, and condition. This treatment is limited to species $\geq$ 150 millimeters Total Length (mm TL), the minimum size used in the mark-recapture portion of the study. In chapter three, emphasis is placed on fish communities (i.e., all species collected), including fish assemblage patterns, measures of species diversity, and an assessment of fish reproductive success. The final chapter contains a general summary of chapters two and three, a discussion of research findings, and suggestions of other avenues for further investigation.

Nomenclature

The freshwater fish fauna of peninsula Florida has a relatively high percentage of endemism at the species, subspecies, and racial levels (Gilbert 1987). Some species such as largemouth bass (*Micropterus salmoides*), and bluegill (*Lepomis macrochirus*) have distinctive subspecies (i.e., *M. s. floridanus* and *L. m. mystacalis*) which are restricted to peninsular Florida (Gilbert 1987). Subspecific populations of these same species (i.e., *M. s. salmoides* and *L. m. macrochirus*) are known to occur in panhandle Florida (C.R. Gilbert, pers. comm.). Intergrades between two subspecies of pickerel; redfin pickerel (*Esox americanus americanus*) and grass pickerel (*E. a. vermiculatus*) are also known to occur in Florida (Crossman 1966). The lakes in this study were located in both peninsula and panhandle Florida; therefore, fish collected from the study lakes probably included different subspecies of the same fish, and subspecific intergrades. Consequently, taxonomic references in this dissertation will be limited to species level identification. The subspecies of mosquitofish (*Gambusia affinis holbrooki*) which occurs east of the Mobile Bay, Alabama, has recently been recognized as a distinct species, *G. holbrooki*; therefore, mosquitofish collected from the study lakes are identified as *G. holbrooki* (Wooten et al. 1988).

Anthropogenic Acidification

Acid rain is a catch-all term used to describe precipitation that has a pH lower than 5.6 (distilled water, equilibrated to atmospheric carbon dioxide, has a pH of 5.6) (Haines 1981). Acid precipitation is primarily caused by anthropogenic emission of nitrogen and sulfur oxides, which are byproducts of industrial processes, electrical power generation, and the combustion of fossil fuels (Gorham 1976). In the atmosphere, nitrogen and sulfur oxides combine with water vapor to form acid vapors. Condensation of acid vapors results in acid precipitation (e.g., rain, snow, and fog).

Anthropogenic acid precipitation has probably been occurring on a small scale since the industrial revolution. Industrial emissions were suspected of affecting human and plant health in and around industrial centers in 17th century England (Cowling 1982). However, it wasn't until the mid 1960s that acid rain was recognized as a regional phenomenon that reportedly had drastic affects in northern Europe, Canada and the northeastern United States (Wright and Gjessing 1976). More recently, acid precipitation has also been reported from the southeastern United States (Haines 1979; Brezonik et al. 1983). The reports of cultural acidification from northern Europe, the northeastern United States, and Canada were usually followed by reports of drastic changes in the population structures of lake biota.

Biotic Response to Acidification

In general terms, acid precipitation and the subsequent acidification of aquatic ecosystems are viewed as harmful to the biota in these systems. However, aquatic organisms appear not to be uniformly affected by cultural acidification. In some instances, both empirical and experimental evidence suggest that certain species are more affected than others. In other instances, the empirical and experimental evidence offer differing accounts of species response to low pH conditions. The following review presents evidence for and against cultural acidification as a process that adversely affects biotic communities.

Non-Fish Biota

Field and laboratory studies on the effects of acidification on decomposers in Norwegian waters found a shift in dominance from bacteria to fungi and a subsequent reduction in the decomposition rates of detrital matter when water pH was below 6.0 (Hendrey et al. 1976; Leivestad et al. 1976). Similar results were also reported by Traaen (1980). However, Schindler (1980) and Muller (1980) found no evidence of reduced decomposition rates in a 27 hectare Canadian lake that they intentionally acidified to a pH of 5.2. Other studies on the effects of acidification on decomposers also show similar discrepancies (see review by Haines 1981). Changes in microbial populations resulting from differences in sample collection and analysis are probably responsible for the conflicting results (Haines 1981).

Reports of the effects of lake pH on phytoplankton, periphyton and macrophyte species composition also show conflicting results. Many empirical and experimental studies have reported that phytoplankton species richness decreased as lake pH declined (Hendrey et al. 1976; Leivestad et al. 1976; Almer et al. 1978; Yan and Stokes 1978; Muller 1980). However, while some species disappeared with increased acidity, the biomass of the remaining species often increased (Hendrey et al. 1976; Leivestad et al. (1976). Reductions in microbial and invertebrate heterotrophic activity probably accounts for the increased biomass of the remaining species (Haines 1981). On the other hand, there were no changes in the number of phytoplankton species in an experimentally acidified Canadian lake (Schindler 1980). Furthermore, despite the tendency toward a reduction in species richness, phytoplankton production and biomass in acidic lakes may be similar in acid and non-acid lakes with similar phosphorus levels (Hendrey et al. 1976; Leivestad et al. 1976; Almer et al. 1978; Yan and Stokes 1978; Haines 1981). Similar results were also reported by Shearer et al. (1987).

The response of planktonic and benthic invertebrates to acidification appears to be similar to that of decomposers and primary producers. The available evidence include reports which found relationships between invertebrate species richness and biomass with lake pH, and reports which did not. Generally, the response of invertebrate communities to acidification appear to be group related.

Roff and Kwiatkowski (1977), Almer et al. (1978), Yan and Stokes (1978), and Haines (1981) all reported that zooplankton biomass was lower in acid than in non-acid lakes. Hendrey and Wright (1976), Almer et al. 1978, and Yan and Stokes (1978) also reported that zooplankton species richness decreased as lake acidity increased. Conversely, there are studies which suggest that zooplankton biomass in unrelated to lake pH. For example, Kettle et al. (1987) reported that the vertical distribution of three zooplankter species in a Canadian lake was influenced more by the vertical distribution of the phytoplankton community (i.e., zooplankton prey base) than by lower pH of the epilimnetic waters. Canfield (1983b) also reported that zooplankton communities in 165 acid and non-acid Florida lakes seemed to be influenced more by phosphorous and nitrogen concentrations than by lake pH.

Haines (1981) suggested that mollusks do not do well in acid environments because they have a high $CaCO_3$ requirement for shell formation. Leivestad et al. (1976) and Almer et al. (1978) noted that some crustacean species were not found in Scandinavian lakes with a pH of 6.0 or below. Fryer (1980) noted that on the Isle of Rhum, the number of crustacean species decreased as lake acidity increased, but suggested that other factors such as low calcium concentrations may also play a part in the exclusion of certain species.

Aquatic insects have shown differing responses to acidification. Species of Ephemeroptera and Plecoptera decline as lake pH declines, and 10 of 22 species of in Norwegian lakes were highly correlated with lake pH (Hendrey and Wright 1976). Similar results have been reported from England (Sutcliffe and Carrick 1973), and Ontario, Canada (Scheider and Dillon 1976). Under experimental laboratory conditions, Ephemeroptera were intolerant of low pH, while Plecoptera were moderately tolerant of the same conditions (Bell 1971). Similar results were reported under experimental field conditions in a New Hampshire stream acidified from pH $\geq$ 5.4 to pH 4.0 (Hall and Likens 1980). While these two groups appear to be adversely affected by low pH conditions, other groups of aquatic insects apparently thrive. For example, Coleoptera, Hemiptera and Megaloptera are more abundant in low pH lakes than in circumneutral lakes (Raddum 1980). Similar findings have been reported from Norwegian lakes (Haines 1981). Odonata, Heteroptera, and some Dipteran also tend to be abundant in lakes with pH levels between 4.2 to 5.0 (Haines 1981). These studies imply that some species are more acid-tolerant than others, and that the more acid-tolerant species benefit from competitive release when the less acid-tolerant species disappear. Competitive release may explain why some species actually expand their numbers with the onset of cultural acidification.

Fish

Acid precipitation has been suspected of altering natural fish populations for at least 70 years. The disappearance of Atlantic Salmon (*Salmo salar*) from a few southern Norwegian rivers in the 1920s was attributed to the low pH of those rivers (Jensen and Snekvik 1972). The decline has continued to the point where the catch of Atlantic salmon in those rivers is now nearly zero (Haines 1981). Populations of roach (*Rutilus rutilus*) were severely reduced in some Swedish lakes in the 1930s, as were pike (*Esox lucius*) in the 1940s, and perch (*Perca fluviatilis*) and eel (*Anguilla anguilla*) in the 1950s (Harvey 1982). These loses were blamed on cultural acidification (Harvey 1982). The disappearance of populations of lake trout (*Salvelinus namaycush*), lake herring (*Coregomus artedii*), white suckers (*Catostomus commersoni*), and other fish species from lakes in the La Cloche Mountains in Ontario, Canada, was attributed to increasing anthropogenic acidity (Beamish and Harvey 1972). Increased anthropogenic acidity was also suspected of eliminating entire fish communities, including brook trout (*Salvelinus fontinalis*), lake trout, white sucker, brown bullhead (*Ictalurus nebulosus*), and several cyprinids from lakes in the Adirondack Mountains of New York, USA over a 40-year period (Schofield 1976).

The evidence of drastic reductions in fish populations which are correlated with reductions in water pH comes primarily from empirical evidence. Despite what seems like clear evidence of anthropogenic acidification drastically reducing fish population, this is apparently not always the case. Many authors have acknowledged that population losses are sometimes partial, and that the remaining species often expand their numbers and show increased growth as other species are lost.

For example, brown trout, roach, and perch from acidified waters (pH 4.4 to 6.0) often showed larger size at age than fish from neutral waters (pH 6.5 to 7.0) (Harvey 1982). In the La Cloche Mountain lakes of Ontario, Canada, populations of yellow perch (Perca flavescens), pumpkinseed (Lepomis gibbosus), lake herring, bluegill, lake whitefish (Coregonus clupeaformis), and brown bullhead appear not to be affected down to pH level 5.0 (Harvey 1980). In another study, the abundance of lake trout and white sucker increased in the early stage of the experimental acidification of Lake 223, in the Experimental Lakes Area of Ontario, Canada (Mills et al. 1987). During the same time, lake trout growth remained constant, but white sucker growth increased. Although the growth rates of these two species were eventually reduced, the reductions were attributed to a scarcity of food organisms and not to the experimental acidification of the lake (Mills et al. 1987). Gunn et al. (1988) also studied fish populations from 20 Canadian lakes thought to be sensitive to acidification. They reported that many of the lakes contained fish species considered to be sensitive to low pH, and that species richness in these lakes was related to lake area, and not to lake pH. Estimated densities and biomass of all major species were similar to reported values from other lakes in the same area, and both lake trout and brown trout (*Salmo trutta*) successfully spawned in these lakes, despite episodes of acid runoff. Based on these findings, Gunn et al. (1988) concluded that the fish populations in these lakes did not exhibit anomalous population characteristics such as loss of species, reduced densities or biomass, or recruitment failure that could be related to acidification.

Mechanisms for Fish Population Losses

Direct mortality

The primary mechanisms responsible for the loss of fish from culturally acidified waters seem to be sudden mortality of adults over a short period of time, and gradual recruitment failure over a longer period of time. Acute mortality of fish in acid waters occurs primarily in streams, usually in association with episodic events (i.e., heavy autumn rains or snow melt) which rapidly reduce stream pH (Haines 1981). The physiological mechanisms involved in acid-induced mortality appear to be ion-regulatory failure, asphyxiation, or elevated heavy metal concentrations in conjunction with low pH (Schofield 1976; Muniz and Leivestad 1980; Haines 1981).

Black bullheads (*Ictalurus melas*) exposed to low pH waters exhibited swelling between outer gill lamellar and remaining tissue, erosion of the lamellae, and swelling of the gill filaments (McKenna and Duerr 1976). Such gill damage impairs respiratory, excretory and liver functions, which eventually causes death in the afflicted fish (Haines 1981). Brown trout exposed to toxic levels of aluminum (900 μg/L) at varying pH levels (4.0 to 6.0), experienced the maximum loss of plasma salts at pH 5.0 (Muniz and Leivestad 1980). In addition to ion loss (i.e. plasma salts), brown trout also exhibited severe mucus clogging of the gills, hyperventilation, and respiratory stress (Muniz and Leivestad 1980). These physiological stresses are probably the mechanisms by which fish succumb to high aluminum levels in low pH waters.

Reproductive and recruitment failure

Adult fish are more resistant to the effects of low pH than any of the other life history stages (Haines 1981). Thus, it is likely that population losses in acid waters are due to reproductive and recruitment failure rather than direct mortality of adult fish (Beamish and Harvey 1972; Beamish et al. 1975; Fritz 1980; Haines 1981; Harvey 1982). Reproductive failure may be brought about by many mechanisms, including a cessation of spawning behavior (Daye and Garside 1975; Fritz 1980), avoidance of suitable spawning areas because of low pH (Johnson and Webster 1977; Fritz 1980), gamete development failure, suspension of embryonic development, and deformed larvae (Fritz 1980).

Beamish et al. (1975) found lower than expected calcium levels in the ovaries of maturing females in acid waters, and suggested that the ova of the affected fish may not develop properly. Fritz (1980) noted that developing fish are influenced by environmental factors such as temperature and salinity, and suggested that low pH and calcium levels may have been responsible for deformities that Beamish (1972) observed in some fish from acid waters.

If successful spawning occurs, populations may still be lost through the failure of younger age classes to recruit into the adult population. Haines (1981) suggested that larval and juvenile fish are more susceptible to low pH than any other life history stage. Beamish and Harvey (1972) and Harvey (1980) reported that most of the fish populations they surveyed in acid lakes contained mainly older individuals, with few juveniles present. Such an age-class structure suggests that fish populations would eventually be lost as the older fish die and are not replaced by younger individuals.

Naturally Acid Waters

Records at the Academy of Natural Sciences of Philadelphia indicate that the existence of naturally occurring acid ($pH < 6.0$) lakes in the U.S. has been known at least since the late 1800s (Patrick et al. 1981). One such lake, Lake Annie, in Highlands County, Florida has probably been acidic for the past 40,000 years (Crisman

1984). Naturally occurring acid waters occur in several areas of the United States, including Wisconsin (Rahel 1982; Wiener 1983), Maine (Haines et al. 1986), Vermont (Haines et al. 1986), New Jersey (Hastings 1979; Patrick et al. 1979) and Florida (Meehean 1942; Crisman et al. 1980; Schulze 1980; Canfield 1983b; Canfield et al. 1983b; Crisman 1984; Keller 1984; Canfield et al. 1985; Williams et al. 1985). These lakes generally occur in regions with high rainfall and unproductive bedrock (Patrick et al. 1981; McWilliams et al. 1980) or in areas where the substrate is mostly sand (Patrick et al. 1981). Typically, these lakes have no external drainage, and many are associated with swamps and marshes (Rahel 1982; Wiener 1983; Williams et al. 1985).

Literature describing life histories and community dynamics of the biota in naturally occurring acid systems is rare. However, many such lakes do support algae, crustaceans, insects, and fish, suggesting that biota in these lakes have probably adapted to the low pH conditions (Patrick et al. 1981). Lake Annie, a 40,000-year-old acid lake in Highlands County, Florida, contains subfossil chironomids and cladocerans of the same genera that are common components in today's naturally acid lakes (Crisman 1984). Surviving fish populations have also been reported from isolated (i.e., seepage) acid pools in the Pine Barrens of New Jersey Cope (1896). Biotic communities have also been reported from acid waters in Wisconsin (Rahel 1982; Wiener 1983), Maine (Haines et al. 1986), Vermont (Haines et al. 1986), New Jersey (Hastings 1979; Patrick et al. 1979), and Florida (Meehean 1942, Crisman et al. 1980; Schulze 1980; Canfield 1983b; Crisman 1984; Keller 1984; Canfield et al. 1985; Williams et al. 1985).

The existence of naturally occurring acid waters which support self-sustaining biotic communities suggests that lake pH may not be adversely affecting the respective biotic communities. There are many such lakes in Florida, many of which may be sensitive to further acidification because of low acid neutralizing capacities (Canfield 1983b). Some of these poorly buffered, acid lakes in northcentral Florida have already been influenced by acid precipitation, but the impact has been slight, averaging 0.5 pH units over the past 20 years (Crisman et al. 1980).

In this dissertation, I present the results of an investigation into fish community structure and population dynamics in 12 naturally acid Florida lakes. The general objectives of this research were to 1) quantify aspects of the population dynamics of selected species, 2) characterize species distribution and associations, and 3) quantify relationships between species distribution, and population dynamics to the morphoedaphic factors in the study lakes.

CHAPTER 2
ABUNDANCE, BIOMASS, GROWTH, AND CONDITION OF SELECTED FISH SPECIES IN SOME NATURALLY ACID FLORIDA LAKES

Introduction

Florida has the highest percentage of acid lakes in the eastern United States (Linthurst et al. 1986). Many of these lakes may be sensitive to further acidification (Canfield 1983b), and may be threatened due to increased acidity of Florida's rainwater (Brezonik et al. 1983). Public concerns about the sensitivity of Florida's softwater lakes to further acidification are based in part on the potential for losses in fishery resources. There are many reports of significant reductions in, or complete losses of fish populations from areas in the northeastern United States, Canada, and Northern Europe where cultural acidification has occurred (Haines 1981). Currently, there are no published accounts of major losses of fish populations from Florida's acid lakes, and published accounts of fish population dynamics in Florida's most sensitive waters are rare.

The available fisheries literature from Florida's acid lakes documents the existence of reproducing fish populations. The early studies surveyed species assemblages, and the abundance and biomass of the fish communities in these lakes (Meehean 1942; Dickinson 1948). More recently, several authors investigated selected aspects of fish biology (Schulze 1980; Keller 1984; Canfield et al. 1985; Lamia 1987) and population ecology (Keller 1984; Lamia 1987) in low pH conditions. This sparse literature suggests that factors other than lake pH, such as lake productivity, may be influencing fish population dynamics in Florida's naturally acid lakes.

This chapter presents results of an investigation into the population dynamics of selected fish species, primarily the sportfishes, largemouth bass and bluegill, from 12 naturally acid Florida lakes. The primary objective of this inquiry was to test the hypothesis that sportfish abundance and biomass in the study lakes were not related to lake pH. Other objectives were to 1) determine the relative abundance, density, biomass, and condition of selected species in the study lakes, 2) determine the growth of largemouth bass in the study lakes and 3) quantify any relationships that may exist between the abundance, density, biomass, condition, and growth of selected species and lake morphoedaphic factors.

Methods

Lake Selection

Many factors contributed to the selection of the 12 study lakes. Initially, personnel from the Florida Department of Environmental Regulation, the U.S.

Environmental Protection Agency, and KNB Engineering and Applied Sciences of Gainesville, Florida, selected potential study lakes from the population of lakes sampled by the U.S. Environmental Protection Agency during Phase I (Eastern Lakes Survey) of the National Surface Water Survey (Linthurst et al. 1986). Four lakes from each of three geographic regions considered to be sensitive to acidification comprised the original population of study lakes. Lakes in these regions are considered sensitive to further acidification because they typically have low acid neutralizing capacities. The general geographic regions of interest were the Florida panhandle, the Trail Ridge of north Florida, and the Ocala National Forest in northcentral Florida (Figure 2-1). A more precise listing of the physiographic regions where the study lakes occurred is presented in Table A-1.

Onsite inspection of prospective study lakes indicated that many could not be sampled. Some of the lakes were located on the Camp Blanding Military Reserve and could not be sampled due to scheduled military exercises. Other lakes were either on private property whose owners would not grant permission to sample the lake, were inaccessible by truck, or had dried up due to drought conditions. Crooked Lake and Lake Tomahawk in the Ocala National Forest, and Lofton Ponds, Moore Lake, and Turkey Pen Pond in the Florida panhandle were the only lakes from the original list of potential study lakes that could be sampled. Personnel from

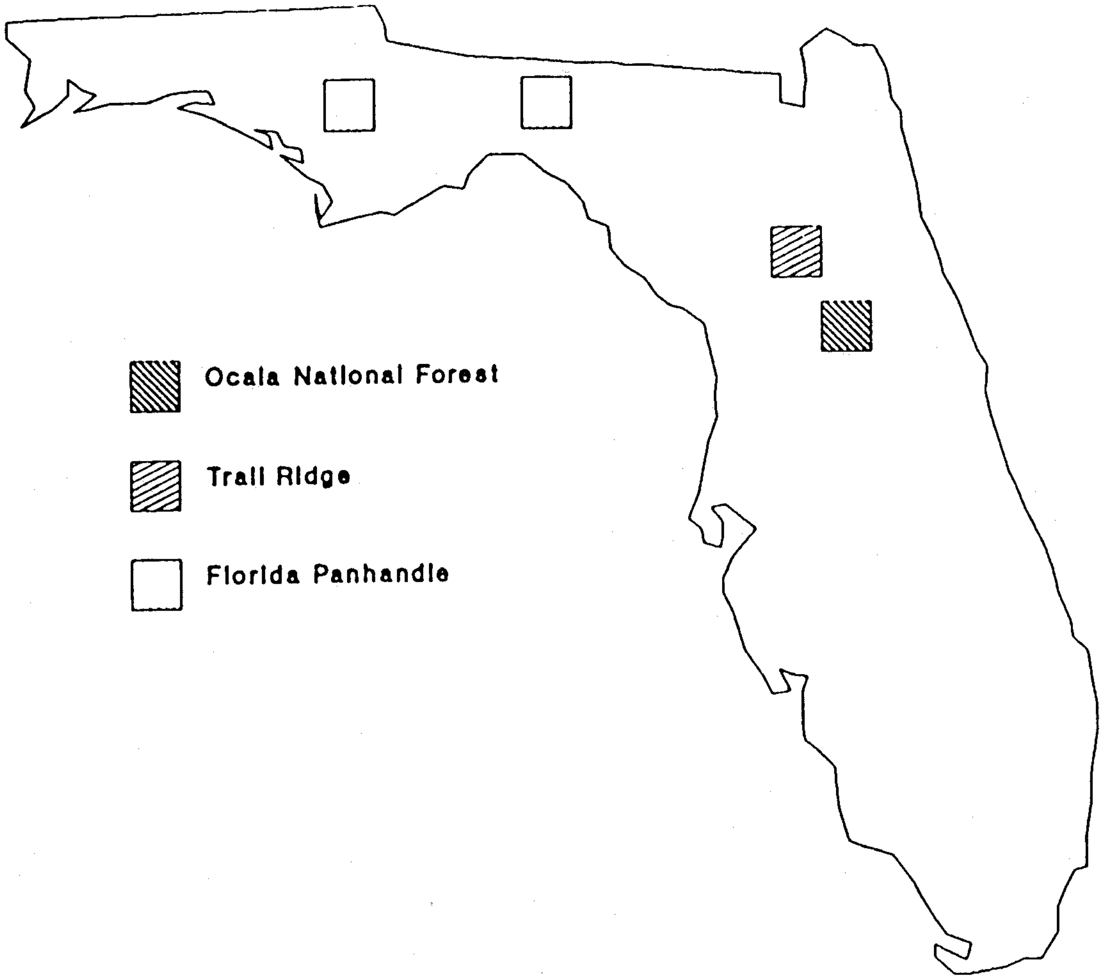


Figure 2-1. Location of the three geographic regions considered to be sensitive to further acidification.

the Department of Fisheries and Aquaculture recommended several substitute study lakes from the geographic regions of interest. The lake selection committee accepted Gobbler and Lawbreaker lakes in the Ocala National Forest, and lakes Deep, McCloud, Barco and Suggs in the Trail Ridge. Curtis E. Watkins of the Florida Department of Environmental Regulation selected Brock Lake in Washington County as the final study lake (Table 2-1).

Fish Sampling

Intensive fisheries sampling on the study lakes began in March 1987 and continued through December 1988. Fish were collected by use of electrofishing gear, experimental gillnets, and fish toxicants. The electrofishing boat was equipped with a 5 kilowatt portable generator and Coffelt VVP-15 or Coffelt VVP-20-4000 electrofishing unit. The experimental gillnets were 50 m long, with each net having five 10 m panels with different sized mesh (i.e., 19, 25, 38, 51, and 76 mm stretched mesh). The fish toxicant rotenone, at 5% active concentration, was used in conjunction with 0.08 hectare block-nets (1 cm stretched mesh) during the summers of 1987 and 1988.

Pulsed alternating current was used to collect fish samples from the littoral areas of the study lakes during daytime and nighttime sampling periods. Each fish collected was identified to species, measured, weighed, marked, and released. Fish $\geq$ 150 millimeter total length (mm TL), were

Table 2-1. Location, surface area and mean depth of study lakes.

Lake	County Township and Range	Surface Area (ha)	Mean Depth (m)
Gobbler	Lake-T15S-R27E-S29	10	3
Lawbreaker	Lake-T15S-R27E-S29	5	4.3
Barco	Putnam-T09S-R23E-S28	13	4.4
Crooked	Lake-T15S-R27E-S33	8	2.3
Deep	Putnam-T09S-R23E-S12	4	3.0
McCloud	Putnam-T09S-R23E-S21	9	3.0
Turkey Pen Pond	Calhoun-T02N-R11W-S24	6	5.0
Lofton Ponds	Leon-T01S-R02W-S36	16	2.9
Brock	Washington-T03N-R16-S29	11	-
Tomahawk	Marion-T16S-R24E-S03	15	4.4
Suggs	Putnam-T09S-R23E-S29	73	1.9
Moore	Leon-T01S-R02W-S14	28	2.9

measured to the nearest mm TL, weighed to nearest gram (g), and marked with a pelvic fin clip or pectoral spine clip. Largemouth bass were also marked with a numbered Floy tag. Population size was estimated for selected species (i.e., species large enough to be marked, with enough marked individuals to allow subsequent recaptures) with Chapman's modification of the Schnabel formula for population estimation using multiple censuses (Ricker 1975). This formula follows the form

$$\hat{N} = \Sigma\ (C_i * M_i)\ /\ R + 1$$

where C_i is the catch at the ith interval, M_i is the number marked at large during the ith interval, and R is the total number of recaptures. Confidence intervals were calculated according to Ricker (1975). Population density and biomass estimates were calculated using equations A and B, respectively.

A. $D = \hat{N} / A$

B. $B = (\hat{N} * MW) / A$

where D is the estimated density of individuals per hectare, $\hat{N}$ is estimated population size, A is the area of the lake in hectares, B is the estimated biomass of individuals per hectare, and MW is the mean weight per individual of the species. Confidence intervals for density and biomass were calculated by replacing the value of $\hat{N}$ in equations A and B above with the value of the upper and lower confidence limit of the populations of interest, as calculated using the Modified Schnabel formula.

Experimental gillnets were also used to assess relative fish abundance in the study lakes. Four experimental gillnets were fished along the bottom of each lake once during each quarter for the duration of the study. One gillnet set was made perpendicular to the north, south, east and west shores of each study lake, and fished along the bottom for approximately 24 hours. All fish caught were separated by species, divided into successively larger 40 mm TL size groups, enumerated, and weighed by species and size group. Length-weight relationships calculated from the electrofishing data provided reliable weight estimates for all decomposed or partially eaten fish found in the gillnets.

Nine of the 12 study lakes were sampled with rotenone. Other considerations prohibited the use of this sampling method in the three remaining lakes. Gobbler Lake was inaccessible to the large boats used to carry the block-nets, Lake McCloud was the site of ongoing experiments that would be jeopardized by the use of rotenone, and Brock Lake supported a fee-fishery that would be damaged with the introduction of rotenone to the lake. Two 0.08 hectare block-nets were set in both the littoral and limnetic zones of each lake, and were sampled according to Shireman et al.

(1981). Briefly, this process included setting out the block-nets, applying rotenone, and dipnetting fish as they come to the surface. Dead fish were collected inside the block-nets for an additional two days after the initial rotenone application. Density and biomass estimates were calculated for each fish species in each net, and weighted by the extent of the habitat (i.e., percentage of total) to obtain whole-lake estimates.

Age, Growth and Condition

Growth rates of largemouth bass were calculated from recaptured tagged specimens and from otoliths removed from largemouth bass killed during gillnetting or rotenone sampling. Whole otoliths, measured according to Hoyer et al. (1985), were used to back-calculate lengths at age. Lengths at age were calculated using the Bagenal and Tesch (1978) modification of the direct proportion method of back-calculating lengths at age. The modified formula follows the form

$$\text{Log } L_n = \text{Log } L + b\ (\text{Log } S_n - \text{Log } S)$$

where L_n is the total length of the fish when the annulus was formed, L is the total length of the fish at the time the otolith was taken, S_n is radius of the annulus n, S is the total radius of the otolith, b is the slope of the otolith radius-body length regression line, and Log refers to base 10 logarithm (Bagenal and Tesch 1978). Coefficients of condition (K) for selected species were calculated using the formula

$$K = W * 100{,}000 / L^3$$

where K is the coefficient of condition, W is the weight of the fish in grams, and L is the total length of the fish in millimeters (Anderson and Gutreuter 1983).

Limnological Sampling

Lake surface areas and shoreline lengths were calculated using Florida Department of Transportation aerial photographs (1:24,000 scale), and a planimeter and cartometer, respectively. A boat-mounted Raytheon recording fathometer was used to make representative bottom tracings of all lakes except Brock. The tracings were made by running four to ten transects across each lake, depending on the size of the lake. Mean depth and coverage of submerged aquatic macrophytes were calculated from the fathometer tracings using the methods of Maceina and Shireman (1980).

Water samples were collected from three open water stations in each of the study lakes. One station in each lake was located at the deepest point in the lake. The Trail Ridge and the Ocala National Forest lakes were sampled 10 to 13 times, and the panhandle lakes, except Brock, were sampled at least six times. Brock Lake was sampled five times. Water temperature and dissolved oxygen concentration were measured at the surface (0.5 m) of each station, and at one meter intervals at the deep station with a Yellow Springs Instruments (YSI) Model 51a dissolved oxygen/temperature meter. Water clarity was measured at the deep station using a 20 cm Secchi disc. Surface (0.5 m) water samples were collected in acid-washed, triple-rinsed, 1-Liter Nalgene bottles. The water samples were placed on ice and transported back to the water chemistry laboratory for analyses by Department of Fisheries and Aquaculture personnel. The collected water samples were analyzed to determine pH, total alkalinity, total acidity, specific conductance, color, and aluminum, chloride, magnesium, sodium, potassium, sulfate, total nitrogen, total phosphorus, and chlorophyll a concentrations.

PH was determined within 24 hours of collection with an Orion Model 601A pH meter calibrated with buffers of pH 4.0, 7.0, and 10.0. Total alkalinity was determined by titration with 0.02 N H_2SO_4. To avoid interference from silicates, phosphorus, and other materials, all titrations were taken to an endpoint of pH 4.5 (APHA 1985). In low alkalinity samples, the equivalence point occurs at pH greater than 4.5; therefore, the reported alkalinities may be slightly higher than the true alkalinities in the study lakes. Total acidity was determined by titration with 0.02 N NaOH to an endpoint of pH 8.3 (APHA 1985). Titration endpoints for total alkalinity and total acidity were determined with the Orion Model 601A pH meter.

Specific conductance was measured with a YSI Model 31 conductivity bridge. Aluminum concentrations were measured colorimetrically with Hach AluVer III aluminum reagent (Hach Chemical Company 1975), and a Perkin Elmer Model 552 spectrophotometer. Chloride concentrations were measured by titration with 0.0141 N mercuric nitrate. The endpoints were determined with diphenylcarbazone (Hach Chemical Company 1975). Total phosphorus concentrations were determined following the methods of Murphy and Riley (1962), after a persulfate digestion in a boiling water bath (Menzel and Corwin 1965). Total nitrogen was determined with a modification of the Kjeldahl method (Nelson and Sommers 1975).

Water samples were analyzed for color, sulfate, sodium, calcium, magnesium, and potassium, after filtration through a Gelman type A-E glass fiber filter. Color was determined with the platinum-cobalt method and matched Nessler tubes (APHA 1985). Sulfate concentrations were determined with a turbidimetric method and SulfaVer IV sulfate reagent (Hach Chemical Company 1975). Sodium, calcium, magnesium, and potassium were determined with atomic absorption spectrophotometry.

The concentration of planktonic algae in each lake was estimated by measuring chlorophyll a concentrations. A measured portion of lake water was filtered through a Gelman type A-E glass fiber filter. The filter was blotted dry, placed on silica gel desiccant, and frozen for no longer than two months. Chlorophyll a concentrations were determined by the methods of Richards and Thompson (1952) and Yentsch and Menzel (1963). Chlorophyll a values were calculated using the equations of Parsons and Strickland (1963). Values were not corrected for pheophytin.

Aquatic Macrophyte Sampling

Aquatic macrophyte abundance was measured on all study lakes except Brock. Measurement were made following the methods of Maceina and Shireman (1980). Briefly, this process includes using a boat mounted fathometer to estimate the percent of areal coverage, and percent of lake volume occupied by aquatic vegetation. Ten randomly selected sampling transects were established around the perimeter of each lake. The width of the emergent plant zone at each transect was measured with a calibrated range finder. Macrophyte biomass was determined from plant samples collected from within 0.25 m^2 quadrats placed in the submerged, floating-leaved, and emergent plant zones (30 stations per lake). Excess water was removed from the plant samples, which were then weighed to the nearest 0.10 kilogram fresh weight.

Fish Stocking

Largemouth bass were not present in electrofishing samples from Lake Gobbler (pH 4.1) and Lawbreaker Lake (pH

4.4), the two most acid study lakes. To determine if this species could survive and reproduce in these lakes, specimens $\geq$ 250 mm TL were taken from nearby Crooked Lake (pH 4.6) and stocked into Lawbreaker Lake (pH 4.4) and Lake Gobbler (pH 4.1).

Data Analysis

Equations used to calculate estimates of fish population, density, biomass, and back calculate lengths at age are presented in the respective sections. Simple linear correlation and partial linear correlation procedures were used to quantify relationships between fish abundance parameters and lake morphoedaphic parameters. Correlation coefficients and partial correlation coefficients were determined using Statistical Analysis System procedures (SAS 1988).

Results

Lake Morphometry and Water Chemistry

The 12 study lakes were small and shallow, ranging in size from 4 to 73 hectares, and mean depth ranging from 1.9 to 5.0 meters (Table 2-1). Mean pH values in the study lakes ranged from 4.1 to 5.7 (Table 2-2). Ten of these lakes had mean pH values below 5.0, and seven had mean pH values below 4.8. Moore Lake and Lake Suggs were the two lakes with mean pH values of 5.0 or above. Mean total alkalinity ranged from 0.0 to 2.3 mg/L as $CaCO_3$, and mean total acidity ranged from 3.4 to 15.0 mg/L as $CaCO_3$ (Table

Table 2-2. Means, standard errors, and sample size of limnological parameters measured in the study lakes.

Parameter		Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Pond	Brock	Tomahawk	Suggs	Moore
pH	$\bar{x}$	4.1	4.4	4.5	4.6	4.6	4.6	4.7	4.8	4.9	4.9	5.0	5.7
	SE	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.06	0.09	0.03	0.05	0.05
	N	12	13	13	13	10	11	8	7	5	12	12	8
Alkalinity (mg/L as $CaCO_3$)	$\bar{x}$	0	0	0.1	0.3	0.3	0.3	0.5	0.9	1.1	1.1	1.9	2.3
	SE	0	0	0.04	0.05	0.09	0.06	0.07	0.1	0.2	0.07	0.1	0.08
	N	12	13	13	13	10	11	8	7	5	12	12	8
Acidity (mg/L as $CaCO_3$)	$\bar{x}$	15	6.4	4.7	5.4	4.7	4.3	4.1	6.1	6.1	3.4	8.9	3.4
	SE	0.4	0.1	0.2	0.1	0.2	0.2	0.1	0.6	0.6	0.1	0.9	0.2
	N	12	13	13	13	10	11	8	5	5	12	12	8
Color (Pt-Co units)	$\bar{x}$	260	0	1	4	3	1	1	28	28	3	280	25
	SE	25	0	0.5	0.8	0.6	0.7	0.7	8	8	0.9	32	3
	N	12	13	13	13	10	11	8	5	5	12	12	8
Specific Conductance (µS/cm at 25C)	$\bar{x}$	69	65	43	46	37	42	20	21	21	34	56	16
	SE	0.8	0.9	0.5	0.6	0.5	0.9	0.5	1.5	1.5	0.4	2	0.4
	N	12	13	13	13	10	11	8	5	5	12	12	8
Calcium (mg/L)	$\bar{x}$	0.7	0.8	0.8	1.1	0.3	0.7	0.4	0.6	0.6	0.6	1.4	0.6
	SE	0.04	0.02	0.05	0.07	0.03	0.02	0.03	0.04	0.04	0.02	0.06	0.01
	N	12	12	13	13	10	11	7	5	5	12	12	7
Magnesium (mg/L)	$\bar{x}$	1.0	1.3	0.7	0.8	0.6	0.8	0.2	0.4	0.4	0.6	1.4	0.5
	SE	0.01	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.03	0.02
	N	12	12	13	13	10	11	7	5	5	12	12	7
Sodium (mg/L)	$\bar{x}$	5.0	4.6	3.2	3.7	3.2	3.5	1.2	1.3	1.5	3.6	5.2	1.5
	SE	0.09	0.06	0.05	0.09	0.04	0.09	0.02	0.02	0.06	0.03	0.2	0.06
	N	12	12	13	13	10	11	7	6	5	12	12	7

Table 2-2. Continued.

Parameter		Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Pond	Brock	Tomahawk	Suggs	Moore
Potassium (mg/L)	$\bar{x}$	0.2	0.8	0.2	0.1	0.2	0.2	0.3	0.2	0.4	0.2	2.4	0.1
	SE	0.02	0.03	0.01	0.02	0.02	0.01	0.01	0.01	0.1	0.01	0.2	0.01
	N	12	12	13	13	10	11	7	6	5	12	12	7
Aluminum (mg/m^3)	$\bar{x}$	100	260	86	80	68	55	60	34	70	47	84	32
	SE	0.01	9	4	6	6	6	10	5	6	4	6	6
	N	12	12	12	12	9	11	6	6	5	11	12	6
Chloride (mg/L)	$\bar{x}$	11	8.0	5.9	7.4	6.8	6.8	2.5	3.1	3.4	7.0	14	3.3
	SE	0.5	0.2	0.3	0.2	0.4	0.4	0.2	0.3	0.4	0.3	0.8	0.2
	N	12	13	13	13	10	11	8	7	5	12	12	8
Sulfate (mg/L)	$\bar{x}$	6.5	11	6.3	5.4	4.2	5.5	2.5	2.7	3.0	3.5	3.7	2.0
	SE	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.6	1.4	0.1	0.8	0.4
	N	12	12	12	12	9	11	6	6	5	11	12	6
Total Nitrogen (mg/m^3)	$\bar{x}$	650	120	100	310	160	170	140	420	350	200	840	390
	SE	52	24	19	38	10	10	10	23	35	18	18	14
	N	11	11	12	11	9	10	6	5	4	12	11	6
Total Phosphorus (mg/m^3)	$\bar{x}$	7	4	3	9	2	4	2	3	99	6	54	5
	SE	0.9	2	0.4	2	0.3	0.2	0.2	0.4	23	3	4	0.7
	N	12	13	13	13	10	11	7	6	5	12	12	7
Chlorophyll _a_ (mg/m^3)	$\bar{x}$	5.3	0.8	0.8	5.3	0.9	1.8	0.7	1.3	11	1.6	5.9	2.8
	SE	0.5	0.1	0.1	3.0	0.2	0.2	0.06	0.3	7	0.2	0.8	0.6
	N	12	13	13	13	10	11	8	7	4	12	12	8
Secchi (m)	$\bar{x}$	0.7	5.2	5.2	2.9	4.1	4.4	3.7	2.9	1.5	4.3	0.6	3.7
	SE	0.08	0.3	0.6	0.1	0.1	0.1	0.3	0.3	0.3	0.2	0.1	1.2
	N	8	7	5	8	3	4	5	5	3	6	6	5

Table 2-2. Continued.

Parameter		Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Pond	Brock	Tomahawk	Suggs	Moore
Surface oxygen (mg/L)	$\bar{x}$	6.0	7.6	7.4	7.2	7.1	7.0	7.7	7.0	6.5	7.2	6.2	8.3
	SE	0.3	0.4	0.3	0.4	0.4	0.3	0.5	0.5	0.6	0.3	0.4	0.6
	N	8	10	5	9	7	4	5	5	3	7	6	5
Bottom oxygen (mg/L)	$\bar{x}$	0.6	7.3	6.4	5.6	5.9	5.6	6.6	5.0	3.6	4.6	2.1	5.4
	SE	0.3	0.4	0.3	0.8	0.9	1.0	0.4	0.8	1.7	0.8	0.7	1.1
	N	8	10	4	9	7	4	5	5	3	7	5	5

2-2). Seven of the study lakes had mean color values below 5.0 Pt-Co units. Lake Suggs and Gobbler Lake were highly (> 250 Pt-Co) colored units (Table 2-2). Mean specific conductance of the study lakes ranged from 16 to 69 µS/cm at 25°C. Mean calcium and magnesium concentrations ranged from 0.3 to 1.4 and 0.2 to 1.4 mg/L, respectively (Table 2-2). Mean potassium concentrations ranged from 0.1 to 2.4 mg/L, but most were below 0.4 mg/L (Table 2-2). Mean sodium and chloride concentrations ranged from 1.2 to 5.2, and 2.5 to 14 mg/L, respectively. Mean sulfate concentrations ranged from 2.0 to 11 mg/L. Mean aluminum concentrations ranged from 32 to 260 mg/m^3, with 10 lakes having averages below 100 mg/m^3 (Table 2-2). Mean total nitrogen concentrations ranged from 100 to 840 $mg/m^{3.}$ and mean total phosphorus concentrations ranged from 2 to 99 mg/m^3. Mean water transparency ranged from 0.6 to 5.5 m, and mean chlorophyll a concentrations ranged from 0.7 to 11 mg/m^3 (Table 2-2).

Macrophytes

The areal coverage of aquatic macrophytes in the study lakes ranged from 1% in Lawbreaker Lake to 97% in Deep Lake (Table 2-3). The portion of lake volume occupied with aquatic macrophytes ranged from <1% in Lake Gobbler to 22% in Lofton Ponds, and the width of the littoral zone in the study lakes ranged from 8 m in Turkey Pen Pond, Deep Lake and Lake Gobbler to 32 m in Moore Lake (Table 2-3). Standing crop (fresh weight) of emergent, floating, and submerged

Table 2-3. Abundance of aquatic macrophytes measured in the study lakes.

Parameter	Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Pond	Tomahawk	Suggs	Moore
Percent Areal Coverage	3	1	37	27	97	78	17	87	43	14	40
Percent Volume Occupied	<1	<1	1	3	21	3	3	22	12	<1	14
Width of Littoral (m)	8	10	9	20	8	9	8	22	17	14	32
Emergent Macrophyte Standing Crop (kg fresh wt./m^2)	6.8	3.8	6.4	27	11	3.7	0.9	1.1	5.7	3.5	6.9
Floating Leaf Macrophyte Standing Crop (kg fresh wt./m^2)	1.2	0	0	3.8	2.5	0.2	0	2.3	1.9	1.7	0.7
Submerged Macrophyte Standing Crop (kg fresh wt./m^2)	<0.1	0.1	2.8	2.4	12	1.1	0.2	2.6	3.6	<0.1	5.1

macrophytes in the study lakes ranged from 0.9 to 27, 0 to 3.8, and <0.1 to 12 kg/m^2, respectively (Table 2-3).

Fish Abundance--Electrofishing

During electrofishing sampling on the 12 study lakes, 6,923 fish, representing fifteen species from seven families, were caught, marked and released (Table 2-4). The families represented in the mark-recapture estimates were Centrarchidae, Catostomidae, Ictaluridae, Esocidae, Amiidae, Lepisosteidae, and Cyprinidae. The number of fish marked and released per lake ranged from 36 fish in Gobbler Lake to 1175 fish in Crooked Lake (Table 2-4). The relative abundance of each marked species varied among the study lakes (Figures 2-2 to 2-13).

In descending order, warmouth (*Lepomis gulosus*), bluegill, and largemouth bass were the most widely distributed species in the 12 study lakes. Of the 15 species collected during mark-recapture sampling, only one species, warmouth, was collected from all study lakes (Table 2-4). The relative abundance of warmouth ranged from 0.9% in Lake McCloud to 20% in Lawbreaker Lake (Figures 2-7 and 2-3, respectively). Generally, warmouth represented less than 7% of the fish greater than 150 mm TL collected by electrofishing. Brock Lake was the only lake where sufficient numbers of warmouth were marked to obtain a population estimate. The estimated density and biomass of warmouth in Brock Lake was 5 fish/hectare and 1.2

Table 2-4. Total number of fish ≥ 150 mm TL captured, by species, with electrofishing gear from the study lakes.

	Lake											
Species	Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
Lepisosteus platyrhincus	3				35						103	
Lepisosteus osseus					9						3	
Amia calva	4				1						82	
Esox americanus	3				23			49		11	17	27
Esox niger								93		13	31	209
Notemigonus crysoleucas				5							9	
Erimyzon sucetta	9	114		602	194		367	215	431	136	94	
Ictalurus natalis				27	8				6	42	33	6
Ictalurus nebulosus											10	
Lepomis gulosus	2	28	8	45	26	4	8	16	9	24	58	54
Lepomis macrochirus	15		322	197	108	207	22	27	107	180	436	119

Table 2-4. Continued.

	Lake											
Species	Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
Lepomis microlophus					1						31	
Micropterus salmoides			84	292	118	226	83	124	338	181	42	308
Pomoxis nigromaculatus				7							41	
Centrarchus macropterus											1	
Total	36	142	414	1175	523	437	480	524	891	587	991	723

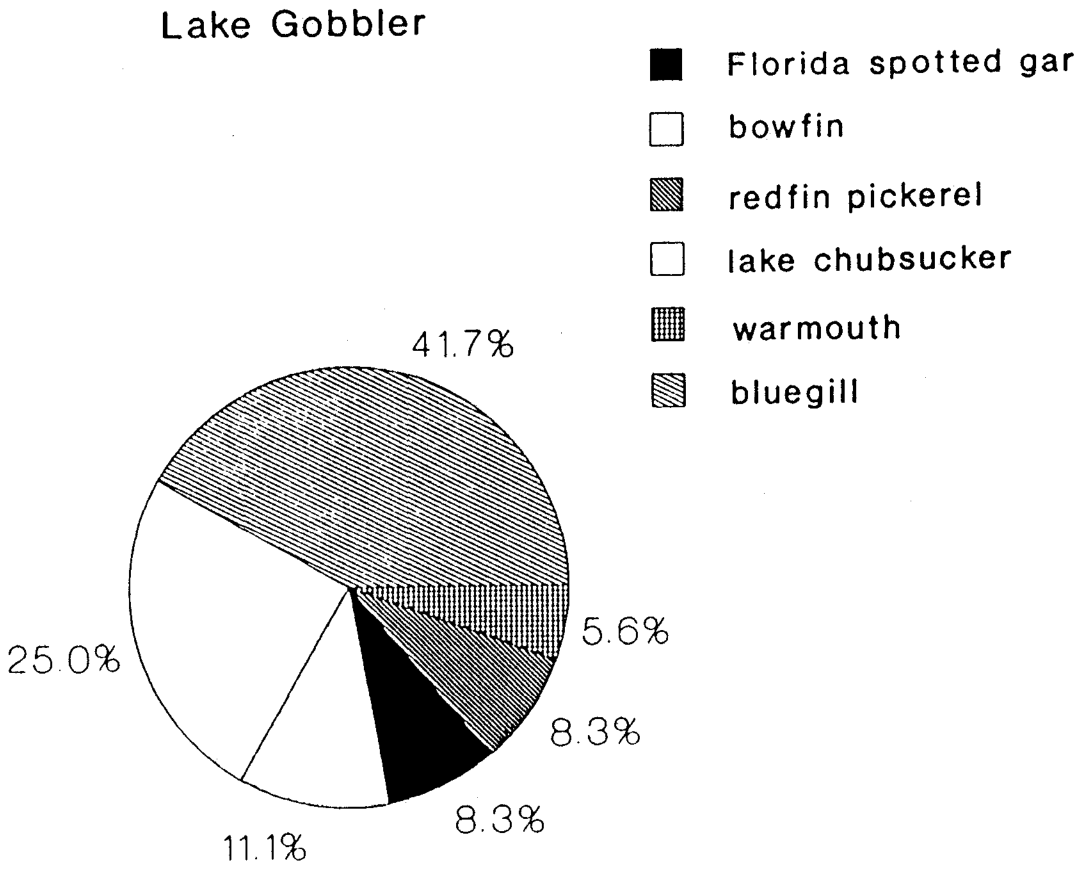


Figure 2-2. Relative abundance of fish species collected with electrofishing gear from Gobbler Lake, Florida.

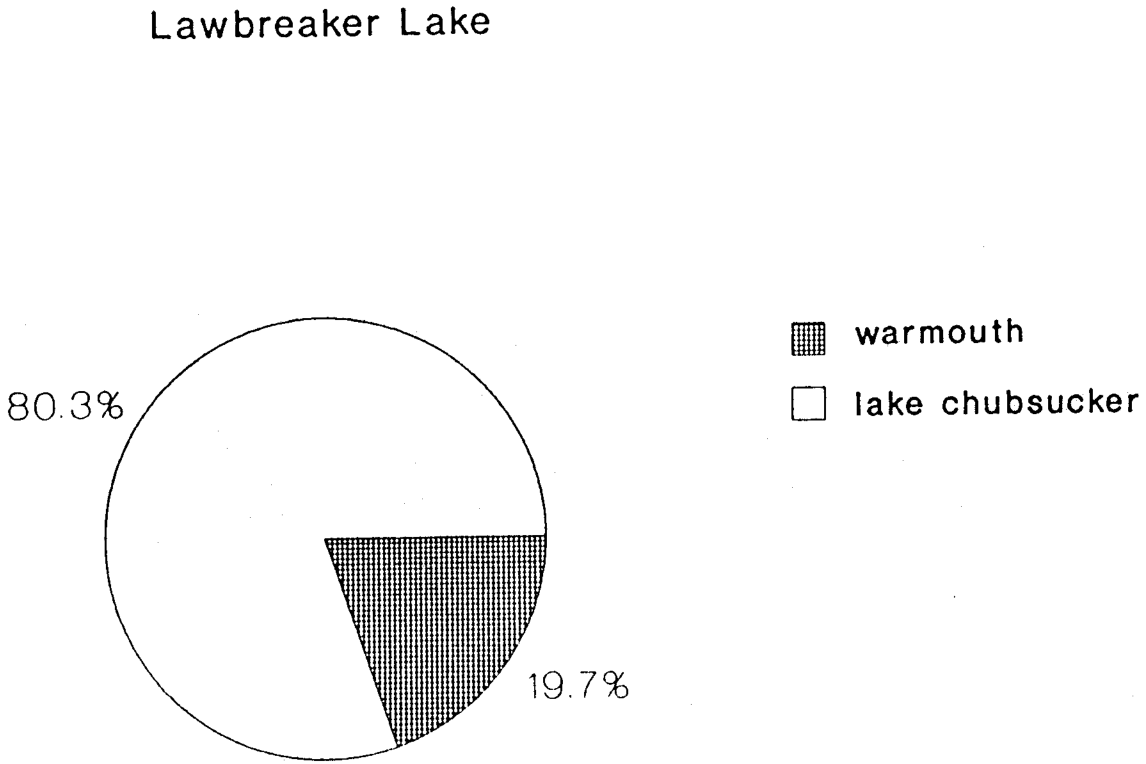


Figure 2-3. Relative abundance of fish species collected with electrofishing gear from Lawbreaker Lake, Florida.

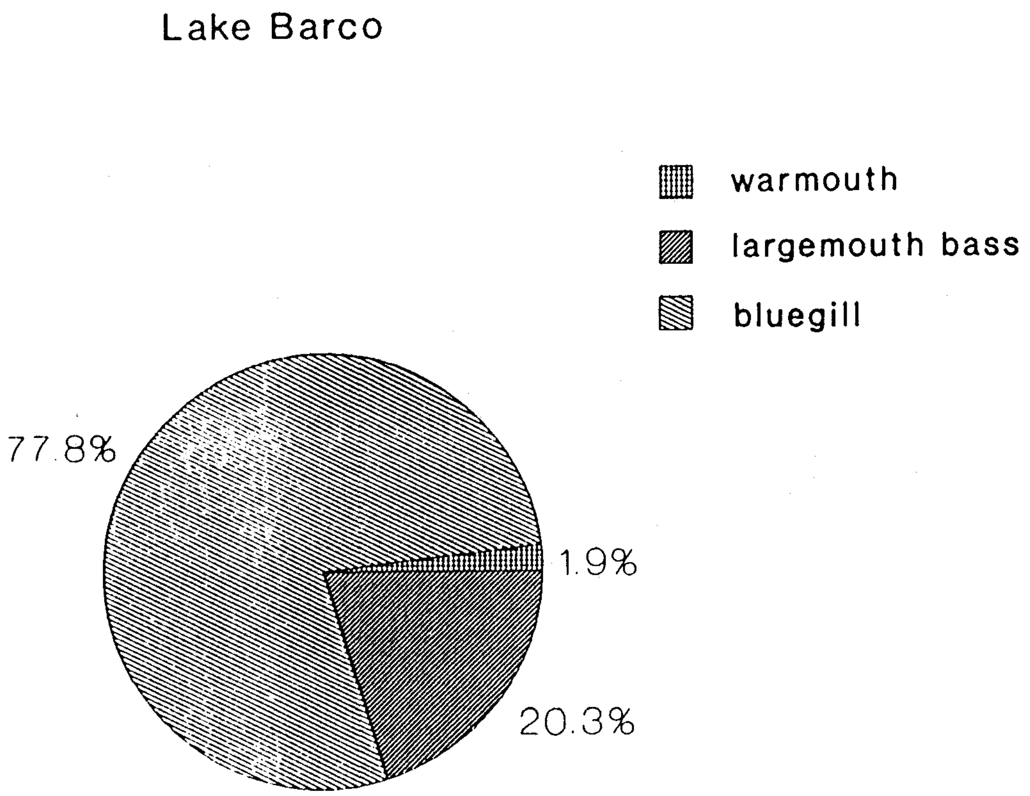


Figure 2-4. Relative abundance of fish species collected with electrofishing gear from Lake Barco, Florida.

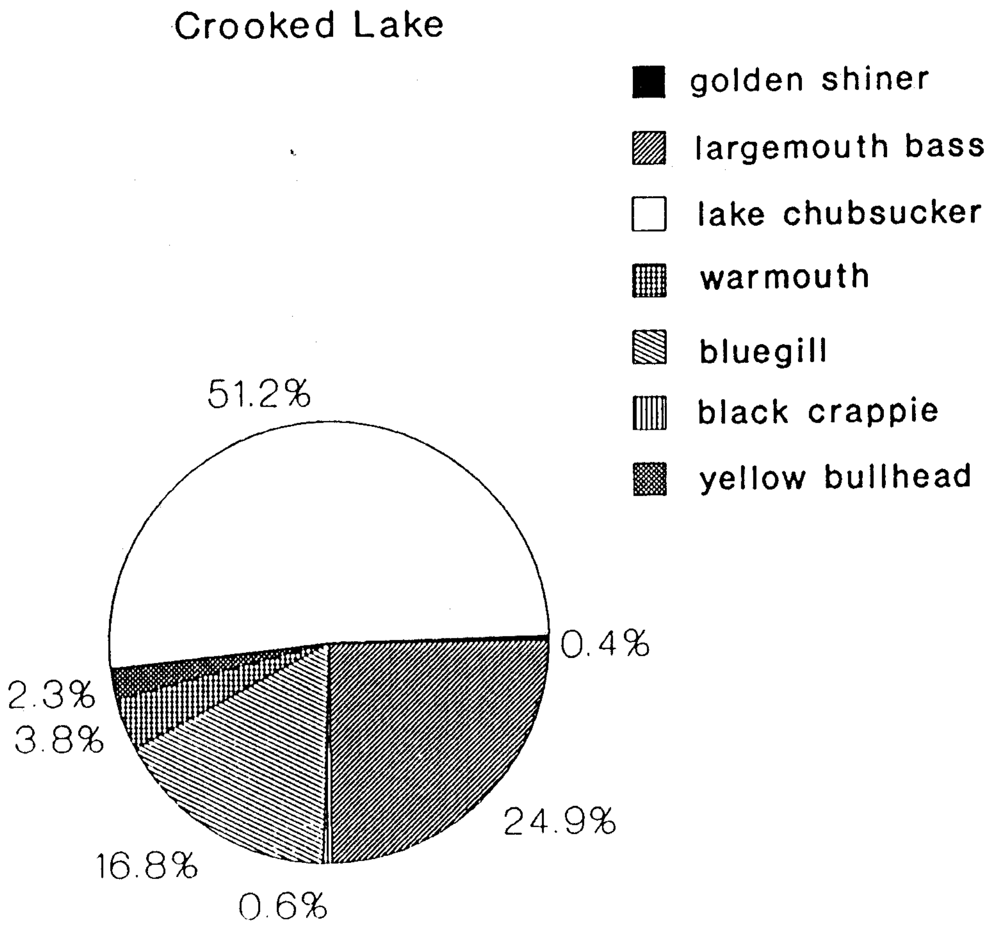


Figure 2-5. Relative abundance of fish species collected with electrofishing gear from Crooked Lake, Florida.

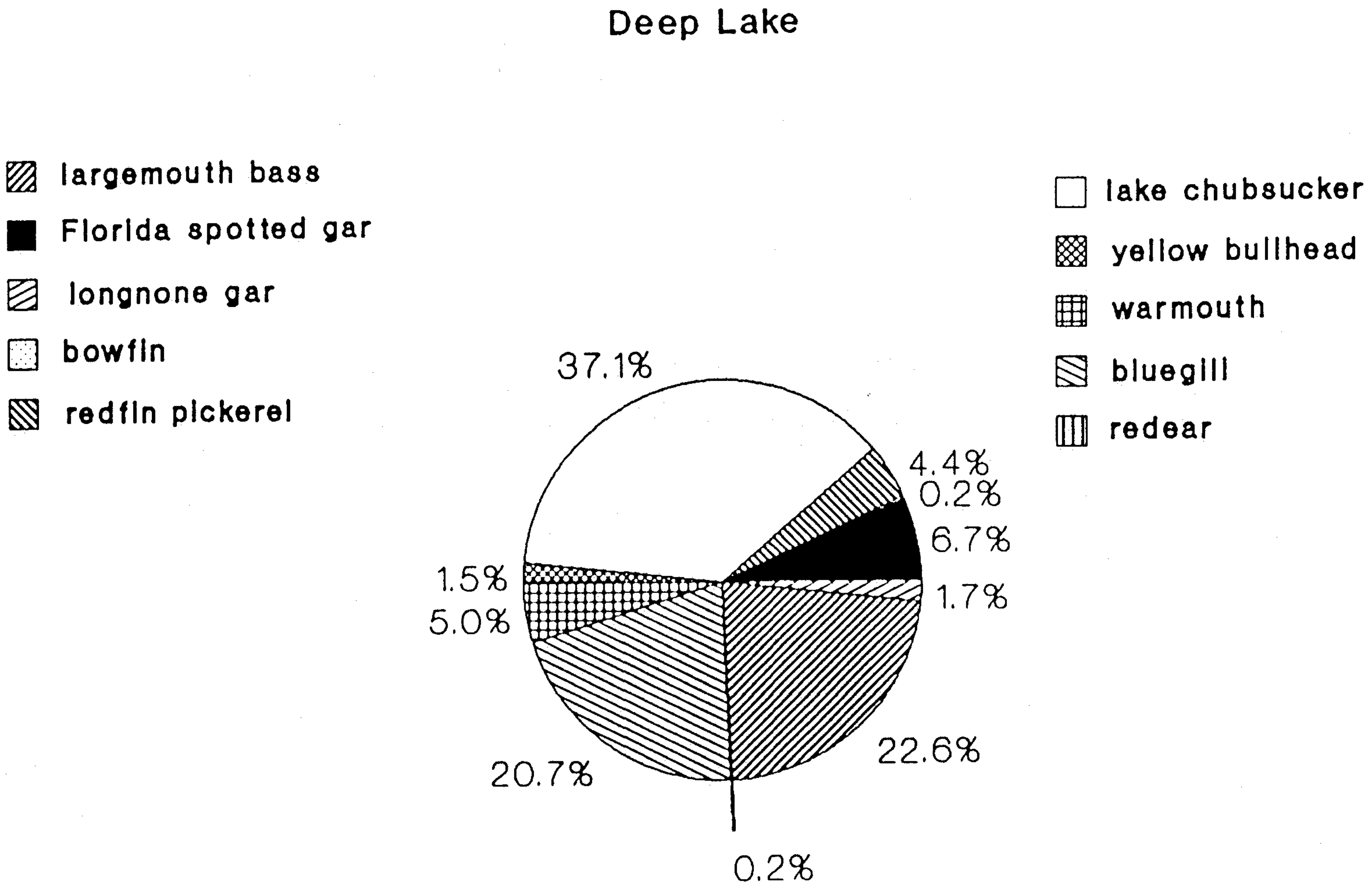


Figure 2-6. Relative abundance of fish species collected with electrofishing gear from Deep Lake, Florida.

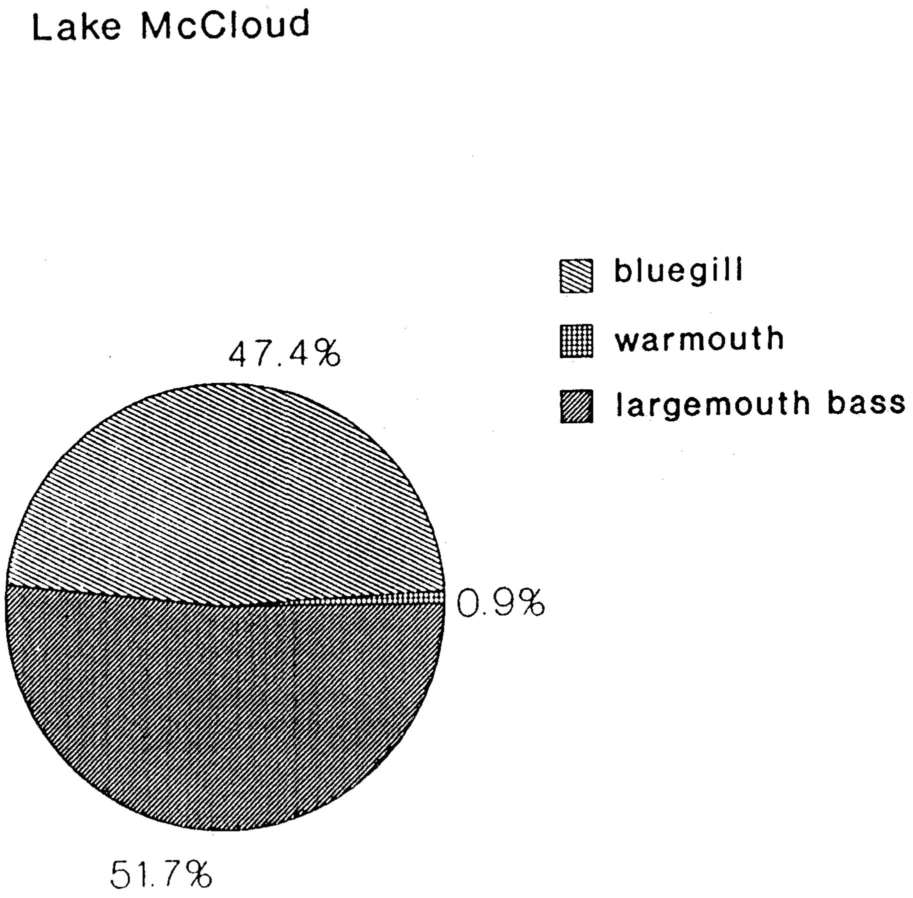


Figure 2-7. Relative abundance of fish species collected with electrofishing gear from Lake McCloud, Florida.

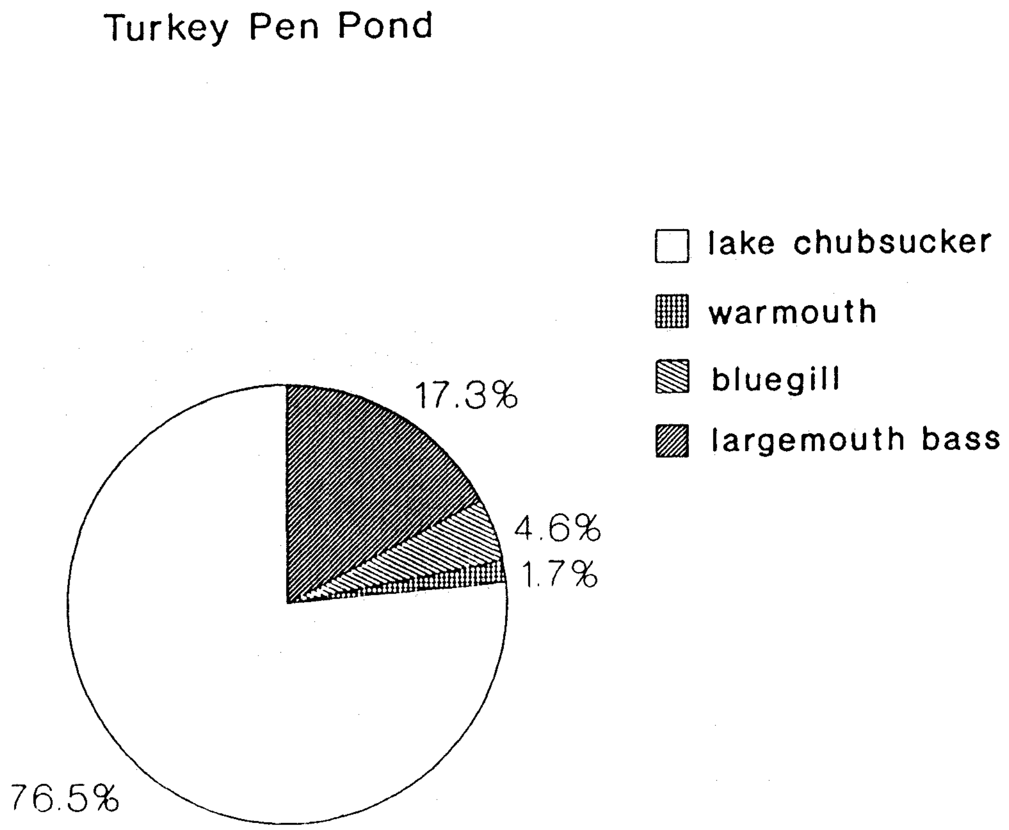


Figure 2-8. Relative abundance of fish species collected with electrofishing gear from Turkey Pen Pond, Florida.

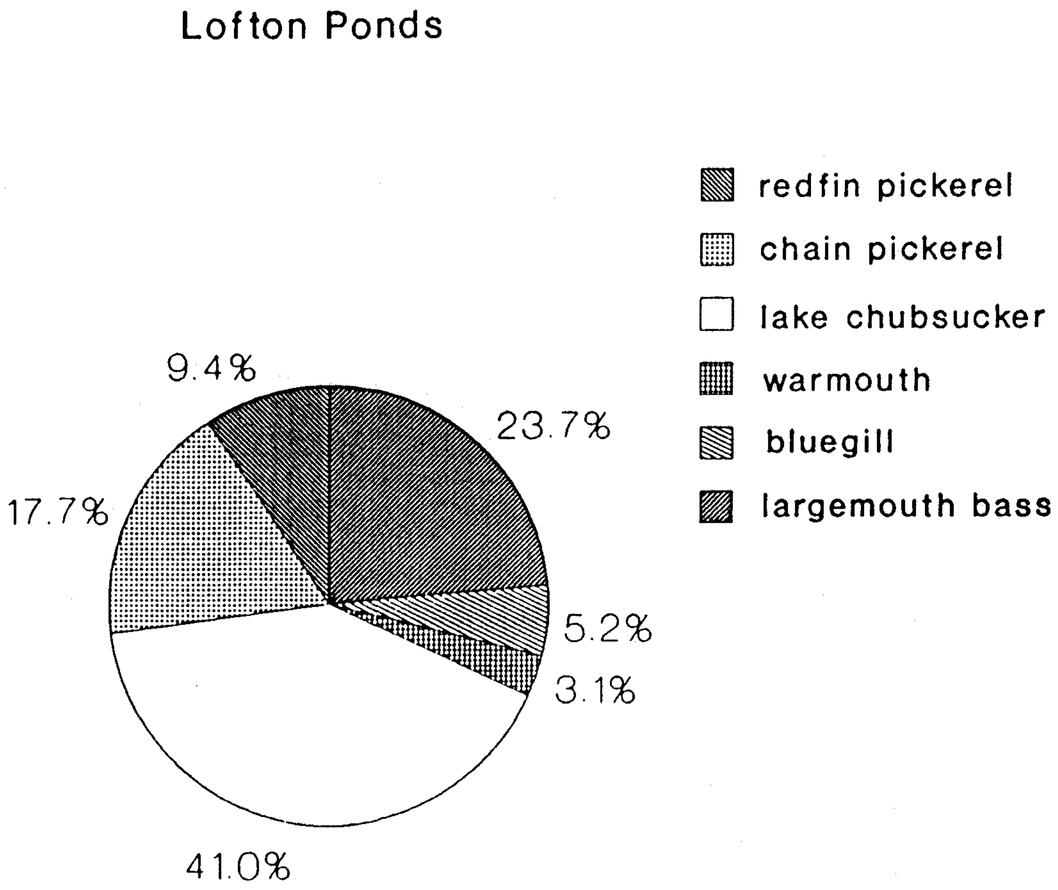


Figure 2-9. Relative abundance of fish species collected with electrofishing gear from Lofton Ponds, Florida.

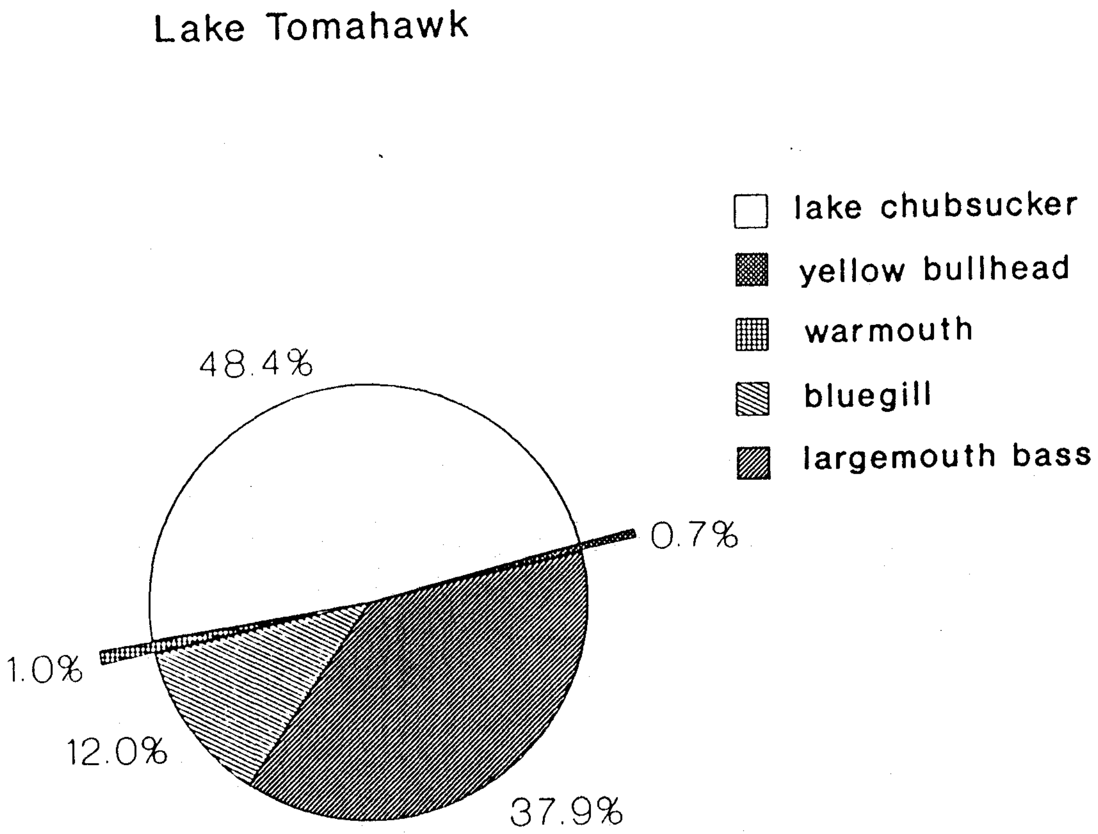


Figure 2-10. Relative abundance of fish species collected with electrofishing gear from Lake Tomahawk, Florida.

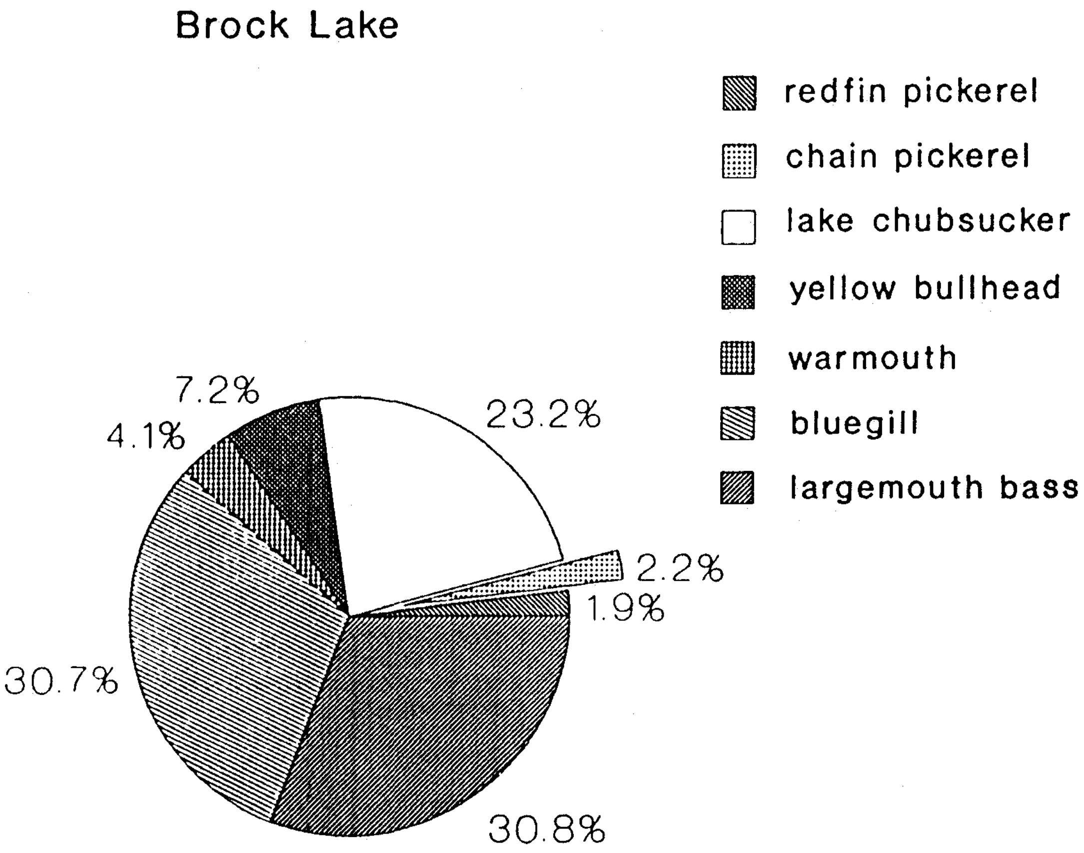


Figure 2-11. Relative abundance of fish species collected with electrofishing gear from Brock Lake, Florida.

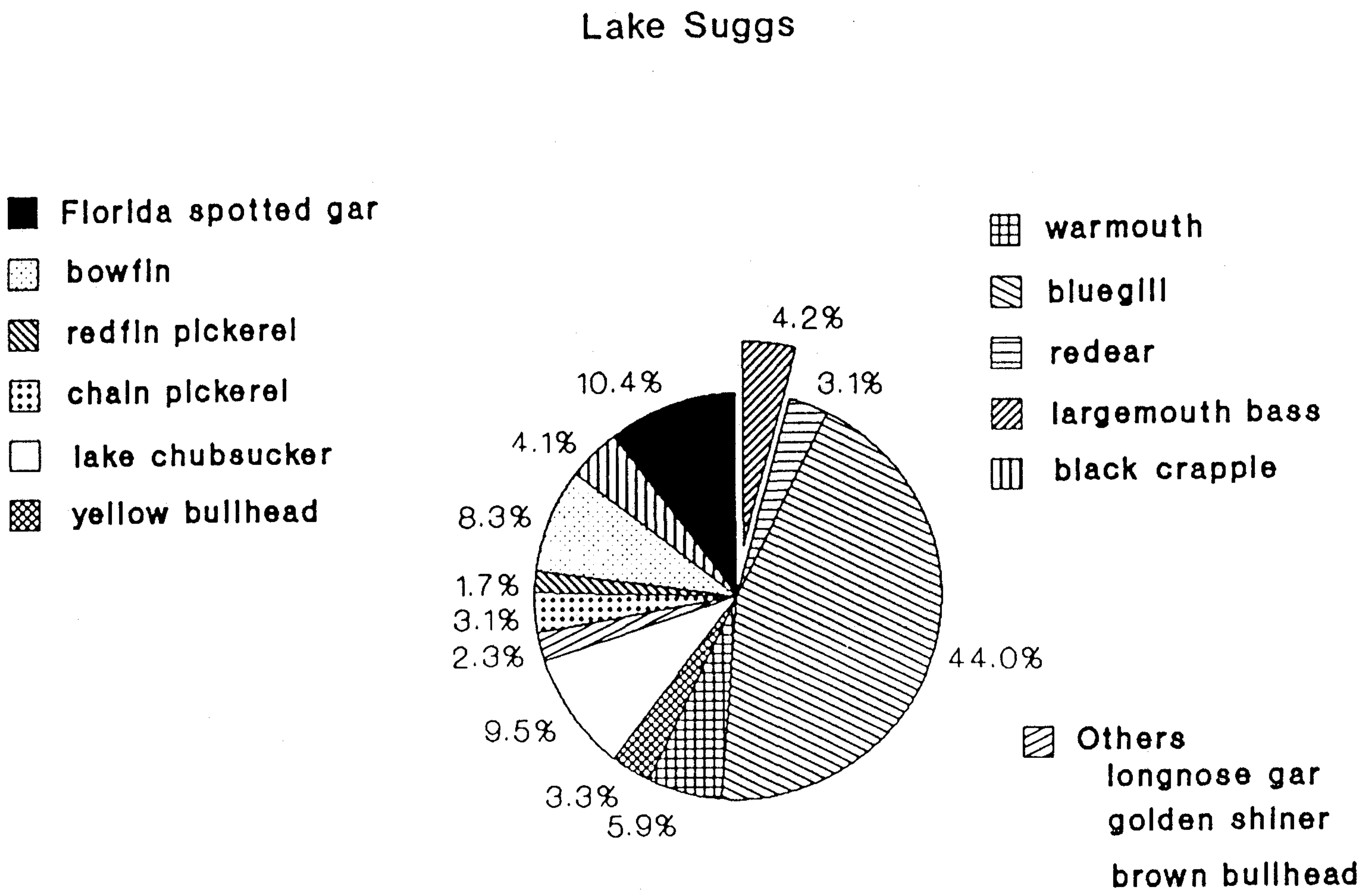


Figure 2-12. Relative abundance of fish species collected with electrofishing gear from Lake Suggs, Florida.

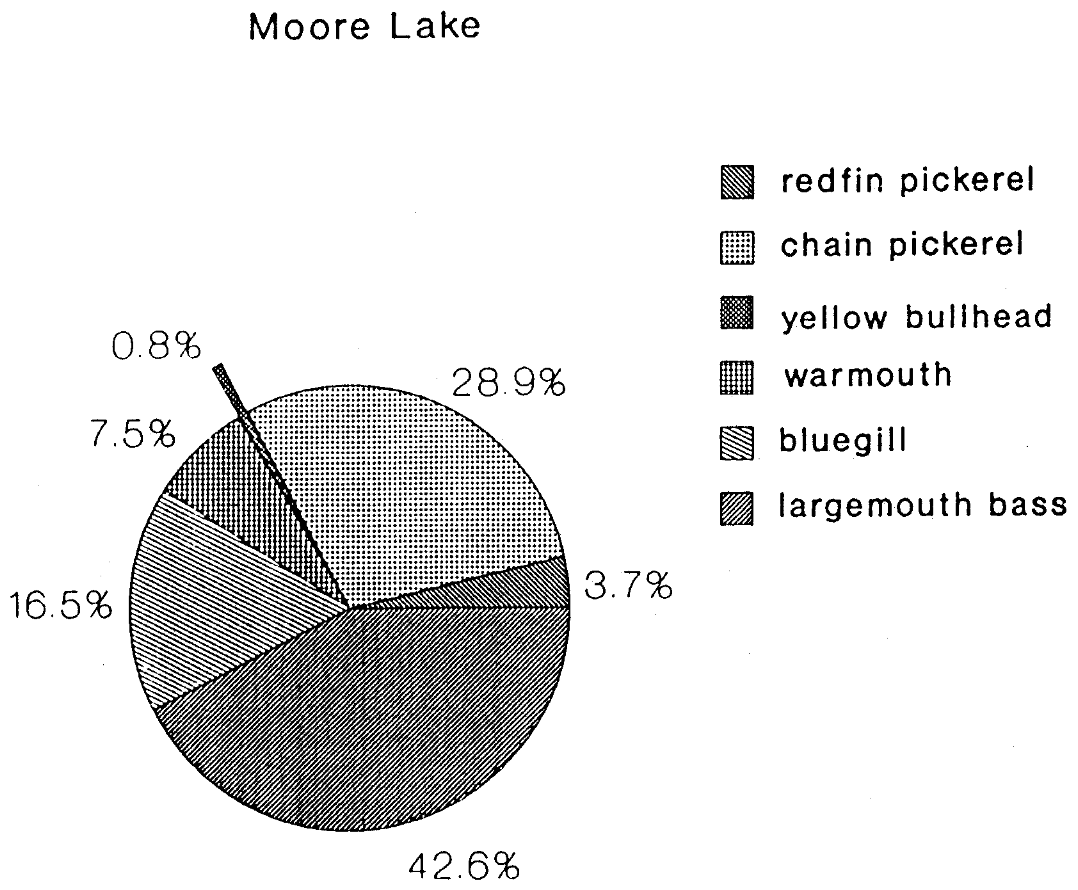


Figure 2-13. Relative abundance of fish species collected with electrofishing gear from Moore Lake, Florida.

kg/hectare, respectively (Table 2-5). The observed relative abundance of warmouth was significantly ($P < 0.10$) related to mean lake aluminum concentrations ($r = 0.87$). Warmouth abundance was not significantly related to mean lake pH ($r = -0.09$), mean lake total alkalinity ($r = -0.08$), or any of the other morphoedaphic parameters measured.

Bluegill were collected from 11 of the 12 study lakes (Table 2-5). The relative abundance of bluegill ranged from 4.6% in Turkey Pen Pond to 78% in Lake Barco (Figures 2-8 and 2-4, respectively). Bluegill was the most abundant species in Lake Barco (78%), Lake McCloud (47%), and Lake Gobbler (42%), and the second or third most abundant species in Crooked Lake, Deep Lake, Turkey Pen Pond, Lake Tomahawk, Brock Lake, Lake Suggs, and Moore Lake (Figures 2-2 to 2-13). Density estimates of bluegill ranged from 2 fish/ha in Turkey Pen Pond to 154 fish/ha in Lake Barco and biomass estimates of bluegill ranged from 0.2 kg/ha in Turkey Pen Pond to 16 kg/ha in Brock Lake (Table 2-5). The observed abundance of bluegill was significantly ($P < 0.10$) related to mean lake aluminum concentrations ($r = 0.60$), but was not significantly ($P > 0.10$) related to mean lake pH ($r = -0.35$), mean lake total alkalinity ($r = -0.26$), or any of the other morphoedaphic parameters measured. Estimated densities and biomasses of bluegill from the study lakes were not significantly ($P > 0.10$) related to mean lake pH ($r = -0.38$ and $r = 0.17$, respectively), mean lake total

Table 2-5. Density and biomass estimates (in parenthesis) and 95% confidence intervals, by species, for fish ≥ 150 mm TL sampled during the mark-recapture procedure used on the study lakes.

		Lake				
Species	Estimate	Lawbreaker	Barco	Crooked	Deep	McCloud
		Lower Bound (Estimates) Upper Bound				
Lepisosteus platyrhincus	Number/hectare	0	0		7(14)29	0
	Kilograms/hectare	0	0		1.2(3.9)11	0
Lepisosteus osseus	Number/hectare	0	0		a	0
	Kilograms/hectare	0	0		a	0
Amia calva	Number/hectare	a	0		a	0
	Kilograms/hectare	a	0		a	0
Esox americanus	Number/hectare	a	0	0	a	0
	Kilograms/hectare	a	0	0	a	0
Esox niger	Number/hectare	0	0	0	0	0
	Kilograms/hectare	0	0	0	0	0
Notemigonus crysoleucas	Number/hectare	0	0	a	0	0
	Kilograms/hectare	0	0	a	0	0
Erimyzon sucetta	Number/hectare	41(101)252	0	143(252)486	62(109)209	0
	Kilograms/hectare	3.5(8.8)22	0	17(34)79	12(23)51	0
Ictaluris natalis	Number/hectare	0	0	a	a	0
	Kilograms/hectare	0	0	a	a	0
Ictaluris nebulosus	Number/hectare	0	0	0	0	0
	Kilograms/hectare	0	0	0	0	0

Table 2-5. Continued.

Species	Estimate	Lake Lawbreaker	 Barco	 Crooked	 Deep	 McCloud
		Lower Bound (Estimates) Upper Bound				
Lepomis gulosus	Number/hectare	a	a	a	a	a
	Kilograms/hectare	a	a	a	a	a
Lepomis macrochirus	Number/hectare	0	69(154)384	a	7(18)44	21(44)101
	Kilograms/hectare	0	4.6(11)30	a	0.5(1.2)3.1	1.8(4.2)11
Lepomis microlophus	Number/hectare	0	0	0	a	0
	Kilograms/hectare	0	0	0	a	0
Pomoxis nigromaculatus	Number/hectare	0	0	0.2(0.7)1.3	0	0
	Kilograms/hectare	0	0	0.05(0.2)0.5	0	0
Centrarchus macropterus	Number/hectare	0	0	0	0	0
	Kilograms/hectare	0	0	0	0	0

alkalinity ($r = -0.32$ and $r = 0.11$, respectively), or any of the other morphoedaphic parameters measured.

Largemouth bass was collected from 10 of the study lakes (Table 2-4). Their relative abundance ranged from 4% in Lake Suggs to 52% in Lake McCloud (Figures 2-12 and 2-7, respectively). Largemouth bass was the most abundant species in Lake McCloud (52%), Moore Lake (43%), and Brock Lake (31%), and the second most abundant species in Lake Barco, Crooked Lake, Deep Lake, Turkey Pen Pond, Lofton Ponds, and Lake Tomahawk (Figures 2-2 to 2-13). The 1988 estimated densities of adult largemouth bass ($\geq$ 250 mm TL) ranged from 2 fish/ha in Lake Suggs to 45 fish/ha in Crooked Lake and biomasses ranged from 1.8 kg/ha in Lake Barco to 25 kg/ha Lake Tomahawk (Table 2-6). The estimated densities and biomasses of subadult (150 to 249 mm TL) largemouth bass during the same period ranged from 0.5 fish/hectare in Lake Suggs to 133 fish/ha in Lake Tomahawk, and from 0.05 kg/ha in Lake Suggs to 14 kg/ha in Lake Tomahawk, respectively (Table 2-6). There was a significant ($P < 0.10$) inverse relationship between the observed relative abundance of largemouth bass and mean lake aluminum levels ($r = -0.58$), but the relationship between the observed relative abundance of largemouth bass and mean lake pH ($r = 0.24$), mean lake total alkalinity ($r = 0.02$), or any of the other morphoedaphic parameters measured were not significant ($P > 0.10$). There was also no significant ($P > 0.10$) relationship between the estimated density and biomass of

Table 2-6. Density and biomass estimates for largemouth bass $\geq$ 150 mm TL sampled during the mark-recapture procedure, and total abundance estimates including young-of-the-year collected during rotenone samples from the study lakes.

			Lake									
Year	Length (mm TL)	Parameter	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
1987	150-249	Number/hectare	7	a	6	a	a	a	68	d	0.2	a
		95% confidence intervals	2-12		2-10				28-171		0.1-0.5	
		Kilograms/hectare	0.7	a	0.5	a	a	a	7.0	d	0.02	a
		95% confidence intervals	0.2-1.3		0.1-1.1				2.6-19.3		0.01-0.06	
	$\geq$250	Number/hectare	1	56	32	16	a	a	11	d	1	14
		95% confidence intervals	1-2	28-122	14-67	10-26			4-26		0.8-2	7-33
		Kilograms/hectare	0.9	30	17	9.1	a	a	11	d	1.2	11
		95% confidence intervals	0.1-2.8	13-78	3.8-52	5.0-17			1.7-40		0.7-3.1	3.6-33
1988	150-249	Number/hectare	13	20	22	17	5	a	133	7	.5	4
		95% confidence intervals	6-34	10-47	8-54	9-34	2-12		75-256	3-17	0.2-2	1-7
		Kilograms/hectare	1.3	2	1.9	1.7	0.6	a	14	0.7	0.05	0.6
		95% confidence intervals	0.5-3.6	0.7-5.9	0.5-5.8	0.8-3.9	0.2-2.1		6.9-29	0.2-1.1	0.01-0.1	0.1-1.2

Table 2-6. Continued.

			Lake									
Year	Length (mm TL)	Parameter	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
	≥ 250	Number/hectare	2	45	28	18	9	9	26	18	2	28
		95% confidence intervals	1-4	33-64	15-56	13-25	5-18	4-25	16-46	14-25	1-2	20-42
		Kilograms/hectare	1.8	24	15	10	8.8	7.6	25	17	2.4	21
		95% confidence intervals	0.3-5.7	15-41	4.1-43	6.5-16	2.5-26	2.7-25	6.7-70	11-29	0.8-3.1	10-42
Total[b]		Number/hectare	15	520	137	c	14		275	c	16	342
		Kilograms/hectare	3.1	28	17		9.4		40		2.5	22

a - No recapture

b - All sizes including young-of-year fish from Table 8.

c - No block-net samples collected.

d - Not sampled in 1987.

adult largemouth bass and mean lake pH (density: r = 0.12 and biomass: r = 0.33) and lake total alkalinity (density: r = -0.07 and biomass: r = 0.15).

Three of the nine lakes for which there were density estimates for both adult and subadult largemouth bass had significant ($P < 0.05$) differences between the two groups. Comparisons of 95% confidence intervals indicated that Lake Barco and Tomahawk Lake had higher densities of subadults than adults, and Moore Lake had higher densities of adults than subadults (Figure 2-14).

Lake chubsucker (Erimyzon sucetta), also a widely distributed species, was collected from nine of the 12 study lakes (Table 2-4). The relative abundance of lake chubsucker ranged from 9% in Lake Suggs to 80% in Lawbreaker Lake (Figures 2-12 and 2-3, respectively). This species was the most abundant in electrofishing samples from Lawbreaker Lake (80%), Turkey Pen Pond (76%), Crooked Lake (51%), Lake Tomahawk (48%), Lofton Ponds (41%), and Deep Lake (37%). Lake chubsucker was also the second or third most abundant species in Brock Lake, Lake Gobbler, and Lake Suggs (Figures 2-2 to 2-13). The relative abundance of lake chubsucker was not significantly ($P > 0.10$) related to mean lake pH (r = -0.25) or total alkalinity (r = -0.57). There was, however, a significant ($P < 0.10$) inverse relationship between lake chubsucker relative abundance and lake mean depth (r = -0.78). Estimated densities and biomasses of lake chubsucker ranged from 3 fish/hectare in Lake Suggs to 277 fish/ha in

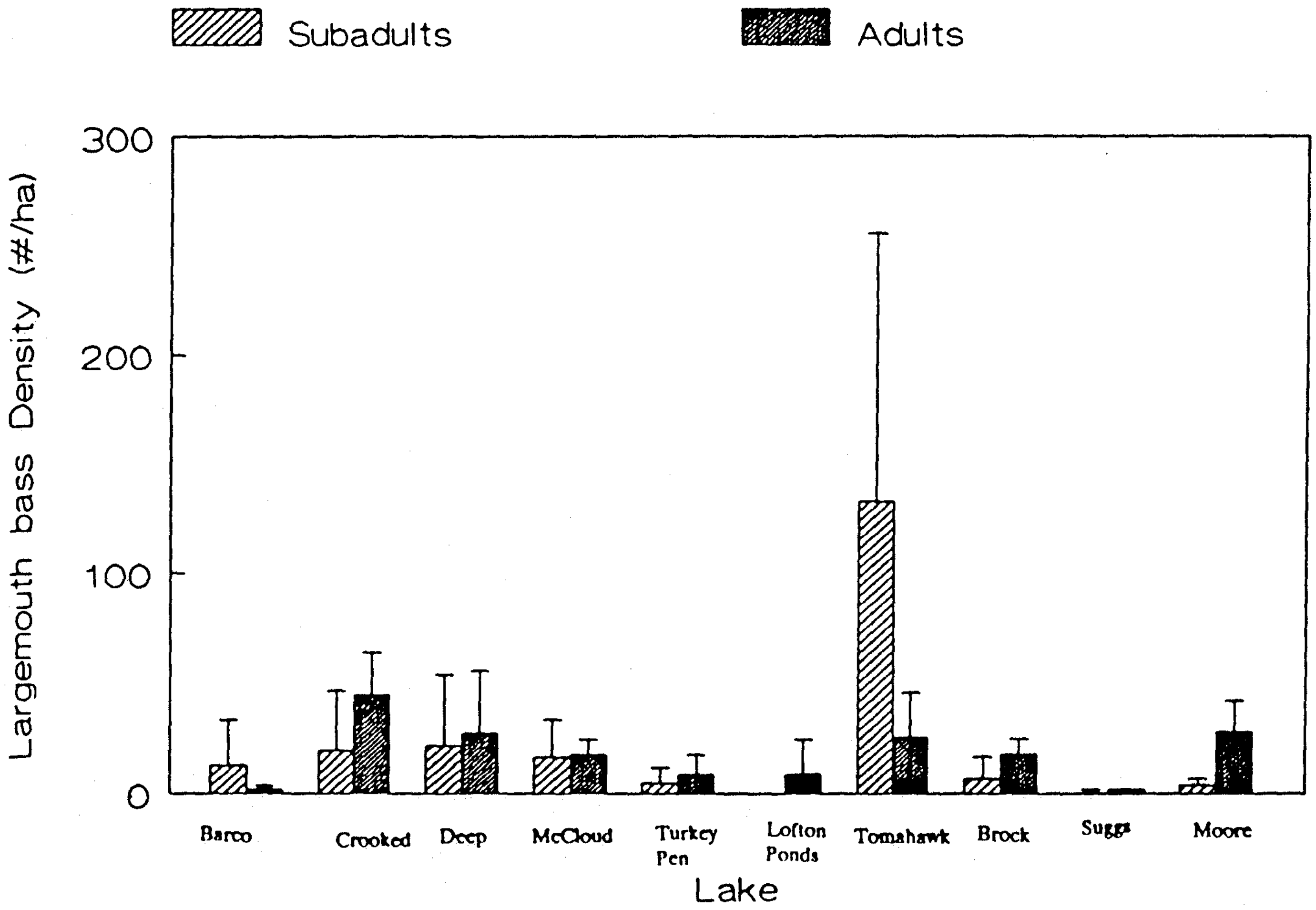


Figure 2-14. Mark-recapture estimates and 95% upper limits of adult (≥ 250 mm TL) and subadult (150-249 mm TL) largemouth bass densities in the 10 study lakes where the species occurred.

Turkey Pen Pond, and 1 kg/ha in Lake Suggs to 38 kg/ha in Brock Lake, respectively (Table 2-5), and were not significantly ($P > 0.10$) related to lake pH (density: $r = -0.40$ and biomass: $r = -0.02$) or total alkalinity (density: $r = -0.56$ and biomass: $r = -0.25$). Lake chubsucker biomass was significantly ($P < 0.10$) related to the biomass (i.e., fresh weight) of emergent aquatic macrophytes ($r = 0.74$).

Three species of ictalurid catfishes were collected with electrofishing gear. They were yellow bullhead (Ictalurus natalis), brown bullhead, and tadpole madtom (Noturus gyrinus) (Table 2-4). The relative abundance of yellow bullhead, the most common of the three species, ranged from 0.7% in Lake Tomahawk to 7% in Brock Lake (Figures 2-10 and 2-11, respectively). Density and Biomass estimates of yellow bullhead, available for only two study lakes were 2 fish/ha and 0.4 kg/ha in Lake Suggs and 25 fish/ha and 9 kg/ha in Brock Lake (Table 2-5). Brown bullhead and tadpole madtom were rare, occurring in one and three lakes, respectively (Table 2-4).

Two species of Esocidae, redfin pickerel and chain pickerel (Esox niger), were collected from six and four study lakes, respectively (Table 2-4). The relative abundance of redfin pickerel ranged from 1.7% in Lake Suggs to 9% in Lofton Ponds (Figures 2-12 and 2-9, respectively). None of the marked redfin pickerel were recaptured; therefore, density and biomass estimates could not be calculated for this species. The relative abundance of chain pickerel ranged from 2% in Brock Lake to 29% in Moore Lake (Figures 2-11 and 2-13, respectively). Chain pickerel density and biomass estimates ranged from 0.9 fish/ha in Lake Suggs to 42 fish/ha in Lofton Ponds, and 0.3 kg/ha in Lake Suggs to 8.6 kg/ha in Moore Lake, respectively (Table 2-5).

Two other important species, bowfin (Amia calva, from the family Amiidae), and Florida spotted gar (Lepisosteus platyrhincus, from the family Lepisosteidae), were collected from three study lakes (Table 2-4). The relative abundance of bowfin ranged from 0.2% in Deep Lake to 11% in Gobbler Lake (Figures 2-6 and 2-2, respectively). Bowfin density and biomass estimates, available only for Lake Suggs, were 3 fish/ha and 3.2 kg/ha, respectively (Table 2-5). The relative abundance of Florida spotted gar ranged from 7% in Deep Lake to 10% in Lake Suggs (Figures 2-6 and 2-12, respectively). The estimated densities of Florida spotted gar were 14 fish/ha and 5 fish/ha in Deep Lake and Lake Suggs, respectively. Estimated biomasses were 3.9 kg/ha and 1.2 kg/ha, respectively. Density and biomass estimates were not calculated for Florida spotted gar in Lake Gobbler due to insufficient sample size (Table 2-5).

Golden shiner (Notemigonus crysoleucas), the only cyprinid present in electrofishing samples, was very rare. The species was only collected from Crooked Lake and Lake Suggs, and comprised less than 1% of the fish collected from both lakes (Figures 2-5 and 2-12, respectively). Density and biomass estimates for golden shiner were not calculated because none of the marked fish were recaptured.

Fish Abundance and Biomass--Gillnetting

The mean number and weight of fish (i.e., of all species) caught per gillnet set in the study lakes ranged from 1 to 16 fish per net set, and 0.1 to 8.8 kg per net set, respectively (Table 2-7). The mean number and weight of fish caught per gillnet set were not significantly ($P > 0.10$) related to mean lake pH ($r = 0.03$ and $r = 0.21$) or total alkalinity ($r = -0.04$, and $r = 0.25$) (Figures 2-15 and 2-16, respectively). The mean number ($r = 0.51$) and weight ($r = 0.89$) of fish caught per gillnet set were significantly ($P < 0.10$) related to chlorophyll *a* concentrations (Figure 2-17).

Total Fish Abundance and Biomass--Block-netting

Nine of the 12 study lakes were sampled with rotenone and block-nets. The estimates of total fish (i.e., all species) in these nine lakes ranged from 53 fish/ha in Lawbreaker Lake to 13,000 fish/ha in Lake Tomahawk. Estimates of total fish biomass ranged from 3.4 kg/ha in Lawbreaker Lake to 95 kg/ha in Crooked Lake (Table 2-8). Estimates of total fish density and total biomass were not significantly ($P > 0.10$) related to mean lake pH ($r = 0.55$ and $r = 0.30$) or mean total alkalinity ($r = 0.45$ and $r = -0.07$) (Figures 2-18 and 2-19, respectively).

Table 2-7. Mean density and biomass of fish collected per experimental gillnet from the study lakes.

		Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Pond	Brock	Tomahawk	Suggs	Moore
	pH	4.1	4.4	4.5	4.6	4.6	4.6	4.7	4.8	4.9	4.9	5.0	5.7
Number of Fish	$\bar{x}$	1	11	1	16	3	1	8	2	15	4	4	4
	SE	0.4	2	0.2	2	1	0.6	1	0.7	4	0.5	1	0.7
	Maximum	2	13	2	24	8	3	13	5	26	7	7	7
	Minimum	1	6	1	10	1	0	5	1	9	3	1	1
	N	4	3	6	6	6	7	3	6	4	7	6	7
Weight of Fish	$\bar{x}$	0.9	0.5	0.1	2.9	0.4	0.1	0.7	0.6	8.8	0.8	1.6	1.4
	SE	0.8	0.1	<0.1	0.4	0.2	<0.1	0.1	0.3	3.4	0.2	0.4	0.2
	Maximum	3.3	0.7	0.2	4.4	0.9	0.4	1.1	2.1	19	1.5	2.8	2.0
	Minimum	0.1	0.3	<0.1	2.1	0.1	0	0.3	0.2	3.4	0.3	0.2	0.2
	N	4	3	6	6	6	6	7	6	4	7	6	7

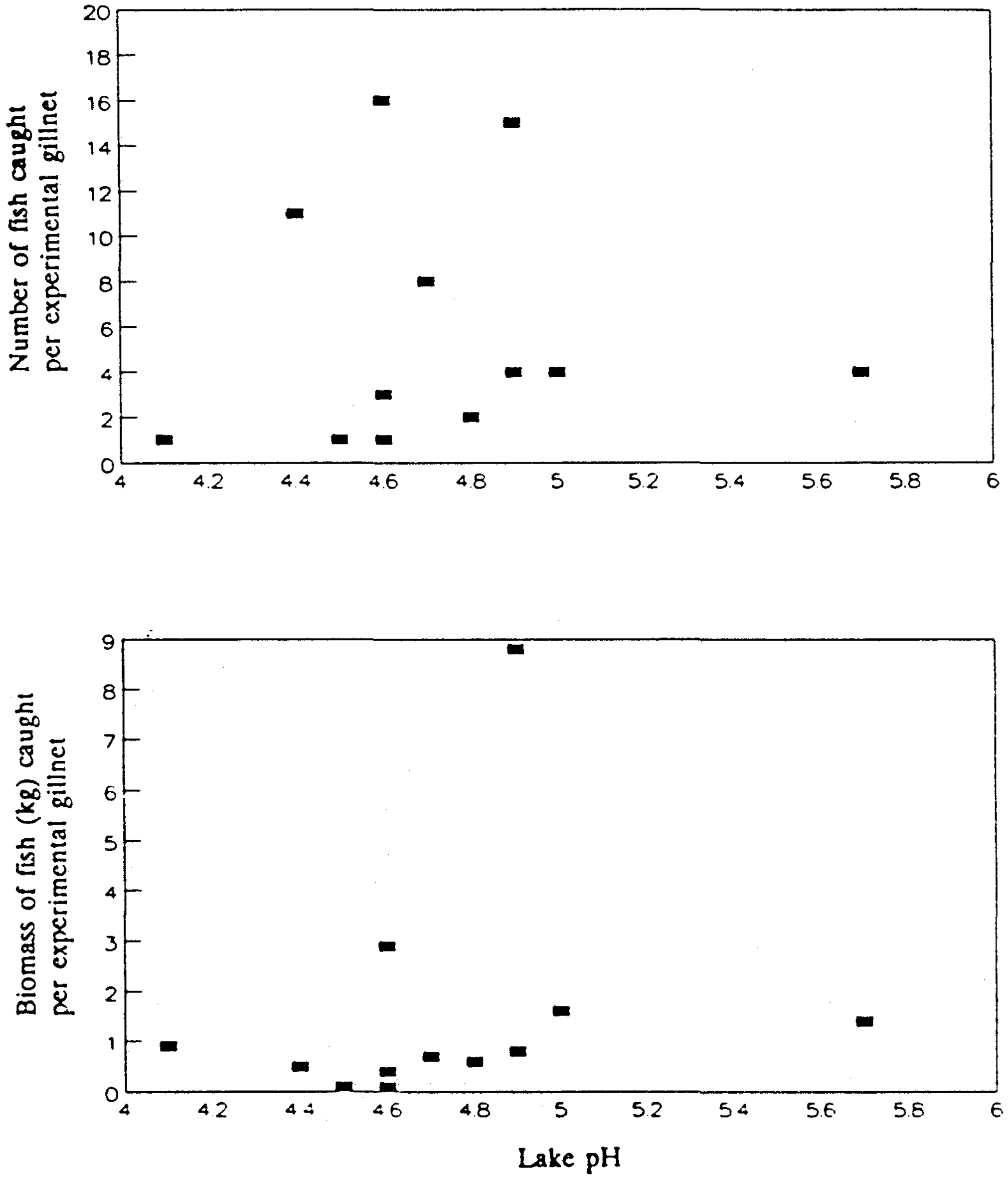


Figure 2-15. Relationship between mean density and biomass of fish collected per experimental gillnet from the study lakes and lake pH.

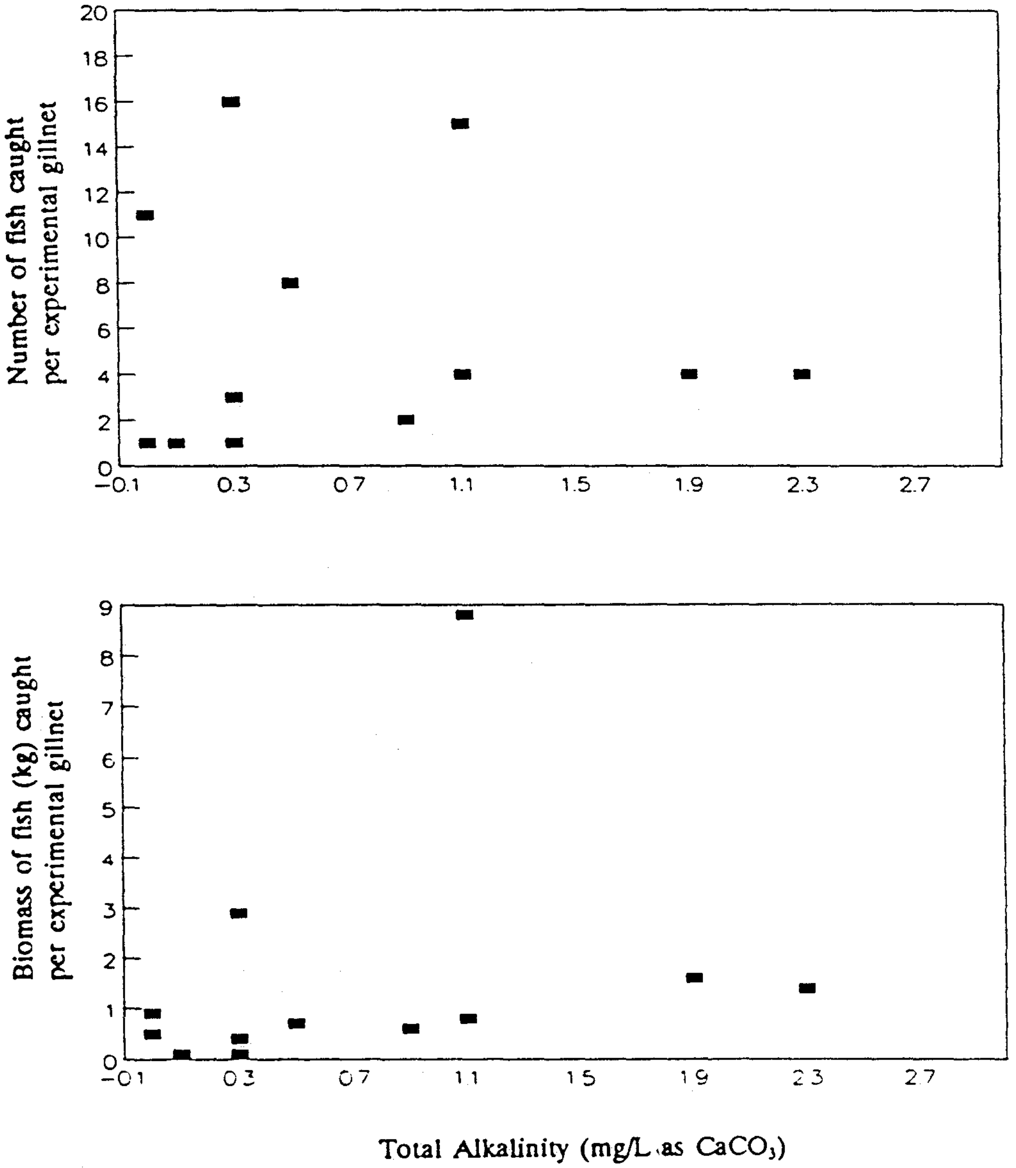


Figure 2-16. Relationship between mean density and biomass of fish collected per experimental gillnet from the study lakes and lake total alkalinity.

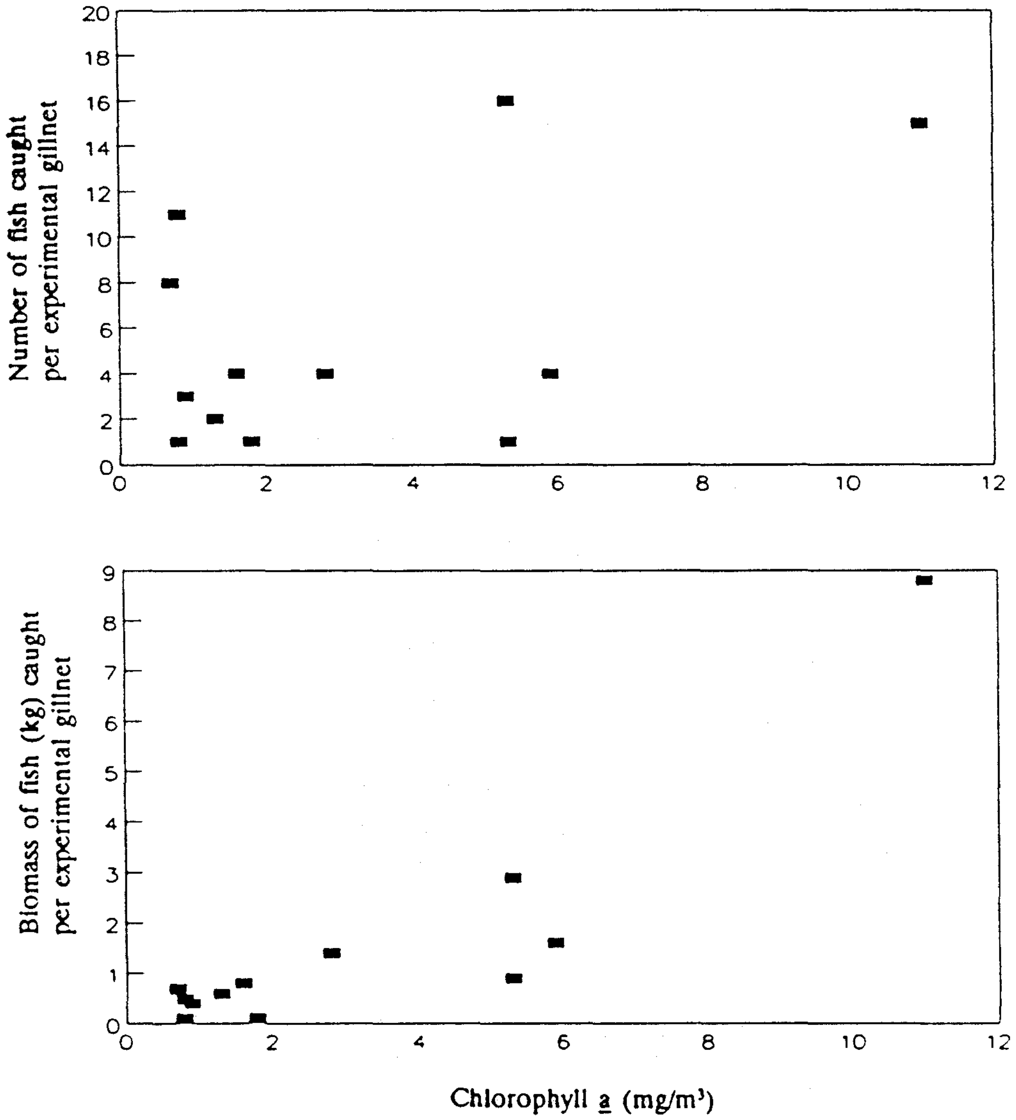


Figure 2-17. Relationship between mean density and biomass of fish collected per experimental gillnet from the study lakes and lake chlorophyll a concentrations.

Table 2-8. Total density and biomass estimates of fish collected per hectare from the study lakes with rotenone and block-nets.

Parameter	Lawbreaker	Barco	Crooked	Deep	Turkey Pen	Lofton Pond	Tomahawk	Suggs	Moore
Number of Fish Species	3	5	12	16	10	10	12	17	14
Density (number/hectare)	53 (31)	230 (180)	3300 (1000)	6600 (870)	3600 (1000)	3800 (530)	13000 (4500)	1700 (630)	8900 (400)
Biomass (kg/hectare)	3.4 (2.8)	6.9 (3.9)	95 (71)	88 (19)	44 (8)	56 (7)	63 (21)	19 (5)	41 (7)
pH	4.4	4.5	4.6	4.6	4.7	4.8	4.9	5.0	5.7
Alkalinity (mg/L as $CaCO_3$)	0	0.1	0.3	0.3	0.5	0.9	1.1	1.9	2.3
Specific Conductance (µS/cm at 25C)	65	43	46	37	20	21	34	56	16
Aluminum (mg/m^3)	260	86	80	68	60	34	47	84	32
Total N (mg/m^3)	120	100	310	160	140	420	200	840	390
Total P (mg/m^3)	4	3	9	2	2	3	6	54	5
Chlorophyll *a* (mg/m^3)	0.8	0.8	5.3	0.9	0.7	1.3	1.6	5.9	2.8

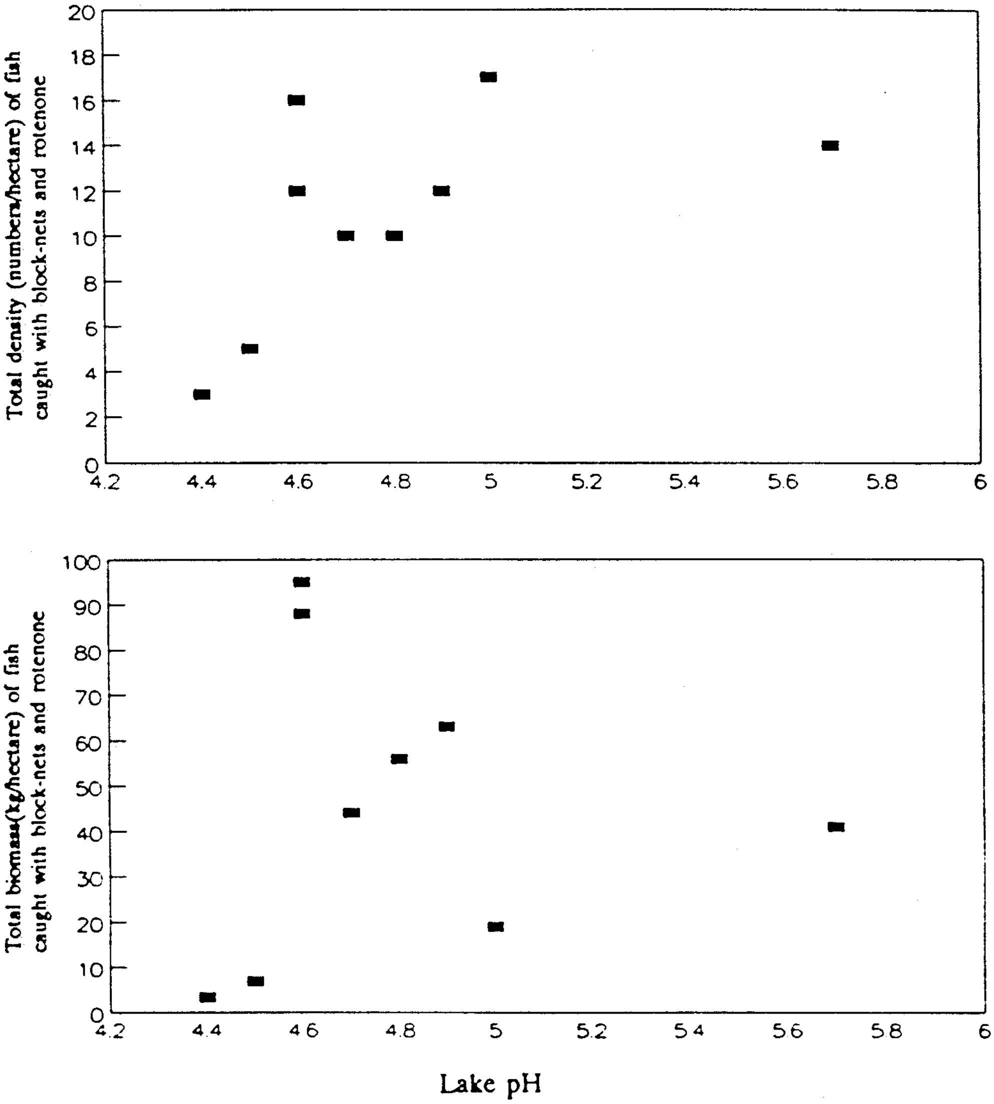


Figure 2-18. Relationship between total density and biomass estimates of fish collected per hectare from the study lakes with rotenone and block-nets and lake pH.

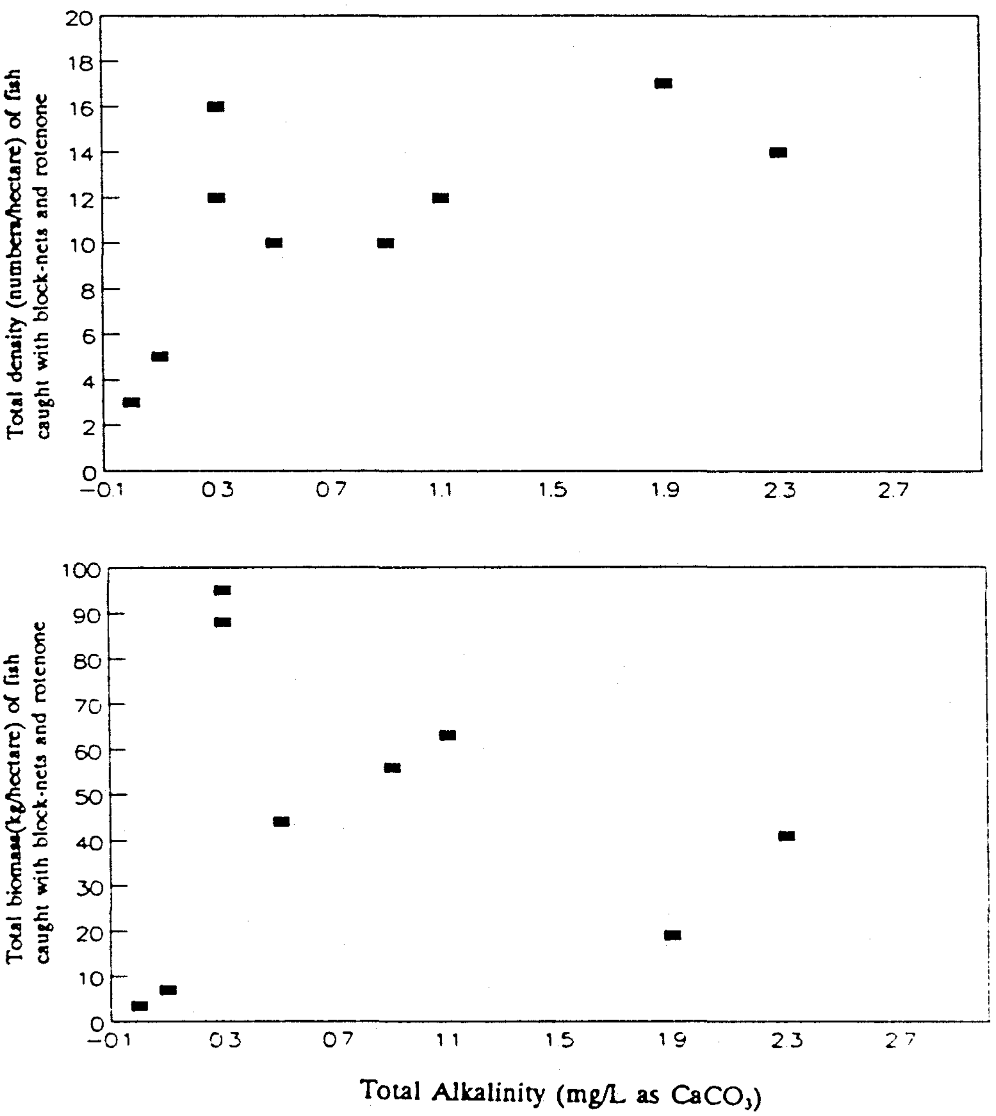


Figure 2-19. Relationship between total density and biomass estimates of fish collected per hectare from the study lakes with rotenone and block-nets and lake total alkalinity.

Condition Factors

The average condition factors (K_{TL}) for subadult and adult fish collected from the study lakes are presented in Tables 2-9 and 2-10, respectively. Adult Florida spotted gar, longnose gar (Lepisosteus osseus), and bowfin had equivalent mean condition factors across the lakes where they were collected, but the available data were insufficient to determine if the coefficients of condition for either species were related to pH or total alkalinity (Table 2-10).

Condition factors for adult chain pickerel ($\geq$ 300 mm TL) and redfin pickerel ($\geq$ 100 mm TL) ranged from 0.52 to 0.55 and from 0.46 to 0.58, respectively (Table 2-10). The available data were insufficient to determine if the coefficients of condition were related to either pH or total alkalinity for chain pickerel, but condition factors for redfin pickerel were not significantly ($p > 0.05$) related to either pH ($r = 0.60$) or total alkalinity ($r = 0.64$). Subadult chain pickerel (< 300 mm TL) condition factors ranged from 0.49 in Lofton Ponds to 0.53 in Brock Lake (Table 2-9). Condition factors for subadult (< 150 mm TL) and adult ($\geq$ 150 mm TL) lake chubsucker ranged from 1.02 to 1.35 and from 1.00 to 1.36 (Tables 2-9 and 2-10), respectively. Although condition factor values for this species were significantly different among lakes. Neither subadult or adult condition factors values were significantly related to pH (subadult: $r = 0.14$ and adult: r

Table 2-9. Mean condition factors (K_{TL}) for subadult fish collected from the study lakes with electrofishing gear (standard errors in parenthesis).

	LAKE											
Species	Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
Esox niger								0.49 (0.02)		0.53 (0.01)	0.52 (0.01)	0.52 (0.01)
Erimyzon sucetta				1.09 (0.03)	1.13 (0.03)		1.35 (0.05)	1.28 (0.06)	1.15 (0.11)	1.02 (0.12)		
Lepomis gulosus	1.85 (0.02)	1.99 (0.13)	1.65 (0.07)	1.86 (0.06)	1.88 (0.04)	1.82 (0.07)	1.74 (0.07)	1.98 (0.12)	1.79 (0.09)		2.04 (0.04)	1.97 (0.09)
Lepomis macrochirus			1.35 (0.04)	1.45 (0.04)	1.39 (0.04)	1.44 (0.03)	1.29 (0.10)	1.73 (0.14)	1.37 (0.05)	1.54 (0.06)	1.64 (0.04)	1.91 (0.10)
Micropterus salmoides floridanus			0.98 (0.02)	1.08 (0.02)	0.99 (0.02)	1.12 (0.02)	1.15 (0.06)	1.19 (0.03)	1.03 (0.01)	1.13 (0.02)	1.13 (0.03)	1.27 (0.04)
Pomoxis nigromaculatus											1.52 (0.29)	

Table 2-10. Mean condition factors (K_{TL}) for adult fish collected from the study lakes with electrofishing gear (standard errors in parenthesis).

	LAKE											
Species	Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
Lepisosteus platyrhincus	0.46 (0.11)				0.34 (0.03)						0.35 (0.01)	
Lepisosteus osseus					0.27 (0.02)						0.32 (0.06)	
Amia calva	1.06 (0.03)										0.95 (0.02)	
Esox americanus	0.46 (0.01)				0.55 (0.03)			0.51 (0.02)		0.52 (0.03)	0.58 (0.05)	0.54 (0.02)
Esox niger								0.54 (0.02)		0.55 (0.03)	0.55 (0.02)	0.52 (0.01)
Erimyzon sucetta	1.20 (0.03)	1.06 (0.02)		1.07 (0.02)	1.13 (0.01)		1.21 (0.02)	1.25 (0.02)	1.00 (0.01)	1.31 (0.03)	1.36 (0.02)	
Ictalurus natalis				1.41 (0.04)	1.35 (0.06)				1.37 (0.05)	1.32 (0.03)	1.36 (0.03)	1.56 (0.05)
Ictalurus nebulosus											1.36 (0.05)	
Lepomis gulosus	1.79 (0.04)	2.08 (0.10)	1.70 (0.06)	1.93 (0.07)	1.98 (0.03)	2.04 (0.10)	2.05 (0.08)	2.13 (0.06)	1.84 (0.06)	2.14 (0.08)	2.18 (0.05)	2.13 (0.04)

Table 2-10. Continued.

	LAKE											
Species	Gobbler	Lawbreaker	Barco	Crooked	Deep	McCloud	Turkey Pen	Lofton Ponds	Tomahawk	Brock	Suggs	Moore
Lepomis macrochirus	1.39 (0.02)	1.44[a] (0.03)	1.42 (0.02)	1.46 (0.02)	1.41 (0.03)	1.50 (0.03)	1.30 (0.08)	1.88 (0.04)	1.35 (0.04)	1.78 (0.03)	1.86 (0.03)	1.99 (0.04)
Lepomis microlophus											1.80 (0.05)	
Micropterus salmoides floridanus		1.17[a] (0.03)	1.00 (0.04)	1.14 (0.02)	1.12 (0.03)	1.17 (0.01)	1.15 (0.05)	1.36 (0.03)	1.14 (0.03)	1.30 (0.02)	1.36 (0.04)	1.30 (0.01)
Pomoxis nigromaculatus				1.23 (0.10)							1.28 (0.02)	

[a] Stocked from Crooked Lake

= 0.33) or total alkalinity (subadult: r = 0.14 and adult: r = 0.56).

Condition factors for adult yellow bullhead ranged from 1.32 in Brock Lake to 1.56 in Moore Lake (Table 2-10). These values were significantly related to pH (r = 0.79), but the statistical relationship was heavily influenced by Moore Lake. When Moore Lake was omitted from the data set, and the data reanalyzed, there was no significant relationship between lake pH and yellow bullhead condition factor. There also was no significant relationship between yellow bullhead condition factor and total alkalinity (r = 0.56; $p > 0.05$). The average condition factor of brown bullhead, collected only in Lake Suggs, was 1.36 (Table 10). The average condition factor for adult black crappie (Pomoxis nigromaculatus) was 1.23 in Crooked Lake and 1.28 in Lake Suggs, the only systems in which they were collected (Table 2-10).

Condition factors for subadult (< 150 mm TL) and adult (≥ 150 mm TL) warmouth, the only cosmopolitan species in this study, ranged from 1.65 to 2.04 and from 1.70 to 2.18 (Tables 2-9 and 2-10), respectively. Condition factors differed significantly among lakes, but the relationship between mean condition factors and mean lake pH (subadult: r = 0.36 and adult: r = 0.55) or total alkalinity (subadult: r = 0.50 and adult: r = 0.57) was not significant.

Condition factors for subadult (<150 mm TL) bluegill ranged from 1.29 in Turkey Pen Pond to 1.91 in Moore Lake

(Table 2-9). Subadult bluegill condition factors were significantly ($P < 0.05$) related to mean lake pH ($r = 0.81$), mean lake total alkalinity ($r = 0.79$), total nitrogen ($r = 0.63$), and the width of the littoral zone ($r = 0.84$). There was also a significant ($P < 0.10$) inverse relationship between subadult bluegill condition factors and lake mean depth ($r = -0.62$). Total alkalinity and lake pH were highly related to each other ($r = 0.93$; $P < 0.01$); therefore, partial correlation analysis were performed when both of these parameters were significantly related to fish condition. Partial correlation analysis, accounting for total alkalinity, showed that the relationship between mean lake pH and the condition factors of subadult bluegill was not significant (partial $r = 0.36$; $P > 0.05$).

Adult bluegill condition factors ranged from 1.30 in Turkey Pen Pond to 1.99 in Moore Lake (Table 2-10). Adult bluegill condition factors were significantly ($P < 0.05$) related to mean lake pH ($r = 0.72$), mean lake total alkalinity ($r = 0.78$), the width of the littoral zone ($r = 0.74$), and mean lake total nitrogen ($r = 0.54$). There was also a significant ($P < 0.10$) inverse relationship between adult bluegill condition factors and study lake mean depth ($r = -0.63$). Partial correlation analysis, accounting for total alkalinity, indicated that relationship between mean lake pH and the condition factor of adult bluegill was not significant (partial $r = -0.02$; $P > 0.05$).

Mean condition factors for subadult largemouth bass (150 - 249 mm TL) sampled during this study ranged from 0.98 in Lake Barco to 1.27 in Moore Lake (Table 2-9). Subadult largemouth bass condition factors were significantly ($P < 0.10$) related to mean lake pH ($r = 0.66$) and total alkalinity ($r = 0.61$), but the exclusion of Moore Lake, a statistical outlier, from the data set resulted in nonsignificant relationships. Mean condition factors for subadult largemouth bass were also significantly related to lake littoral zone width ($r = 0.65$). Mean condition factors of adult largemouth bass ($\geq$ 250 mm TL) ranged from 1.00 in Lake Barco to 1.36 in Lofton Ponds and Lake Suggs (Table 2-10) and were significantly ($P < 0.10$) related to mean lake pH ($r = 0.59$), total alkalinity ($r = 0.70$), lake littoral zone width ($r = 0.57$; Figure 2-20), and total nitrogen ($r = 0.79$; Figure 2-21). Partial correlation analysis, accounting for total alkalinity, indicated that the relationship between lake pH and the average condition factor of adult largemouth bass was not significant (partial $r = -0.22$; $P > 0.05$).

Age and Growth of Largemouth Bass

The age of largemouth bass collected from the study lakes ranged from Age 0 (i.e, young of the year) to at least Age IV. The whole otolith method of determining the age largemouth bass is not reliable for aging fish older than Age IV (Hoyer et al. 1985); therefore, otoliths were read

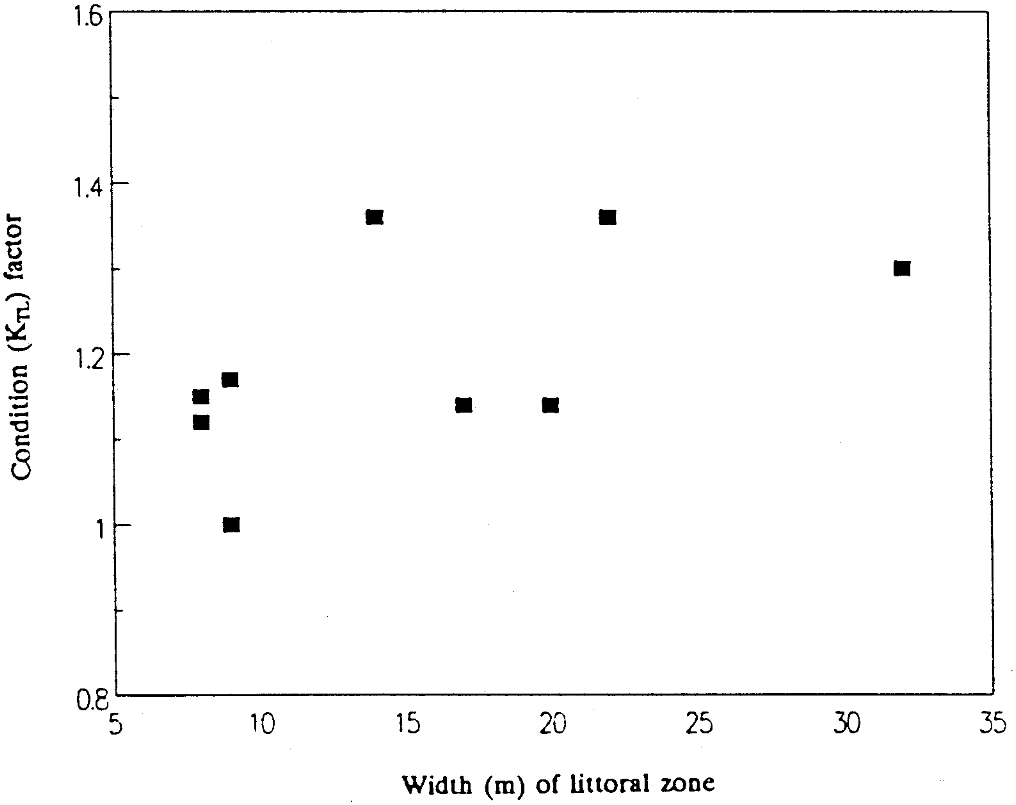


Figure 2-20. Relationship between mean condition factors (K_{TL}) for adult largemouth bass collected from the study lakes with electrofishing gear and the width of lake littoral zone.

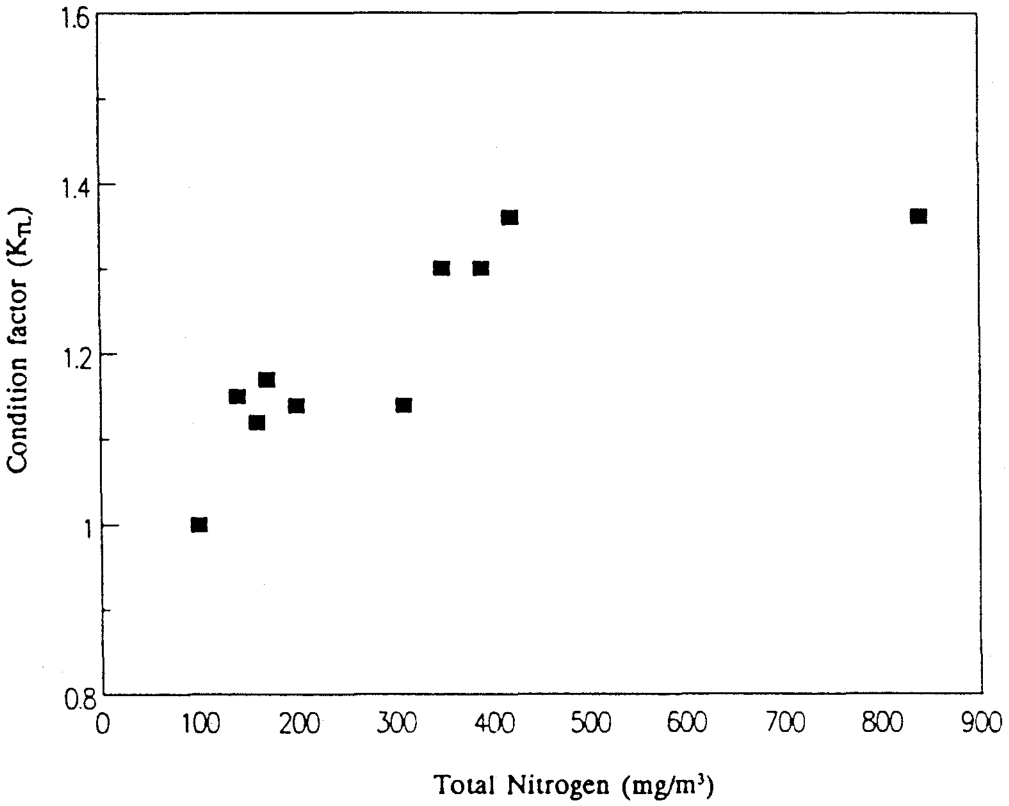


Figure 2-21. Relationship between mean condition factors (K_{TL}) for adult largemouth bass collected from the study lakes with electrofishing gear and lake total nitrogen concentrations.

only to Age IV. Back calculated length at Age I ranged from 99 mm TL in Lake McCloud to 174 mm TL in Lake Barco. Months to recruitment to adult stock ranged from 23 months in Lake Barco to 36 months in Deep lake (Table 2-11). Neither back calculated length at Age I or months to recruitment to adult stock were significantly ($P > 0.10$) related to mean lake pH (length at Age I: $r = 0.07$ and month to recruitment: $r = 0.10$) or mean lake total alkalinity (length at Age I: $r= 0.17$ and months to recruitment: $r= 0.10$) (Figures 2-22 and 2-23, respectively).

Floy-tagged fish used for estimating growth rates were at large from 26 to 553 days and daily growth rates (mm/day) were determined from the actual growth that occurred between the initial tagging and recapture date. Largemouth bass could not be externally sexed; therefore, the calculated growth rates represent pooled sex data. Porak et al. (1986) reported that significant growth differences occurred between male and female largemouth bass by Age II (> 250 mm TL), with females having significantly greater growth rates. Differential capture based on sex could have biased the growth rate data. However, since the electrofishing samples were collected throughout all study years, the growth rates were assumed to represented lakewide averages for both sexes.

Growth rates for individually tagged subadult and adult largemouth bass were equivalent at 0.15 mm/day (S.E. = 0.02). Therefore, the age data for both groups were pooled

Table 2-11. Mean back calculated length at Age I and months to adult recruitment (i.e., ≥ 250 mm TL) for largemouth bass collected from the study lakes.

Lake	pH	N	Age I (mm TL±SE)	Months to 250 mm TL
Gobbler	4.1	-	--	--
Lawbreaker	4.4	-	--	--
Barco	4.5	6	174±19	23
Crooked	4.6	17	126±6	24
Deep	4.6	7	132±6	36
McCloud	4.6	3	99±4	31
Turkey Pen	4.7	16	116±6	29
Lofton Ponds	4.8	22	126±5	29
Brock	4.9	11	155±11	21
Tomahawk	4.9	28	147±3	30
Suggs	5.0	2	148±6	31
Moore	5.7	36	134±4	29
Means of Means	--	-	136±7	28

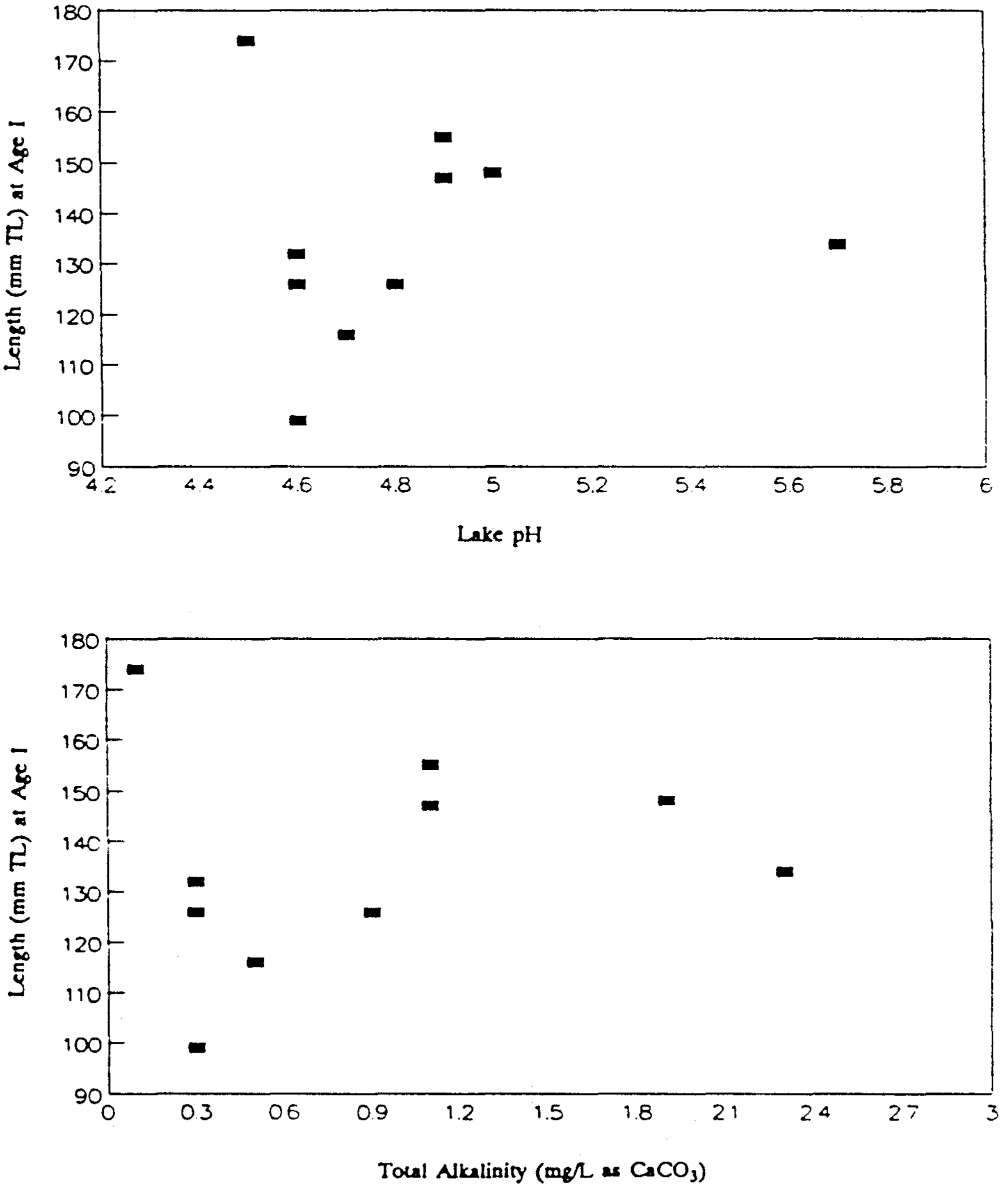


Figure 2-22. Relationship between mean back calculated length at Age I for largemouth bass collected from the study lakes and lake pH and total alkalinity.

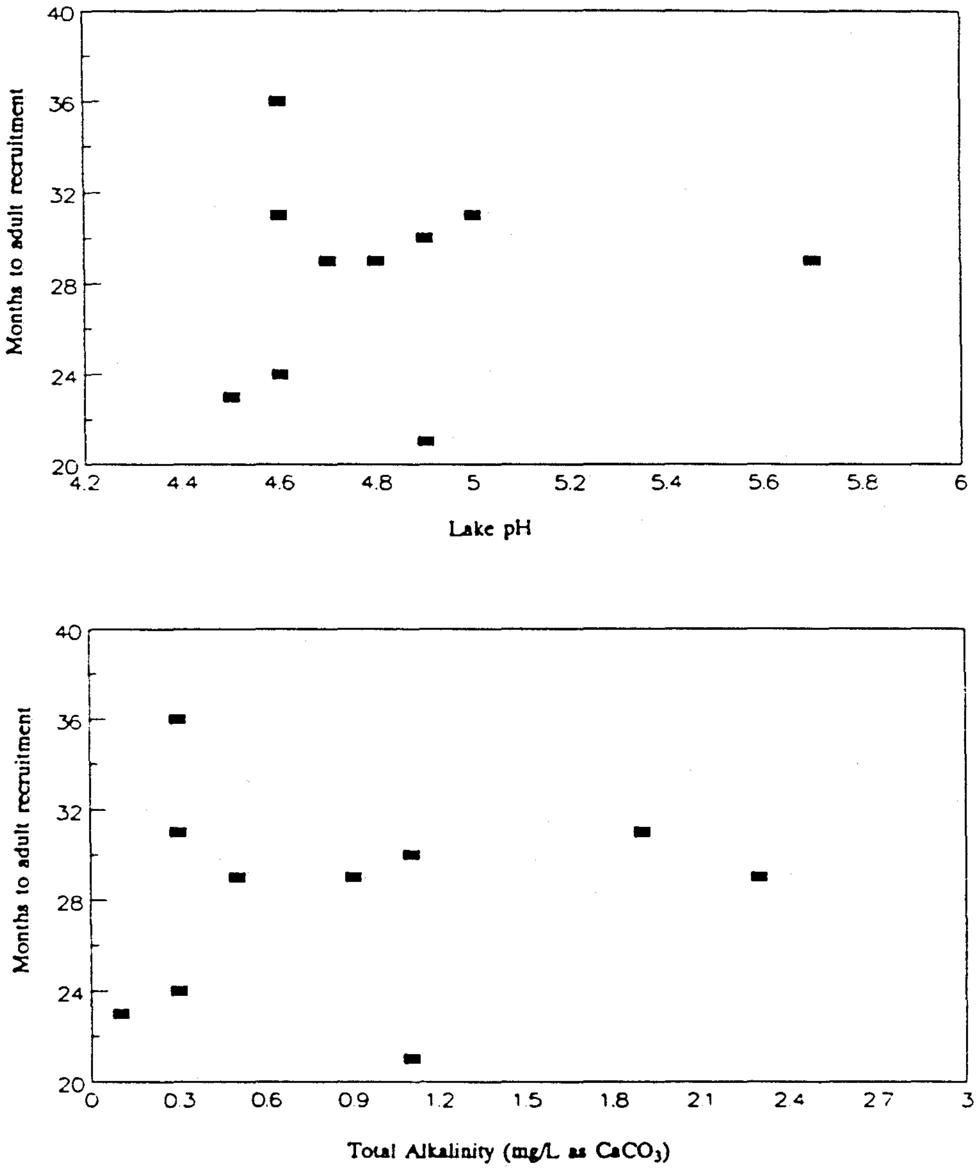


Figure 2-23. Relationship between months to adult recruitment (i.e., ≥ 250 mm TL) for largemouth bass and lake pH and total alkalinity.

for further analyses. Growth rates were not available for largemouth bass in Lofton Ponds because no marked fish were recaptured. Mean daily growth rates for largemouth bass in the 11 remaining study lakes ranged from 0.07 mm/day in Lake Barco to 0.18 mm/day in Brock Lake (Table 2-11). Mean daily growth rates for largemouth bass stocked in Gobbler Lake (pH 4.1) and Lawbreaker Lake (pH 4.4) were 0.21 mm/day and 0.09 mm/day, respectively. Mean daily growth rates were significantly ($P < 0.10$) correlated with mean lake pH ($r = 0.60$) and mean lake total alkalinity ($r = 0.61$). Partial correlation analysis indicated that mean daily growth rates were not significantly related ($P > 0.10$) to mean lake pH (partial $r = 0.10$) when total alkalinity was taken into consideration.

Lake Gobbler (pH 4.1 and mean growth rate of 0.21 mm/day) and Lawbreaker Lake (pH 4.4 and mean growth rate 0.09 mm/day) did not have an indigenous population of largemouth bass. Growth rates were based upon fish stocked into both of these systems. The remainder of the study lakes, except Lake Barco, had equivalent daily growth rates. Lake Barco's fish had lower daily growth rates than fish from Crooked Lake (0.15 mm/day) and Brock Lake (0.18 mm/day) (Table 2-12).

Fish Stocking

Thirty-three adult ($\geq$ 250 mm TL) largemouth bass were stocked into Lawbreaker Lake during the winter of 1987 and

Table 2-12. Mean daily growth rates (mm TL/day) tagged largemouth bass collected from the study lakes.

Lake	pH	Total Alkalinity (mg/L as $CaCO_3$)	N	mm/day	Standard Error
Gobbler[a]	4.1	0	4	0.21	0.04
Lawbreaker[a]	4.4	0	7	0.09	0.02
Barco	4.5	0.1	6	0.07	0.02
Crooked	4.6	0.3	36	0.15	0.01
Deep	4.6	0.3	3	0.13	0.01
McCloud	4.6	0.3	13	0.13	0.06
Turkey Pen	4.7	0.5	7	0.14	0.03
Lofton Pond	4.8	0.9	b		
Brock	4.9	1.1	32	0.18	0.02
Tomahawk	4.9	1.1	21	0.13	0.01
Suggs	5.0	1.9	24	0.15	0.02
Moore	5.7	2.3	18	0.17	0.03
Means of Means				0.14	0.01

[a] Growth of fish stocked by University of Florida.

[b] No recaptures

eight additional adults were stocked during the fall of 1988. At Lake Gobbler, 22 adult largemouth bass were stocked in March 1988. During subsequent sampling occasions, largemouth bass were captured at both lakes. The recaptured fish had been at large for periods ranging from three weeks to 12 months in Lawbreaker Lake, and from 2 1/2 months to 13 months in Lake Gobbler. As of October 1989, attempt to document successful reproduction of the stocked fish has been unsuccessful.

Discussion

Study Site

The 12 study lakes were small and shallow, typical characteristics of many of Florida's acid lakes (Linthurst et al. 1986). Gobbler Lake and Lake Suggs were highly colored (average color > 250 Pt-Co units), but seven lakes had average color values < 5 Pt-Co units, suggesting that organic acids were not the principal cause of acidity (see Canfield et al. 1984). The study lakes were also very dilute (mean specific conductance < 70 μS/cm @ 25° C), reflecting the effects of regional geology and hydrology (Canfield and Hoyer 1988; Lee and Schnoor 1988; Pollman and Canfield, in press). Although the lakes in this study were relatively unproductive compared to other non-acid Florida lakes, they varied substantially in trophic state, ranging from oligotrophic to eutrophic (Frosberg and Ryding 1980; Canfield and Hoyer 1988). The study lakes supported extensive growths of aquatic macrophytes, as half the lakes had littoral zones exceeding 10 m in width. This extensive littoral area represents potentially suitable habitats for the fish in these lakes.

Fish Abundance--Electrofishing

Fifteen species representing seven families were captured during mark-recapture sampling. Of the fifteen species collected during the mark-recapture sampling, almost half were from the family Centrarchidae. Warmouth, the only cosmopolitan species across the 12 study lakes, also belonged to this family. Other widely distributed species included bluegill, largemouth bass and lake chubsucker, collected from 11, 10, and 9 lakes, respectively. Although lake chubsucker, largemouth bass, and bluegill were the three most abundant species, respectively, species assemblages across the study lakes were highly variable. These findings were similar to those of Meehean (1942), who reported Centrarchidae-dominated assemblages in five lakes in the Ocala National Forest, and noted that there was considerable variation in the species assemblages. Meehean (1942) also suggested that such variation was typical for other lakes in the forest.

Lake chubsucker was the most abundant species in six of the nine study lakes where the species was collected, and the second or third most abundant species in the other three lakes. Largemouth bass was the most abundant species in three of the ten study lakes where it occurred, and the second most abundant fish in another six study lakes. Bluegill was the most abundant fish in three of the 11 study lakes where it occurred, and the second or most abundant species in another six study lakes. These results indicate that largemouth bass was the dominant predator, and that lake chubsucker and bluegill were the primary (i.e., most abundant) prey species in these low pH lakes.

Although largemouth bass was the most abundant predator in these low pH systems, other predatory fish were frequently present, and on occasion, were themselves the most abundant or second most abundant predator. Bowfin was the most abundant predator in Lake Gobbler, and bowfin and Florida spotted gar were the most abundant predators in Lake Suggs. Largemouth bass was the most abundant predator in Moore Lake and Lofton Ponds, but chain pickerel was also a common component on the assemblages of both these lakes. Some of the species found in the study lakes such as largemouth bass, bluegill, bluespotted sunfish (Enneacanthus gloriosus), and yellow bullhead have also been reported from other low pH lakes in Florida (Meehean 1942; Schulze 1980; Keller 1984), New Jersey (Hastings 1979), and Wisconsin (Rahel 1982; Rahel and Magnuson 1983; Wiener 1983).

The relative abundance lake chubsucker, the most abundant species in the study lakes, was not related to lake pH or total alkalinity, but was inversely related to lake mean depth. Lake chubsucker density and biomass were also not related to lake pH or total alkalinity, but were related to the biomass (kg fresh weight) of emergent aquatic macrophytes. These findings suggest that the abundance, density, and biomass of the most abundant species in the study lakes were affected more by lake habitat availability (e.g., mean depth) and complexity (e.g., amount of emergent macrophytes) than by lake pH or total alkalinity.

The observed relative abundance of warmouth, bluegill, and largemouth bass were not significantly related to mean lake pH or total alkalinity. Their relative abundances were, however, significantly related to lake mean aluminum levels. Warmouth and bluegill relative abundance were directly related to lake aluminum levels, while largemouth bass relative abundance was inversely related to aluminum levels. While these findings may indicate that aluminum concentrations were affecting the relative abundance of these species, other factors can also explain the observed patterns in the relative abundance.

The susceptibility of fish to aluminum toxicity depends on the form of the aluminum and the pH of the waters (Baker 1982; Baker and Schofield 1982). Aluminum is most toxic to fish (i.e., brook trout and white sucker) at pH levels between 5.2 and 5.4 (Baker 1982). Under these conditions, aluminum toxicity involves precipitation and coagulation of aluminum hydroxide on gill membranes, or adsorption and nucleation of aluminum polymers at surface interfaces (Baker 1982). Aluminum's differential toxicity at different pH levels is caused by complexation of the metal with dissolved organic ligands (Baker 1982). Generally, aluminum is most toxic at pH levels around 5.0 because the metal precipitates from solution and is available for uptake by fish (Baker 1982).

In addition to aluminum, waterborne calcium concentrations can also effect pH toxicity to fish. In both laboratory experiments and related field surveys, fish survival times in low pH waters increased with increasing calcium concentrations (Brown 1982). Similar empirical evidence has also been reported for 700 Norwegian lakes (Wright and Snekvik 1978).

Aluminum is present in dilute, softwater systems due to the percolation of surrounding soils by strong mineral acids (Muniz and Leivestad 1980). The species richness of lakes depends on a colonization event, during which the lake is connected to a source of fish species, and the ecological interaction of all species with each other and the new environment (Barbour and Brown 1974). Florida's softwater lakes are often seepage lakes with no inlet or outlet streams (Williams et al. 1985). Some of the lakes in this study had obvious colonization routes (e.g., Lake Suggs, Lake Gobbler, and Deep Lake), and more fish species were also collected in these lakes than the true seepage lakes (e.g., Lake Lawbreaker, Lake Barco, and Lake McCloud). Therefore, the significant relationship observed between both bluegill and warmouth with lake aluminum concentrations probably reflects the interaction of these factors, (i.e., softwater lakes with high aluminum concentrations, and isolated seepage lakes with few species) and not the adverse effects of high aluminum concentrations on fish. The significant inverse relationship observed between the relative abundance of largemouth bass and mean lake aluminum also reflects the combination of low aluminum levels (i.e., non-seepage lake) and more fish species (increased colonization rates due to inflow or outflow streams).

The mark-recapture procedure used to estimate population size, density, and abundance was a limited success. Although the total number of fish marked was large, there were instances where none of the marked individuals of a given species were recaptured. The lack of recaptures effectively prohibits an accurate estimation of population size, density or biomass for these species. There were also instances where population estimates for a given species were available only from one or two lakes. Test of significant correlations between two variables is tested as a t-test with n - 2 degrees of freedom (Sokal and Rohlf 1981). Thus, species with population estimates from only one or two lakes were excluded from correlation analysis. As a result, only three species, largemouth bass, bluegill, and lake chubsucker were included in the correlation analyses of fish density and biomass to lake morphoedaphic parameters.

Largemouth bass and bluegill density and biomass were not related to lake pH, total alkalinity, or other morphoedaphic parameters measured such as area, mean depth, and areal coverage of aquatic vegetation. The density and biomass of these species may be affected more by factors such as ecological interactions with other fish species than by lake pH or total alkalinity.

In most of the lakes for which there were estimates of both adult and subadult largemouth bass, the estimates were equivalent. Lake Barco and Lake Tomahawk had higher densities of subadults, and Moore Lake had higher densities of adults. These results suggest that the majority of the study lakes had successfully reproducing largemouth bass populations, with eventual recruitment of juveniles into the adult stock. The structure of the largemouth bass populations (i.e., highly skewed age-group distribution) in Lake Barco, Tomahawk Lake, and Moore Lake suggest that these populations may be reflecting the presence of strong year classes (Aggus and Elliot 1975).

Fish Abundance and Biomass--Gillnetting

Fish abundance and biomass, as indexed from experimental gillnetting were not related to lake pH or total alkalinity, but were related to chlorophyll *a* concentrations. Chlorophyll *a* concentration was the only significant factor influencing the number and weight of fish caught in experimental gillnets for a 50 lake data set containing acid and non-acid Florida lakes (including the 12 lakes in the present study) (Canfield et al. 1989).

Chlorophyll a concentrations have been shown to be strongly affected by total phosphorus concentrations (Dillon and Rigler 1974), and both parameters have, at times, been used as a measure of lake trophic state (Moyle 1946; Shannon and Brezonik 1972; Dillon and Rigler 1975; Frosberg and Ryding 1980) or to predict fish yield (Oglesby 1977; Hanson and Leggett 1982). These findings suggest that lake trophic state, and not lake pH or total alkalinity is the primary factor affecting the abundance and biomass of fish, as indexed by experimental gillnets, in Florida's acid lakes.

Fish Abundance and Biomass--Block-netting

The estimated densities and biomass of fish collected from the nine study lakes sampled with rotenone were similar to fish populations in five acid (pH 5.4 - 5.6) lakes in the Ocala National Forest (Meehean 1942). In the present study, rotenone sampling yielded from 53 to 13,000 fish/hectare, and from 3.4 to 95 kg/ha. Meehean (1942), also using rotenone, collected from 540 to 22,000 fish/hectare, and from 20 to 95 kg/ha. Meehean (1942) attributed the differences in the fish abundance from his study lakes to the "ecological maturity" as indexed by the abundance of aquatic macrophytes.

The total abundance and biomass of all fish, as determined by rotenone and block-net sampling, were not related to lake pH, total alkalinity, or any of the standard measures of lake trophic state such as total phosphorus, total nitrogen, chlorophyll a, and secchi disc transparency. Total fish abundance and biomass in 14 acid Florida lakes (including nine lakes in the present study) were not related to lake pH or total alkalinity, but were related to the percent coverage of aquatic macrophytes (Canfield et al. 1989). The coverage of aquatic macrophytes was also not related to lake pH or total alkalinity (Canfield et al. 1989). The findings of this study and that of Canfield et al. (1989) suggest that habitat complexity, as indexed by the abundance of aquatic macrophytes, is an important factor affecting fish populations in the study lakes. The absence of detectable relationships between total fish abundance and biomass, and the more conventional measures of trophic state in the nine lakes in this study may be reflecting the presence of extensive growths of aquatic macrophytes. Conventional measures such as chlorophyll a or total phosphorus concentrations cannot be used to assess lake trophic state when the lake is dominated by aquatic macrophytes (Canfield et al. 1983a). The results of this study, and those of Canfield et al. (1989) and Meehean (1942), suggest that fish populations in Florida's naturally acid lakes are affected more by lake trophic state and/or habitat complexity, as indexed by aquatic macrophytes, than by lake pH.

Condition Factors

Fishery biologists have traditionally used weight related indices to describe the condition, plumpness, robustness or "well-being" of fish (Carlander 1977). Harvey (1982) noted that acid stress alters fish population size, food supply, growth, and metabolism, and suggested that condition factor could be good indicator of acid-stressed fish. The condition factors for fish in this study were compared with values presented in Carlander (1977) and other published studies. Carlander (1977) and others generally provided no chemistry data for the water bodies included in their reports. The values used for comparison represent studies from throughout the United States, and undoubtedly included many non-acid lakes. These values, while not representative of all low pH situations, provide a general pattern of possible values, and serve as a guide for determining if condition factors for fish in this study exhibited possible effects of low pH conditions.

Mean condition factors for longnose gar in the present study were within the range of published literature values (0.13 to 0.41) reported for the species (Carlander (1977). Both adult and subadult chain pickerel condition factors were equivalent to values reported for fish taken from Lake Conway (Guillory 1979) and Blue Cypress Lake (Herke 1959), two non-acid Florida lakes. The range of mean condition factors (1.32 - 1.56) for yellow bullhead in this study was comparable to the range (1.05 - 1.66) reported for Alabama and Wisconsin (Carlander 1969). The average condition factor (1.36) of brown bullhead, collected only in Lake Suggs, was within the range (1.06 - 1.80) reported for the species from Alabama, Illinois, Minnesota, and Wisconsin (Carlander 1969).

Average condition factors for adult black crappie collected during this study were below the range of condition factors (1.33 - 1.88) reported for highly eutrophic Lake George, Florida (Huish 1954). Condition factors values from this study were comparable to the range (1.20 - 1.62) reported for black crappie during years of slow growth and high population densities in Lake Okeechobee, Florida (Schramm et al. 1985). The available data on the size of the adult black crappie populations in Crooked Lake and Lake Suggs were insufficient to determine if food resources might be limited due to high population densities.

Average warmouth condition factors for fish in this study were not related to lake pH and were equivalent to the condition factors (1.66 - 2.36) reported for combined subadult and adult data from Alabama, Illinois, Iowa, and Oklahoma (Carlander 1977). Similar values have also been reported for subadult warmouth collected from the acid Okefenokee Swamp (1.66 - 2.25) and the Suwannee River (1.39 - 2.15), Georgia (Germann et al. (1974); however, condition factors of adult fish in the Okefenokee Swamp (2.31 - 3.06) and Suwannee River (2.31 - 2.76) were higher than the values in this study, and other published literature values for adults of the species (Carlander 1977).

Mean condition factors for subadult and adult bluegill were not related to lake pH and were comparable to the values reported for subadult (1.31 - 1.78) and adult (1.47 - 1.93) in Lake Baldwin and Lake Wales, two non-acid Florida lakes (Colle and Shireman 1980). Condition factors of bluegill from five low pH and six circumneutral lakes in northern Wisconsin were not related to lake pH, but were significantly related to bluegill population density (Wiener (1983). There are also several published examples where the growth and condition of bluegill were inversely related to population density (Carlander 1977).

Mean condition factors for largemouth bass in the present study were related to the width of the lake littoral zone and total nitrogen concentrations, but not to lake pH. These values were comparable to values reported from other Florida lakes. Condition factors for largemouth bass Ages I and II, ranged from 1.05 to 1.14 and 1.05 to 1.25, respectively, in eight Florida lakes (Keller 1984). The average pH of these lakes ranged from 4.5 to 7.0. Kingsley Lake, a large circumneutral (pH 7.0) oligotrophic lake, however, had mean condition factors of 1.1 for both subadult and adult largemouth bass (Keller 1984). Colle and Shireman (1980) reported on four years of seasonal condition factors for Lake Wales and Lake Baldwin, lakes that had mean annual pH > 7.0 and different habitat complexity due to changes in the coverage of aquatic macrophytes. Subadult largemouth bass seasonal condition factors ranged from 1.06 to 1.27 when Hydrilla verticillata coverage was < 50%, but ranged from 0.91 to 1.12 when coverage exceeded 50%. Adult fish had seasonal condition factors that ranged from 1.06 to 1.58 when coverage was < 30% and from 1.03 to 1.48 when coverage exceeded 30%. Mean seasonal condition factors for subadult and adult largemouth bass from three fertilized ponds in south Florida ranged from 1.36 to 1.89 and 1.35 to 1.90, respectively (Clugston 1964). Mean condition factors for adult largemouth bass was 1.27 for five acid lakes, 1.26 for three acid colored lakes, and 1.42 for three circumneutral eutrophic Florida lakes (Canfield et al. 1985). The results of this study and other Florida studies suggest that fish condition factors in Florida are probably affected more by factors such as lake trophic status, prey availability, and habitat complexity than by low pH.

Age and Growth of Largemouth Bass

Largemouth bass is a major predator in the majority of Florida's aquatic systems, including the ten acid lakes (pH 4.5 - 5.7) in the present study where the species occurred. Consequently, the growth calculated for this study was compared with published Florida values for the species.

The daily growth rates for adult largemouth bass (≥ 250 mm TL) in all the study lakes except Lake Barco were equivalent to published growth rates for the species in

Florida (Table 2-13). Adult largemouth bass populations with average daily growth rates < 0.10 mm/day, 0.10-0.15 mm/day and > 0.15 mm/day are classified as poor, average, and good, respectively (Crumpton and Smith 1975). Based these criteria, Lake Barco was the only lake in this study where the daily growth rates of largemouth bass were below average.

Back calculated length at Age I and months to adult recruitment were generally below published values for largemouth bass. Chew (1974) reported first year growth of 188 mm TL and 16 months to 250 mm TL in Lake Hollingsworth, Florida and 148 mm TL and 24 months in Lake Weir, Florida. Hoyer et al. (1985) found first year growth of 187 mm TL and 24 months to recruitment in Lake Baldwin, Florida based on a six year average. Canfield et al. (1985) reported equivalent first year growth (180 mm TL) in five acid clear, three acid colored, and three neutral north-central Florida lakes, but growth was suppressed after Age I in both classes of acid lakes. Canfield et al. (1985) attributed growth reductions to either physiological stress associated with acidity and heavy metals or to poorer food supplies in the acid lakes (or to both). Porak et al. (1986) found 175 mm TL to be the average first year growth and 21 months to be the average time to adult recruitment for largemouth bass populations in five Florida lakes and one river. Porak et al. (1986) characterized Florida systems in which

Table 2-13. Mean daily growth rates (mm TL/day) of largemouth bass, by size group, collected from the study lakes and other Florida lakes.

Study Site	Size group (mm TL/day) 150-249	> 250	Technique for Growth Determination	Reference
11 lakes, Florida	0.29	0.15	otoliths <250 tagging data	Present study
5 lakes, 1 river, Florida	0.28	0.12	otoliths	Porak et al. 1986
5 acidic lakes, Florida	0.24	0.10	otoliths	Canfield et al. 1985
3 acidic colored lakes, Florida	0.25	0.11	otoliths	Canfield et al. 1985
3 circumentral lakes, Florida	0.27	0.20	otholiths	Canfield et al. 1985
Lake Baldwin, Florida	0.30	0.15	tagging data	Shireman and Maceina 1983
Lake Pearl, Florida				
100% plant coverage	0.13	0.11	tagging data	Shireman et al. 1982
1% plant coverage	0.22	0.16	tagging data	Department of Fisheries and Aquaculture, University of Florida
Lake Hollingsworth, Florida	0.26	--	length-frequency	Chew 1974
Lake Weir, Florida	0.22	--	length-frequency	Chew 1974

recruitment to adult stocks was in excess of 24 months as slow growing populations.

Daily growth rates of largemouth bass Age I and older in this study were equivalent to literature values for Florida systems with pH values > 5. However, first year growth was slower than other values reported for Florida. Reduced first year growth was the cause of the longer than average time to reach adult size (250 mm TL). Largemouth bass feed primarily on zooplankton until approximately 30 mm TL, then progress to a diet of larger invertebrates such as aquatic insects, amphipods, and freshwater shrimp. By 75 mm TL, young-of-the-year (YOY) largemouth bass will utilize fish as a primary prey source if an adequate sized forage are present (Kramer and Smith 1960; Chew 1974; Aggus and Elliot 1975). For example, YOY largemouth bass in Bull Shoals Lake, Arkansas that fed predominantly on invertebrates had reduced growth and survival when compared to individuals that fed primarily on fish (Aggus and Elliot 1975).

The occurrence of YOY largemouth bass in the 10 study lakes with indigenous populations and their subsequent growth to adult stocks indicate that these 10 lakes were supporting reproducing populations at pH values from 4.5 to 5.7. The below average daily growth rate of largemouth bass in Lake Barco, and the reduced first year growth that occurred in the remaining study lakes may be due to the limited availability of prey items for the small fish found in these lakes. The scarcity of small fish prey for juvenile largemouth bass in the study lakes and adult largemouth bass in Lake Barco probably reflects the oligotrophic conditions found in many of the lakes, rather than physiological stress associated with low pH conditions found in these systems.

Fish Stocking

Largemouth bass stocked into Lake Gobbler and Lawbreaker Lake were recaptured on numerous occasions. Many had been at large for well over a year. These findings indicate that adult largemouth bass could survive the low pH conditions found in Lake Gobbler and Lawbreaker Lake; thus the absence of adult largemouth bass apparently was not due directly to the acute toxicity of low pH and high aluminum concentrations. Furthermore, the April 1989 sacrifice of a recaptured female at Lake Gobbler revealed that this particular fish had well developed ovaries in preparation for the upcoming spawning season. This discovery suggests that although there is no current evidence of successful spawning, largemouth bass gonadal development is apparently not adversely affected by pH levels down to 4.1.

Conclusions

Fish populations in the 12 study lakes did not appear to be affected by the acid conditions in these lakes. The sportfishes largemouth bass and bluegill were collected down to pH 4.5 and 4.1, respectively. The density, biomass, growth and condition of these and other selected species were not related to lake pH across a pH range from 4.1 to 5.7. These measures of fish abundance and relative health (i.e., level of stress as indicated by growth and condition) were more frequently related to lake trophic state as indexed by chlorophyll a concentrations or aquatic macrophyte abundance, and habitat availability and complexity, as indexed by the width of the littoral area and extent of emergent macrophytes.

The results of this investigation support the null hypothesis that fish communities in Florida's naturally acid lakes are unrelated to lake pH. Similar results have also been reported from the few fisheries studies conducted in other low pH lakes (Meehean 1942), and across a pH range from acid to non-acid Florida lakes (Canfield et al. 1989). The fish in these lakes have apparently adapted to this environment, and seem not to be in immediate danger from further acidification. Threats to fishery resources from further acidification may still exist below pH 4.1, the lowest pH of the 12 study lakes, although lakes with lower pH levels and reproducing fish populations are known (D.E. Canfield, pers. comm).

CHAPTER 3
FISH SPECIES DIVERSITY AND ASSEMBLAGE PATTERNS IN 12 NATURALLY ACID FLORIDA LAKES

Introduction

Fish population losses from culturally acidified waters are well documented. These losses, dating back to the 1920's (Jensen and Snekvik 1972), have been attributed to the sudden mortality of adult fish in acidified rivers, and gradual recruitment failure in acidified lakes (Haines 1981; Harvey 1982). Generally, fish susceptibility to low pH conditions varies by species, and with the life history stage of the species. In toxicity tests with acids, adult fish were more resistant to low pH than were embryo and fry of the same species (McKim 1977). The works of Beamish and Harvey (1972), Rahel and Magnuson (1983), Wales and Beggs (1986), Mills et al. (1987) and others also suggest that fish species have differential tolerance to low pH waters.

Fishery science typically deals with the dynamics of exploited fish populations, and aims to maintain or improve some level of sustainable yield. Fishery biologists, therefore, often concentrate their efforts on a few commercially or recreationally important species, while other members of the same fish community are less likely to be studied. While this approach to fishery management has been successful in the past, data exists to suggest that it may not be adequate in all situations (Tonn et al. 1983). In some situations, the ability to predict changes in a lake's fish assemblage in response to some management strategy or environmental perturbation can best be achieved by a community level approach (Tonn et al. 1983).

The differential tolerance of fish to low pH waters allows for the evaluation of the effects of acidification at the community level, including measures of diversity and species assemblage patterns. Given two or more comparable environments, the one with the higher species diversity is seen as less severe, and thus able to support a wider range of species, including species whose habitat optimum is narrow. Furthermore, the presence or absence of sensitive species can serve as indicators of impacted (e.g., acidified) ecosystems.

Toward this end, the fisheries data collected from the 12 acid study lakes described in chapter two were subjected to further analysis. These analyses centered on ecological measures of fish communities, and were intended to complement the work presented in chapter two. The primary objective of these analyses was to test the hypothesis that species richness and the Shannon-Weaver diversity index (H')) were unrelated to lake pH. Other objectives of these analyses were to 1) assess the reproductive success of selected species, 2) determine if there were predictable patterns of fish assemblages, and 3) determine if lake water chemistry had any effect of structuring the observed patterns of fish assemblages in the 12 study lakes.

Methods

Species richness, the total number of species collected per lake, was compiled from experimental gillnet collections, electrofishing, and block-nets. The Shannon-Weaver index (H') was calculated from the block-net data, using the equation:

$$H' = -\sum_{i=1}^{s} (P_i * \log P_i)$$

where s is the number of species, and Pi is the proportion of the total number of individuals consisting of the ith species, and log is base 10 logarithms (Poole 1974).

Community Analysis

A classification procedure (i.e., cluster analysis) was used to evaluate the fish community data, and ordination procedures (i.e., discriminant function analysis, and canonical discriminant function analysis) were used to evaluate the limnological data. Classification procedures assign objects into classes based on degree of similarity, and ordination procedures assign objects or classes along environmental gradients (Gauch 1982; Digby and Kempton 1987).

Reproduction

The reproductive success of selected species was assessed using length-frequency distributions from the electrofishing, experimental gillnets and rotenone sampling to determine the presence of YOY fish. The gear types used in this study and the method used to assess reproductive success (i.e., length-frequency distributions) were most effective on large species. Therefore, some species were excluded form reproductive assessment because sexual maturity may occur at lengths $\leq$ 30 mm TL (Lee et al. 1980). The species to small for definitive assessment were; taillight shiner (*Notropis maculatus*), an unidentified shiner (*Notropis* sp.), tadpole madtom, golden topminnow (*Fundulus chrysotus*), lined topminnow (*Fundulus lineolatus*), bluefin killifish (*Lucania goodei*), mosquitofish, least killifish (*Heterandria formosa*), pygmy killifish (*Leptolucania ommata*), pirate perch (*Aphredoderus sayanus*), everglades pygmy sunfish (*Elassoma evergladei*), and swamp darter (*Etheostoma fusiforme*). YOY of the remaining species could be sampled, with the following lengths used to determine their presence or absence: Florida spotted gar < 200 mm TL (Carlander 1969), longnose gar < 200 mm TL (Carlander 1969), bowfin < 200 mm TL (Carlander 1969), redfin pickerel < 100 mm TL (Crossman 1962), chain pickerel < 300 mm TL (Guillory 1979), golden shiner < 80 mm TL (Carlander 1969), lake chubsucker < 120 mm TL (Shireman et al. 1978), yellow bullhead < 120 mm TL (Carlander 1969), brown bullhead < 120 mm TL (Carlander 1969), seminole killifish (Fundulus seminolis) < 100 mm TL (DuRant et al. 1979), brook silverside (Labidesthes sicculus) < 40 mm TL (Nelson 1968), warmouth < 100 mm TL (Carlander 1977), bluegill < 100 mm TL (Carlander 1977), dollar sunfish (Lepomis marginatus) < 40 mm TL (Lee et al. 1980), redear (Lepomis microlophus) < 100 mm TL (Wilber 1969), largemouth bass < 120 mm TL (otoliths present study, Porak et al. 1986), black crappie < 100 mm TL (Huish 1954, Maceina and Shireman 1982), and flier (Centrarchus macropterus) < 80 mm TL (Carlander 1977). The presence of YOY of these species was interpreted as proof of successful reproduction of those species. However, the absence of YOY of a given species was not interpreted as unsuccessful reproduction. Such absences may be attributed to factors other than unsuccessful reproduction, such as gear selectivity or sampling efficiency.

Data Analysis

Simple linear correlation and partial linear correlation procedures were used to quantify relationships between species diversity measures (i.e., species richness and Shannon-Weaver diversity index (H')) and lake morphoedaphic parameters. Correlation coefficients and partial correlation coefficients were determined using Statistical Analysis System procedures (SAS 1988).

The multivariate analyses were also carried out using the Statistical Analysis System (SAS 1988). The fish species occurrence list was converted to a lake by species presence/absence data matrix, then subjected to an agglomerative cluster method, using unweighted pair-group averaging (SAS cluster procedure, AVERAGE option). This procedure was used to determine if there were repeatable patterns of fish assemblages in the 12 study lakes. Ordination techniques require a priori groupings of the data to be analyzed (Gauch 1982; Digby and Kempton 1987); therefore, the limnological data were grouped by lakes (i.e., 12 lakes placed into four groups) for ordination analysis. The groupings were based on the result of the cluster analysis, such that most of the lakes with similar fish assemblages were placed in the same group. The fish assemblage in Lake Gobbler was intermediate between the assemblage patterns in two nearby clusters. Lake Gobbler's fish assemblage contained species (e.g., bowfin, and Florida spotted gar) which were only collected from lakes in one of the nearby clusters. Because Lake Gobbler was highly colored (260 Pt-Co units), it was placed in the group which also contained the two species mentioned above, and a highly colored lake (i.e., Lake Suggs; 280 Pt-Co units). After being grouped, the limnological data were subjected to discriminant functions analysis (SAS discriminant procedure, non-parametric method), and canonical discriminant functions analysis (SAS canonical discriminant procedure). The discriminant procedure determines criteria for classifying observation into two or more groups, and the canonical discriminant procedure determines which subset of the quantitative variables best uncovers the differences between classes (SAS 1988).

Due to insufficient degrees of freedom (i.e., more variables than experimental units), the initial discrimant functions analysis only performed univariate analysis of variance. This procedure revealed that conductivity, chloride, sulfate, water color, calcium, and magnesium concentrations differed significantly ($P < 0.1$) among the four groups. The groups were then re-evaluated with discriminant function analysis using these six variables and lake pH as the evaluation criteria. Canonical discriminant analysis was also performed to determine which of seven variables were most influential in differentiating among the groups.

Results

Fish Species Diversity

Thirty-three species of fish were collected from the 12 study lakes (Table 3-1). Fish species richness ranged from four species in Lake Lawbreaker to 23 species in Lake Suggs (Table 3-2). Species richness was not correlated with pH ($r = 0.51$; $p > 0.05$; Figure 3-1), but was significantly correlated with lake surface area ($r = 0.63$; $p < 0.05$; Figure 3-2a), total alkalinity ($r = 0.66$; $p < 0.05$; Figure

Table 3-1. Fish species occurrence in the study lakes based on electrofishing, experimental gillnets, and rotenone sampling. Open circles represent actual occurrence and dashed line represent species distribution across pH levels.

pH	Gobbler 4.1	Lawbreaker 4.4	Barco 4.5	Crooked 4.6	Deep 4.6	McCloud 4.6	Turkey Pen 4.7	Lofton Ponds 4.8	Brock 4.9	Tomahawk 4.9	Suggs 5.0	Moore 5.7
Total Number of Species	10	4	6	14	19	5	11	11	13	15	23	16
Esox americanus	0	-	-	-	0	-	-	0	0	-	0	0
Ictalurus natalis	0	-	-	0	0	-	0	-	0	0	0	0
Gambusia holbrooki	0	0	0	0	-	0	0	0	0	0	0	0
Enneacanthus gloriosus	0	-	-	-	0	-	-	-	-	0	0	0
Lepomis gulosus	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis macrochirus	0	-	0	0	0	0	0	0	0	0	0	0
Lepisosteus platyrhincus	0	-	-	-	0	-	-	-	-	-	0	
Erimyzon sucetta	0	0	-	0	0	-	0	0	0	0	0	
Noturus gyrinus	0	-	-	-	-	-	-	-	0	-	0	0
Amia calva	0	-	-	-	0	-	-	-	-	-	0	
Fundulus lineolatus		0	-	0	0	-	0	0	0	0	-	0
Micropterus salmoides			0	0	0	0	0	0	0	0	0	0
Etheostoma fusiforme			0	0	-	0	-	-	0	0	0	0
Labidesthes sicculus				0	0	-	0	0	0	0	0	0
Notemigonus crysoleucas				0	-	-	-	-	-	-	0	

Table 3-1. Continued.

pH	Gobbler 4.1	Lawbreaker 4.4	Barco 4.5	Crooked 4.6	Deep 4.6	McCloud 4.6	Turkey Pen 4.7	Lofton Ponds 4.8	Brock 4.9	Tomahawk 4.9	Suggs 5.0	Moore 5.7
Pomoxis nigromaculatus				0	0	----	----	----	----	----	0	
Lepisosteus osseus					0	----	----	----	----	----	0	
Heterandria formosa					0	----	----	----	----	0	0	
Elassoma evergladei					0	----	0	0	----	----	----	0
Esox niger								0	0	----	0	0
Lepomis marginatus										0	----	0
Fundulus chrysotus				0	0	----	0	----	----	0	0	
Centrarchus macropterus										0	0	
Lepomis microlophus											0	0
Notropis maculatus					0							
Ictalurus nebulosus											0	
Fundulus seminolis				0	----	----	----	0				
Lucania goodei					0							
Leptolucania ommata									0	0	----	0
Aphredoderus sayanus											0	
Notropis sp.			0	0								
Fundulus cingulatus							0					
Anguilla rostrata					0							

Table 3-2. Species richness (number of species/lake) and Shannon-Weaver index (H') of species diversity for the study lakes.

Lake	pH	Species richness	Species diversity (H')
Gobbler	4.1	10	*
Lawbreaker	4.4	4	0.66
Barco	4.5	6	1.32
Crooked	4.6	14	1.23
Deep	4.6	19	1.82
McCloud	4.6	5	*
Turkey pen	4.7	11	0.91
Lofton Ponds	4.8	11	1.26
Brock	4.9	13	*
Tomahawk	4.9	15	0.84
Suggs	5.0	23	1.34
Moore	5.7	16	1.15

*These lakes were not sampled with block-nets and rotenone; therefore, Shannon-Weaver diversity indices could not be calculated.

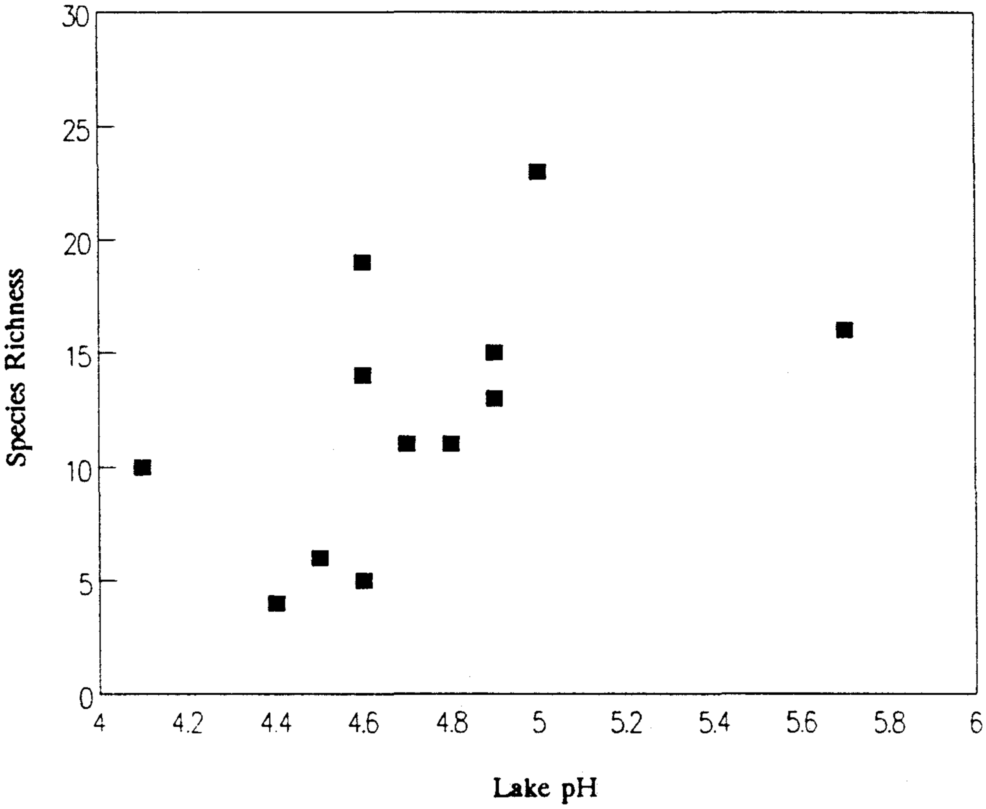


Figure 3-1. Fish species richness (number of species per lake) in relation to mean lake pH for the 12 study lakes.

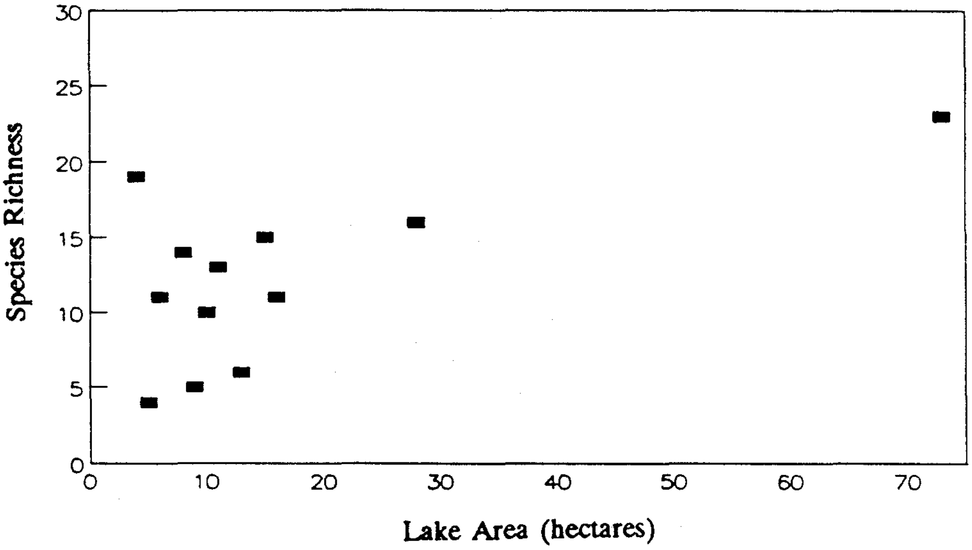


Figure 3-2a. Fish species richness (number of species per lake) in relation to lake area for the 12 study lakes.

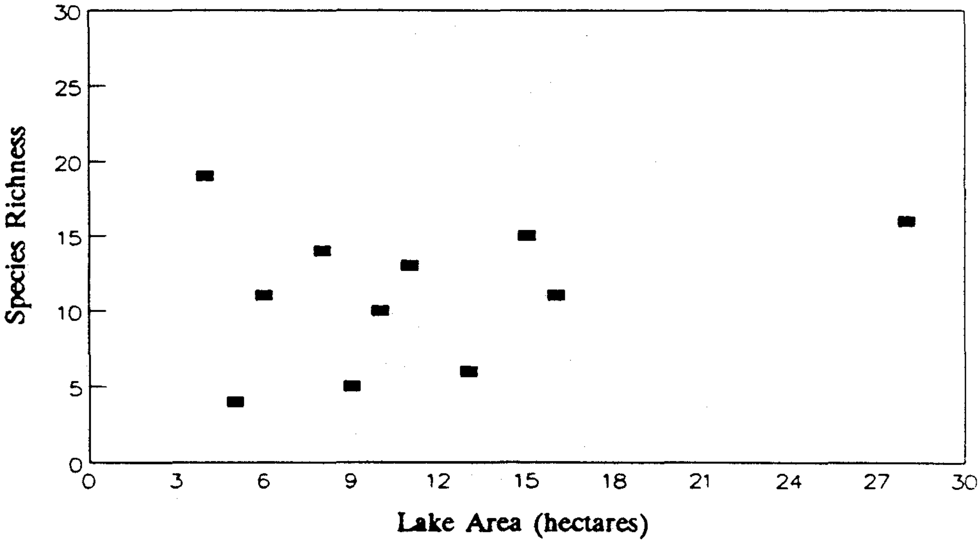


Figure 3-2b. Fish species richness (number of species per lake) in relation to lake area for 11 study lakes, excluding Lake Suggs.

3-3), and total nitrogen ($r = 0.55$; $p < 0.1$; Figure 3-4) in the 12 acid study lakes.

The strong correlation between fish species richness and lake surface area in the study lakes was heavily influenced by Lake Suggs, which was 2.6 times larger than the next largest lake, Moore Lake (Figure 3-2a). With Lake Suggs removed from the data set, there was no significant correlation between fish species richness and lake surface area ($r = 0.25$; $p > 0.05$; Figure 3-2b). Total alkalinity and total nitrogen also were correlated to each other ($r = 0.49$). Partial correlation analyses, accounting for the effects of total nitrogen, demonstrated that there was no significant relationship between fish species richness and total alkalinity (partial $r = 0.54$; $p > 0.05$).

Shannon-Weaver (H') index of species diversity for the nine lakes sampled with block-nets and rotenone ranged from 0.66 in Lawbreaker Lake to 1.82 in Deep Lake (Table 3-2), and was not correlated with lake pH ($r = 0.025$; $p > 0.05$) or total alkalinity ($r = 0.042$; $p > 0.05$;) (Figure 3-5), but was significantly correlated ($r = 0.69$; $p < 0.05$) to the areal coverage of aquatic macrophytes (Figure 3-6).

Fish Assemblage Patterns

The cluster procedure revealed the presence of four distinct groups of lakes which had similar fish assemblages (Figure 3-7). The species richness in the groups ranged from 5 fish per lake to 17 fish per lake, with the same

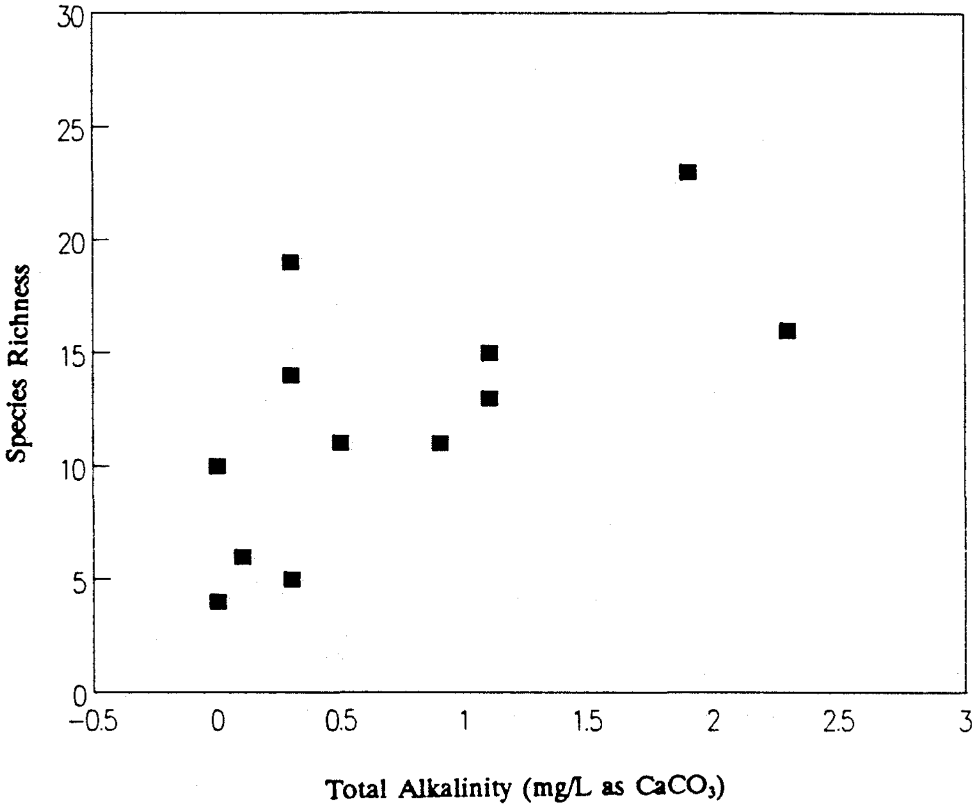


Figure 3-3. Fish species richness (number of species per lake) in relation to lake total alkalinity for the 12 study lakes.

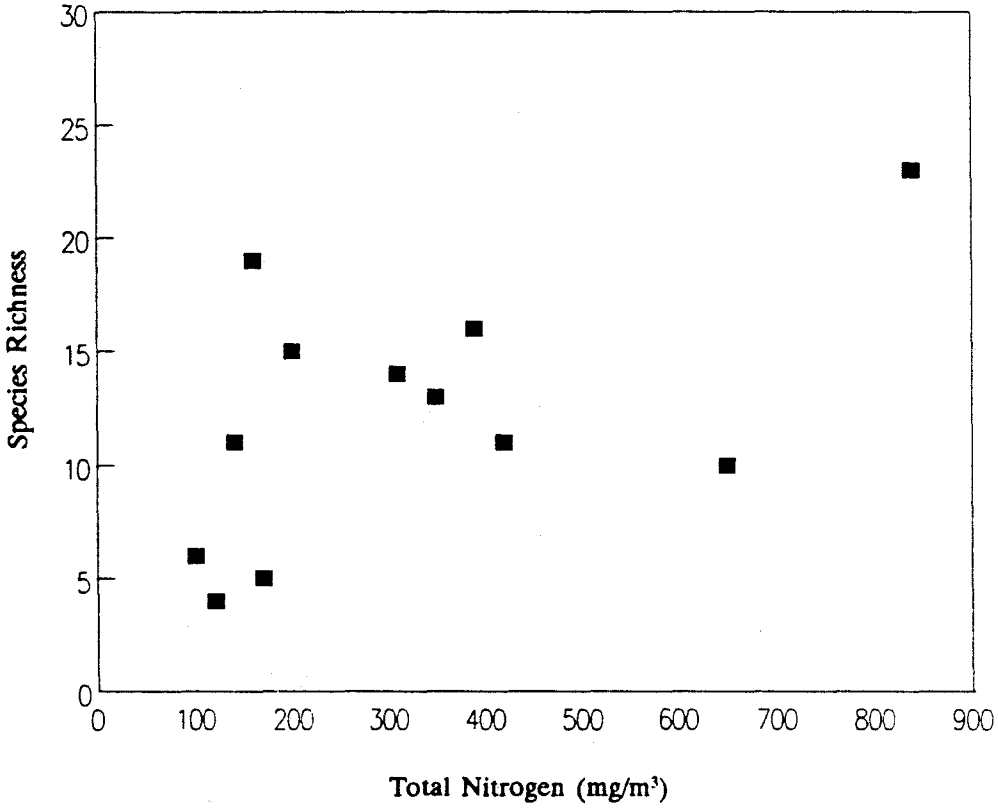


Figure 3-4. Fish species richness (number of species per lake) in relation to lake total nitrogen for the 12 study lakes.

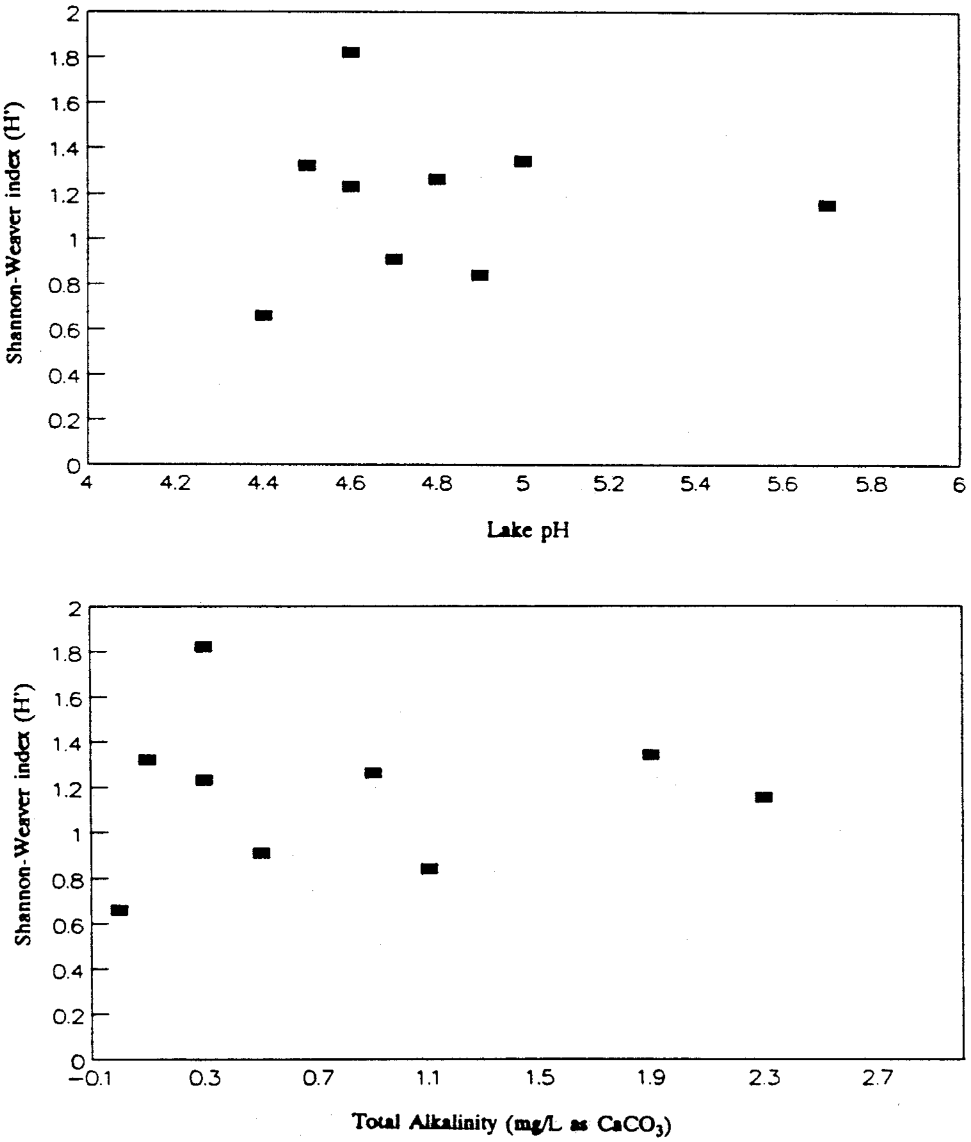


Figure 3-5. Shannon-Weaver index (H') of fish species diversity in relation to lake pH and total alkalinity in the nine study lakes sampled with block-nets and rotenone.

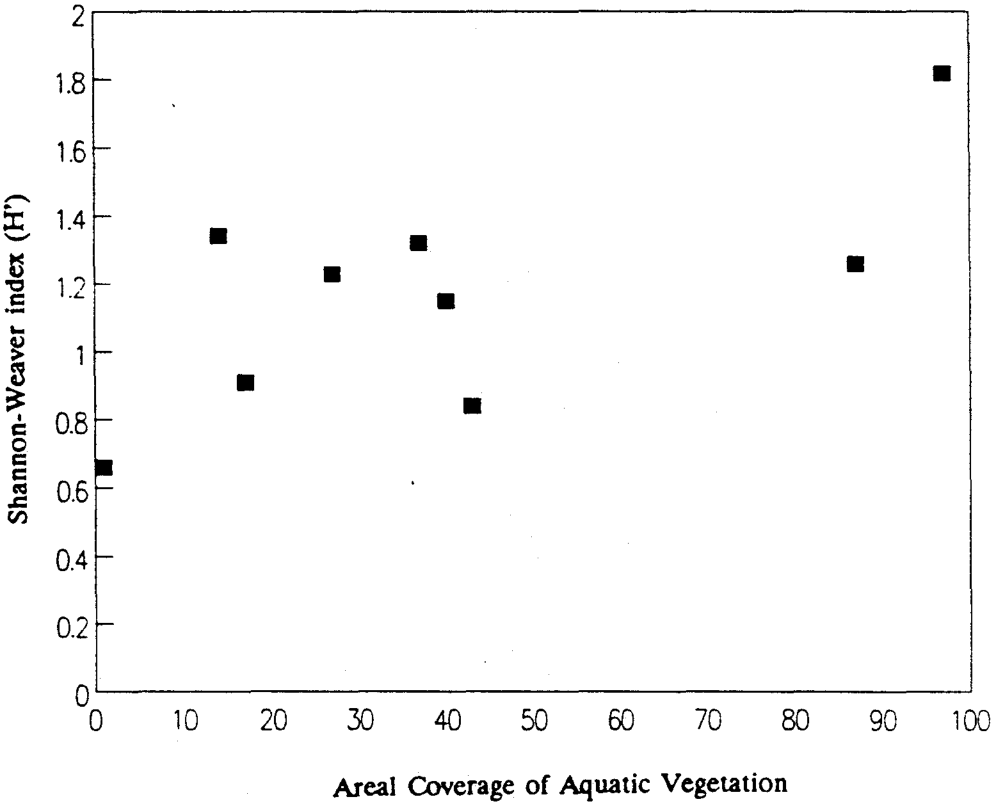


Figure 3-6. Shannon-Weaver index (H') of fish species diversity in relation to the areal coverage of aquatic vegetation in the nine study lakes sampled with block-nets and rotenone.

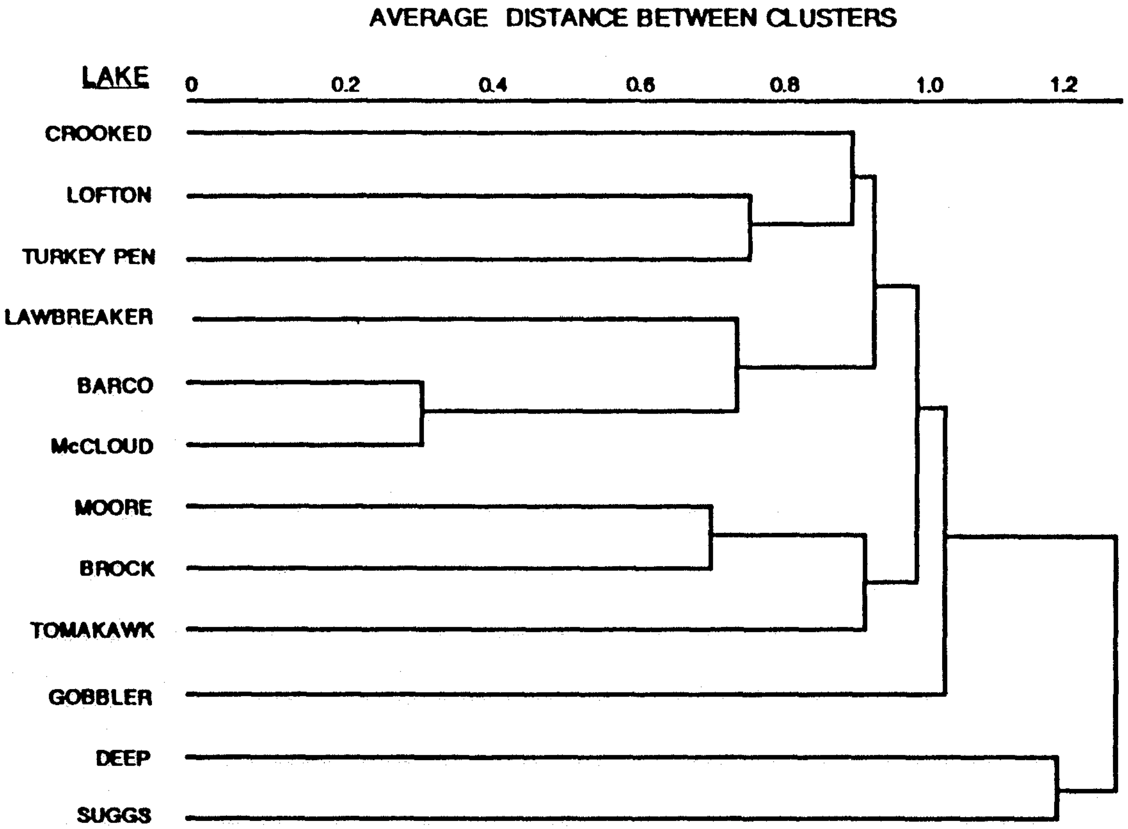


Figure 3-7. Cluster dendrogram showing similarities in fish assemblage patterns based on the presence/absence data matrix of the 33 species collected from the 12 study lakes.

core-group of about five species present in all the lakes (Table 3-3).

The first group, Group A, contained three lakes (Crooked Lake, Lofton Ponds, and Turkey Pen Pond) had an average of 12 species. The species most commonly found (i.e., occurring in at least two-thirds of lakes) in these lakes were yellow bullhead, mosquitofish, warmouth, bluegill, lake chubsucker, lined topminnow, largemouth bass, swamp darter, brook silversides, everglades pygmy sunfish, and seminole killifish (Table 3-3). The second group, Group B, also contained three lakes (lakes Lawbreaker, Barco, and McCloud), but only contained an average of five species, most commonly mosquitofish, warmouth, bluegill, largemouth bass, and swamp darter (Table 3-3). Three lakes (Moore Lake, Brock Lake, and Lake Tomahawk) comprised the third group, Group C, which had an average 15 species. The most common species in Group C were redfin pickerel, yellow bullhead, mosquitofish, bluespotted sunfish, warmouth, bluegill, lake chubsucker, tadpole madtom, lined topminnow, largemouth bass, swamp darter, brook silverside, and pygmy killifish (Table 3-3). The fourth group, Group D, also contained three lakes (Lake Gobbler, Deep Lake and Lake Suggs) and had an average of 17 species. The common species in Group D were redfin pickerel, yellow bullhead, mosquitofish, bluespotted sunfish, warmouth, bluegill, Florida spotted gar, lake chubsucker, tadpole madtom, bowfin, largemouth bass, swamp darter, brook silversides,

Table 3-3. Species composition of the four fish assemblages as indicated by cluster analysis.

GROUP A

Lakes

	Crooked	Lofton Ponds	Turkey Pen Pond
Species	*Ictalurus natalis*	*Esox americanus*	*Ictalurus natalis*
	Gambusia holbrooki	*Gambusia holbrooki*	*Gambusia holbrooki*
	Lepomis gulosus	*Lepomis gulosus*	*Lepomis gulosus*
	Lepomis macrochirus	*Lepomis macrochirus*	*Lepomis macrochirus*
	Erimyzon sucetta	*Erimyzon sucetta*	*Erimyzon sucetta*
	Fundulus lineolatus	*Fundulus lineolatus*	*Fundulus lineolatus*
	Micropterus salmoides	*Micropterus salmoides*	*Micropterus salmoides*
	Etheostoma fusiforme	*Labidesthes sicculus*	*Labidesthes sicculus*
	Labidesthes sicculus	*Elassoma evergladei*	*Elassoma evergladei*
	Notemogonus crysoleucas	*Esox niger*	*Fundulus chrysotus*
	Poxomis nigromaculatus	*Fundulus seminolis*	*Fundulus cingulatus*
	Fundulus chrysotus		
	Fundulus seminolis		
	Notropis sp.		

GROUP B

LAKES

	Lawbreaker	Barco	McCloud
Species	*Gambusia holbrooki*	*Gambusia holbrooki*	*Gambusia holbrooki*
	Lepomis gulosus	*Lepomis gulosus*	*Lepomis gulosus*
	Erimyzon sucetta	*Lepomis macrochirus*	*Lepomis macrochirus*
	Fundulus lineolatus	*Micropterus salmoides*	*Micropterus salmoides*
		Etheostoma fusiforme	*Etheostoma fusiforme*
		Notropis sp.	

Table 3. Continued.

GROUP C

Lakes

	Moore	Brock	Tomahawk
Species	*Esox americanus*	*Esox americanus*	*Ictalurus natalis*
	Ictalurus natalis	*Ictalurus natalis*	*Gambusia holbrooki*
	Gambusia holbrooki	*Gambusia holbrooki*	*Enneacanthus gloriosus*
	Enneacanthus gloriosus	*Lepomis gulosus*	*Lepomis gulosus*
	Lepomis gulosus	*Lepomis macrochirus*	*Lepomis macrochirus*
	Lepomis macrochirus	*Erimyzon sucetta*	*Erimyzon sucetta*
	Noturus gyrinus	*Noturus gyrinus*	*Fundulus lineolatus*
	Fundulus lineolatus	*Fundulus lineolatus*	*Micropterus salmoides*
	Micropterus salmoides	*Micropterus salmoides*	*Etheostoma fusiforme*
	Etheostoma fusiforme	*Etheostoma fusiforme*	*Labidesthes sicculus*
	Labidesthes sicculus	*Labidesthes sicculus*	*Heterandria formosa*
	Elassoma evergladei	*Esox niger*	*Lepomis marginatus*
	Esox niger	*Leptolucania ommata*	*Fundulus chrysotus*
	Lepomis marginatus		*Centrarchus marcopterus*
	Lepomis microlophus		*Leptolucania ommata*
	Leptolucania ommata		

Table 3. Continued.

GROUP D

Lakes

	Suggs	Gobbler	Deep
Species	*Esox americanus*	*Esox americanus*	*Esox americanus*
	Ictalurus natalis	*Ictalurus natalis*	*Ictalurus natalis*
	Gambusia holbrooki	*Gambusia holbrooki*	*Enneacanthus gloriosus*
	Enneacanthus gloriosus	*Enneacanthus gloriosus*	*Lepomis gulosus*
	Lepomis gulosus	*Lepomis gulosus*	*Lepomis macrochirus*
	Lepomis macrochirus	*Lepomis macrochirus*	*Lepisosteus platyrhincus*
	Lepisosteus platyrhincus	*Lepisosteus platyrhincus*	*Erimyzon sucetta*
	Erimyzon sucetta	*Erimyzon sucetta*	*Amia calva*
	Noturus gyrinus	*Noturus gyrinus*	*Fundulus lineolatus*
	Amia calva	*Amia calva*	*Micropterus salmoides*
	Micropterus salmoides		*Labidesthes sicculus*
	Etheostoma fusiforme		*Pomoxis nigromaculatus*
	Labidesthes sicculus		*Lepisosteus osseus*
	Notemigonus crysoleucas		*Heterandria formosa*
	Pomoxis nigromaculatus		*Elassoma evergladei*
	Lepisosteus osseus		*Fundulus chrysotus*
	Heterandria formosa		*Notropis maculatus*
	Esox niger		*Lucania goodei*
	Fundulus chrysotus		*Anguilla rostrata*
	Centrarchus macropterus		
	Lepomis microlophus		
	Ictalurus nebulosus		
	Aphredoderus sayanus		

longnose gar, least killifish, and golden topminnow (Table 3-3).

Environmental Water Chemistry

The means of the seven parameters used to evaluate lake group water chemistry were different, but the within group variability was high (Table 3-4). Discriminant analysis of the grouped water chemistry data indicated that the distances between the groups (based on the pooled covariance matrix) were not significant ($P > 0.05$) (Table 3-5).

Canonical discriminant analysis of the grouped water chemistry data derived three canonical variates (i.e., linear combinations of the quantitative variables) which explained 100% of the statistical variation found among the four groups of lakes (Table 3-6). The first canonical variate (which accounted for 79% of the variation along that axis) was most heavily influenced by chloride (canonical $r = 0.80$) and water color (canonical $r = 0.78$). The second canonical variate, which accounted for an additional 18% of the variation along the second axis, was most heavily influenced by sulfate (canonical $r = 0.91$). A graphical representation of the results of the canonical discriminant analysis (i.e., canonical variates 1 vs. canonical variate 2) shows the relative positions of the groups, based on means of the seven chemical parameters (Figure 3-8).

Table 3-4. Results of discriminant function analysis of limnological data showing group means of the seven parameters used to evaluate group chemistry.

Variable		A	B	C	D
pH	$\bar{X}$	4.7	4.5	5.1	4.4
	SE	<0.01	<0.01	<0.01	<0.01
	N	3	3	3	3
Conductivity (µS/cm at 25 °C)	$\bar{X}$	28	50	24	54
	SE	9	7	5	9
	N	3	3	3	3
Chloride (mg/L)	$\bar{X}$	4.4	6.9	4.6	10.7
	SE	1.5	0.6	1.2	2.1
	N	3	3	3	3
Sulfate (mg/L)	$\bar{X}$	3.5	7.5	2.8	4.7
	SE	0.9	1.6	0.5	0.9
	N	3	3	3	3
Color (Pt-Co units)	$\bar{X}$	6	0.6	20	180
	SE	3.5	0.4	8.1	88
	N	3	3	3	3
Magnesium (mg/L)	$\bar{X}$	0.4	0.9	0.5	1.0
	SE	0.2	0.2	0.1	0.3
	N	3	3	3	3
Sodium (mg/L)	$\bar{X}$	2.0	3.7	2.2	4.5
	SE	0.8	0.4	0.7	0.6
	N	3	3	3	3

Table 3-5. Results of discriminant function analysis of the limnological data, listing multivariate statistics and F approximations[*].

Statistic	Value	F	Num DF	Den DF	Pr > F
Wilk's Lambda	0.01	1.45	21	6	0.33
Pillia's Trace	2.14	1.42	21	12	0.27
Hotelling-Lawley Trace	28.14	0.9	21	2	0.65

[*] The multivariate tests listed above test the hypothesis that the class means are equal in the population.

Table 3-6. Results of the canonical discriminant analysis, listing canonical correlation, eigenvalues, and total canonical structure of the three canonical variable derived from the analysis.

	Canonical Correlation	Adjusted Canonical Correlation	Approx. Standard Error	Squared Canonical Corr.
1	0.95	0.91	0.03	0.90
2	0.82	0.73	0.09	0.67
3	0.45	0.17	0.24	0.20

	Eigenvalue	Proportion	Cumulative Proportion
1	8.96	0.79	0.79
2	2.03	0.18	0.97
3	0.25	0.03	1.00

Test of HO: The canonical correlation in the current row and all that follow are zero.

	Likelihood Ratio	Approx. F	Num. DF	Den. DF	Pr > F
1	0.03	0.8	21	6	0.71
2	0.26	0.5	12	6	0.87
3	0.80	0.2	5	4	0.94

Total Canonical Structure

	CAN1	CAN2	CAN3
pH	0.47	0.39	-0.49
Conductivity	0.63	0.57	-0.12
Chloride	0.80	0.21	0.01
Sulfate	0.18	0.91	-0.04
Color	0.78	-0.24	-0.03
Calcium	0.29	0.26	0.00
Magnesium	0.62	0.52	0.22

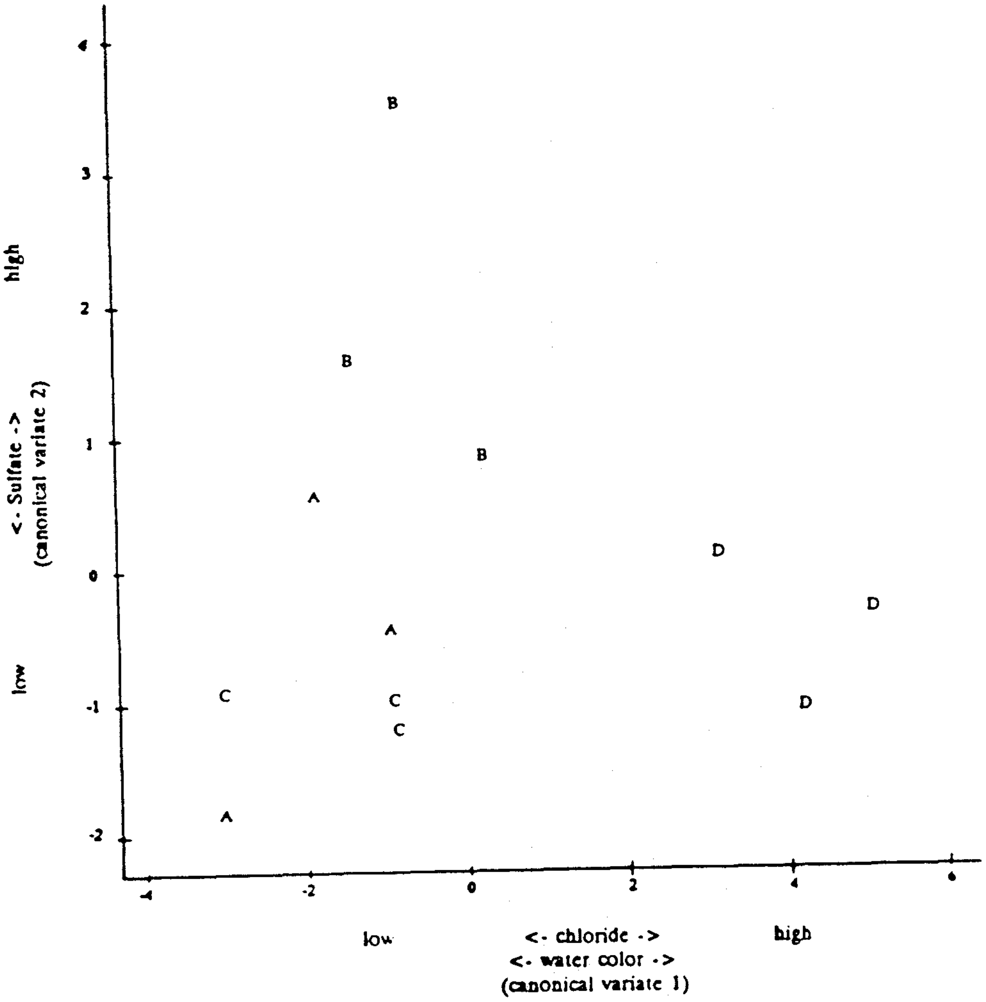


Figure 3-8. Graphical representation of the distribution of the four lake groups along the first and second canonical variates derived from lake water chemistry data.

Reproduction

YOY fish were collected from all study lakes although not all species were represented with yearling fish. Table 3-7 lists both documented (D) and undocumented (ND) occurrences of YOY fishes for all study lakes, and the minimum pH at which adults and YOY fish were collected are presented in Table 3-8.

The family Lepisosteidae had documented reproduction in three of the four lakes where it was collected. YOY Florida spotted gar were collected in three lakes (pH $\geq$ 4.6), but none were collected in Lake Gobbler (pH 4.1). YOY longnose gar were collected from Lake Suggs (pH 5.0), but none were collected from Deep Lake (pH 4.6).

Bowfin, the sole North American member of the family Amiidae, was collected from three lakes ranging in pH from 4.1 to 5.0. However, YOY were not collected from any of these lakes.

Esocidae occurred from a pH of 4.1 to 5.7 in six lakes, with YOY being collected across all pH values. Redfin pickerel was collected in six lakes from a pH of 4.1 to 5.7 with the YOY occurring in electrofishing samples from all six lakes. Chain pickerel occurred in four lakes (pH $\geq$ 4.8), and YOY were present in electrofishing samples from all four lakes.

Cyprinidae (golden shiner, _Notropis_ _maculatus_, and an unidentified shiner, _Notropis_ sp.) were collected at pH ranging from 4.5 to 5.0. YOY golden shiners were collected

Table 3-7. Documented (D) and undocumented (ND) occurrence of young-of-the-year fish collected by electrofishing, experimental gillnets, and rotenone sampling for all species in each lake.

pH	Gobbler 4.1	Lawbreaker 4.4	Barco 4.5	Crooked 4.6	Deep 4.6	McCloud 4.6	Turkey Pen 4.7	Lofton Ponds 4.8	Brock 4.9	Tomahawk 4.9	Suggs 5.0	Moore 5.7
Esox americanus	D[a]				D			D	D		D	D
Ictalurus natalis	D			D	D				ND	D	D	D
Gambusia holbrooki	ND[b]	ND	ND	ND		ND	ND	ND	ND		ND	ND
Enneacanthus gloriosus	ND				ND					ND	ND	ND
Lepomis gulosus	D	D	D	D	D	D	D	D	D	D	D	D
Lepomis macrochirus	ND		D	D	D	D	D	D	D	D	D	D
Lepisosteus platyrhincus	ND				D						D	
Erimyzon sucetta	ND	D		D	D		D	D	D	D	D	
Noturus gyrinus	ND								ND		ND	
Amia calva	ND				ND						ND	
Fundulus lineolatus		ND		ND	ND		ND	ND	ND	ND		ND
Micropterus salmoides			D	D	D	D	D	D	D	D	D	D
Etheostoma fusiforme			ND			ND			ND		ND	
Labidesthes sicculus				ND	D		ND	ND	ND	ND	ND	D
Notemigonus crysoleucas				D							ND	
Pomoxis nigromaculatus				ND							D	
Lepisosteus osseus					ND						D	

Table 3-7. Continued.

pH	Gobbler 4.1	Lawbreaker 4.4	Barco 4.5	Crooked 4.6	Deep 4.6	McCloud 4.6	Turkey Pen 4.7	Lofton Ponds 4.8	Brock 4.9	Tomahawk 4.9	Suggs 5.0	Moore 5.7
Heterandria formosa					ND					ND	ND	
Elassoma evergladei							ND	ND				ND
Esox niger								D	D		D	D
Lepomis marginatus										ND		D
Fundulus chrysotus				ND	ND							
Centrarchus macropterus										D	ND	
Lepomis microlophus											D	ND
Notropis maculatus					ND							
Ictalurus nebulosus											ND	
Fundulus seminolis								D				
Lucania goodei					ND							
Leptolucania ommata									ND			
Aphredoderus sayanus											ND	
Notropis sp.			ND									
Fundulus cingulatus							ND					
Anguilla rostrata					ND							

[a] Documented occurrence of young-of-year fish
[b] Presence of young-of-year not documented

Table 3-8. Minimum pH values in the 12 study lakes in which adults and young-of the-year were collected.

Family and Species	Minimum pH adults only collected	Minimum pH reproduction documented
Lepisosteidae		
Lepisosteus platyrhincus	4.1	4.6
Lepisosteus osseus	4.6	5.0
Amiidae		
Amia calva	4.1	ND[a]
Esocidae		
Esox americanus	4.1	4.1
Esox niger	4.8	4.8
Cyprinidae		
Notemigonus crysoleucas	4.6	4.6
Catostomidae		
Erimyzon sucetta	4.1	4.4
Ictaluridae		
Ictalurus natalis	4.1	4.1
Ictalurus nebulosus	5.0	ND
Cyprinodontidae		
Fundulus seminolis	4.8	4.8
Atherinidae		
Labidesthes sicculus	4.6	4.7
Centrarchidae		
Lepomis gulosus	4.1	4.1
Lepomis macrochirus	4.1	4.5
Micropterus salmoides	4.5	4.5
Pomoxis nigromaculatus	4.6	5.0
Lepomis marginatus	4.9	5.7
Centrarchus macropterus	4.9	4.9
Lepomis microlophus	5.0	5.0

[a] reproduction not documented.

in Crooked Lake, but none were collected from Lake Suggs. An unidentified shiner was collected in Lake Barco (pH 4.5), but their small size prevented documentation of reproduction with the gear type utilized.

Catostomidae (lake chubsucker) were collected from nine lakes (pH 4.1 - 5.0). With the exception of Lake Gobbler (pH 4.1), YOY lake chubsucker were collected from all the study lakes (pH 4.4 - 5.0) where the species occurred.

Three members of the family Ictaluridae were collected in the study lakes: yellow bullhead (pH 4.1 - 5.7), brown bullhead (pH 5.0)), and tadpole madtom (pH 4.1 - 5.0). The tadpole madtom's small size precluded reproductive assessment. YOY yellow bullhead were collected from six of the seven lakes where the species occurred. Brock Lake (pH 4.9) was the only site in which YOY yellow bullhead were not collected. Brown bullhead were only captured in Lake Suggs, but YOY were not collected during the study.

Pirate perch, the lone member of the family Aphredoderidae, was only collected in Lake Suggs (pH 5.0), but their small size precluded verification of reproduction.

Five members of the family Cyprinodontidae (i.e., golden topminnow, seminole killifish, lined topminnow, bluefin killifish, and pygmy killifish) were collected from the study lakes (pH 4.4 to 5.7). Of these, only one species, seminole killifish, collected from two lakes, was large enough for reproduction to be documented with the technique used. Yearling seminole killifish were collected from Lofton Ponds (pH 4.8), but none were collected from Crooked Lake (pH 4.6), the other lake where this species occurred.

Poeciliidae (mosquitofish and least killifish) were collected across the entire range of pH sampled, but YOY could not be effectively sampled with the gear type used in the project.

Atherinidae (brook silversides) were collected from eight of the study lakes (pH 4.6 - 5.7). YOY brook silversides were collected from two (Deep Lake, pH 4.7 and Moore Lake, pH 5.7) of the eight study sites.

Members of the family Centrarchidae were collected from all the study lakes. Two species, bluespotted sunfish, and everglades pygmy sunfish, were too small to assess their reproductive success. Warmouth was the only cosmopolitan species collected in the study and reproduction was documented at all study lakes (pH 4.1 - 5.7). Adult bluegill were collected in 11 of the 12 study lakes, and YOY were present in electrofishing samples in all of these lakes except Lake Gobbler (pH 4.1). YOY dollar sunfish were collected in Moore Lake (pH 5.7), but were not captured from Lake Tomahawk (pH 4.9). YOY redear were collected from Lake Suggs (pH 5.0), but none were collected from Moore Lake (pH 5.7). Adult flier were collected from Lake Tomahawk and Lake Suggs (pH 4.9 and 5.0, respectively), but juveniles were only collected in Lake Tomahawk. Only adult (> 282 mm TL) black crappie were collected from Crooked Lake (pH 4.6), but Lake Suggs (pH 5.0) contained a sustaining population of YOY, subadults, and adults.

YOY largemouth bass were collected from all 10 study lakes where the species occurred with both electrofishing collections and block-net data. Both Lake Gobbler (pH 4.1) and Lawbreaker Lake (pH 4.4) did not have endemic populations of largemouth bass; thus, adult fish were stocked into these lakes during late 1987 and early 1988. However, YOY have not been collected from either lake as of October 1989.

Discussion

Species Diversity

Fish species richness in the 12 study lakes ranged from 4 to 23 species, and was not related to lake pH. Therefore, the hypothesis that species richness in the study lakes was unrelated to lake pH cannot be rejected. This finding differs from those of Keller (1984) and Canfield et al. (1989), who found that species richness was weakly correlated to lake pH for a larger number of acid and non-acid Florida lakes (38 and 50, respectively). Positive relationships between fish species richness and lake pH have also been reported for lakes in the northeastern United States and Canada (Harvey 1975; Wright and Snekvik 1978; Overrein et al. 1981; Harvey and Lee 1982; Schofield 1982; Baker 1982; Somers and Harvey 1984).

Although there is evidence suggesting that reduced fish species richness in low pH lakes may be a general phenomenon for both northern and southern lakes, other factors can also influence species richness. In this study, fish species richness was significantly correlated to total nitrogen concentrations, and Shannon-Weaver diversity index was related to the areal coverage of aquatic macrophytes. Canfield et al. (1989) found that in addition to lake pH, fish species richness was also correlated to lake surface area, total alkalinity, total nitrogen, and color in 50 acid and non-acid Florida lakes. Using multiple regression analyses, Canfield et al. (1989) determined that only lake surface area and water color were significant predictors of fish species richness. Wiener (1983) surveyed six naturally acid Wisconsin lakes, collected between five and 11 species (median = 8), and reported that species richness was lower in the acid lakes as compared to circumneutral lakes of similar size and physical characteristics. Wiener (1983) also noted that there was no difference in lake productivity, as measured by chlorophyll a concentrations, and attributed the difference in species assemblage to water quality characteristics, specifically pH and waterborne calcium concentration. Haines et al. (1986) surveyed eight naturally acid Maine lakes, collected between one and nine species (median = four), and reported that lake surface area, divalent cation concentration, and maximum depth accounted for most of the variability in the number of fish species found in the lakes.

Although fish species richness in the study lakes was not significantly related to lake pH, it did appear to decline below pH 5.0. These findings follow similar trends found in northern lakes where species richness fell dramatically below pH 6.0 (Eilers et al. 1984; Magnuson et al. 1984; Haines et al. 1986; Wales and Beggs 1986; Matuszek and Beggs 1988), but the correlation between species richness and pH for Florida lakes with pH < 5.0 was not significant.

Lake surface area and correlates of productivity such as total nitrogen or chlorophyll a concentrations have proven to be useful predictors of fish community characteristics in northern lakes (Ryder et al. 1974; Jones and Hoyer 1982; Tonn et al. 1983; Eadie and Keast 1984; Rago and Wiener 1986). For example, lake area was the dominant factor affecting fish species richness in over 2900 Canadian lakes when lake pH was greater than 6.0 (Matuszek and Beggs 1988). Similar results have also been reported for Maine (Haines et al. 1986; Pauwels and Haines 1986) and Wisconsin (Rahel 1982; Tonn and Magnuson 1982; Rahel 1986). Additionally, maximum depth (Pauwels and Haines 1986), elevation, latitude, dissolved organic carbon, and total aluminum (Matuszek and Beggs 1988), habitat complexity factors (e.g., vegetation), and lake connectedness (Tonn and Magnuson 1982) have all been shown to affect fish species richness. These reports, along with the results of this investigation, suggest that lake trophic status as indexed by total nitrogen concentrations (Smith 1982; Canfield 1983a) and/or habitat complexity as indexed by the coverage of aquatic macrophytes (Smith 1972; Prince and Maughan 1978; Crowder and Cooper 1982; Savino and Stein 1982; Durocher et al. 1984) may be important factors influencing fish species diversity (as measured by species richness and the Shannon-Weaver index) in naturally acid lakes in Florida, as well as in other areas where such lakes occur.

Fish Assemblage Patterns

The cluster analysis of the presence/absence data suggested four distinct fish assemblages, with each having consistent patterns of species composition. These patterns do not appear to be related to lake water chemistry. The discriminant analyses, based on water chemistry data grouped by fish assemblage type, indicated that the differences in the water chemistry among the four classes of lakes were not significant. However, the assemblage patterns uncovered during these analyses were somewhat different from those uncovered in acid and non-acid lakes in Wisconsin (Rahel 1982; Tonn and Magnuson 1982; Tonn et al. 1983), and Maine (Pauwels and Haines 1986).

Unlike the examples from Wisconsin (Rahel 1982; Tonn and Magnuson 1982; Tonn et al. 1983), and Maine (Pauwels and Haines 1986) where quantitative fish abundance data were used to determine assemblage patterns, the analysis in this study were based on qualitative fish abundance data (i.e., fish presence or absence). Therefore, the assemblage types found in the study lakes did not yield information about the relative abundance of the species which comprise the assemblage. Instead, the assemblage patterns found in the study lakes provided minimal information about which species one could expect to find in environmental conditions similar to that in the lakes where the respective assemblages occurred.

The south Georgia-peninsular Florida fish fauna can be divided into northern and southern segments, with St. Johns and Suwannee river drainages included in the northern segment and the remaining rivers of peninsular Florida included in the southern segment (Gilbert 1887). These two segments have some differences in faunal types, due in part to the high degree of endemism found in the southern segment (Gilbert 1987). The St. Johns River serves as the apparent boundary between northern and southern forms of the same species (C.R. Gilbert, pers. comm.). Therefore, one would expect that there might be differences in the faunal assemblages of the panhandle study lakes as compared to the peninsular study lakes. Despite the possible differences in faunal components between the panhandle and peninsular study lakes, some general assemblage patterns were identified across the study lakes.

The general trend in the four assemblages encountered in the study lakes was a species richness gradient, from relatively species poor to relatively species rich. These assemblages patterns appear to be influenced by the degree of lake connectedness or distance from other water bodies. This speculation seems reasonable when one compares the faunal assemblages of the isolated seepage lakes with that of the connected drainage lakes. For instance, the greatest differences in the four assemblages occurred between the seepage and drainage lakes in the study. The most depauperate assemblage (mean = 5 species per lakes) was found in the most isolated group of lakes. These lakes (i.e., lakes Barco, McCloud, and Lawbreaker) were true seepage lakes without identifiable surface drainages. By comparison, the richest of the four assemblages (mean = 17 species per lake) was found in lakes with a direct connection to another water body or appears to have intermittent connections to nearby streams during high water events (i.e., Gobbler Lake, Deep Lake and Lake Suggs). For example, Lake Gobbler is connected to Jumping Gully, Lake Suggs is connected to Mill Creek, and Deep Lake sits at about the same elevation (i.e., is in the floodplain) of, and lies less than 0.5 km from a tributary of Cabbage Creek.

The next two assemblages were intermediate between the rich assemblage and the depauperate assemblage, and occurred in lakes with adjoining marshes or wetlands (i.e., Crooked Lake, Lofton Pond, Turkey Pen Pond, Brock lake, Lake

Tomahawk, and Moore Lake). The differences between these two assemblages were negligible (mean = 12 and 15 species per lake, respectively).

Based on these findings, one could expect to find a depauperate assemblage consisting primarily of warmouth, bluegill, largemouth bass, swamp darter and mosquito fish in the more isolated (i.e., true seepage) of the naturally acid lakes. In the less isolated lakes, with adjoining marshes or wetlands, additional species such as yellow bullhead, lake chubsucker, lined topminnow, brook silversides, everglades pygmy sunfish, and seminole killifish may also be present. Connected lakes, with direct or intermittent contact with streams or rivers would likely contain many species, including but not be limited to, all the species listed above, plus additional species such as bowfin, Florida spotted gar, longnose gar, least killifish, and golden topminnow. Accordingly, its conceivable that the seepage lakes in this study had fewer fish species because they were isolated and were without established immigration routes.

This inference is supported by Barbour and Brown (1974) who noted that fish species richness, and community composition in lakes depended on colonization events during which the lakes were connected to a source (e.g., rivers) of additional fish species. Furthermore, lake colonization patterns are similar to that of islands, where colonization rates are directly related to the degree of isolation (Brown

1981). Therefore, its likely that streams and wetlands associated with the drainage lakes in this study probably served as potential immigration routes during high water events, and may account for the relatively rich fish fauna in these lakes. For example, Deep Lake is classified as a landlocked seepage lake (Dickinson et al. 1982), but the anadromous american eel, Anguilla rostrata, was collected there during electrofishing sampling. The presence of the eel strongly suggests that Deep Lake probably had a recent connection to a tributary of nearby (approx. 0.5 km) Cabbage Creek. These findings imply that fish species richness and assemblage patterns in the study lakes reflect the colonization patterns of seepage versus drainage lakes, and not the adverse effect(s) of low pH conditions.

Environmental Water Chemistry

The results of the discriminant analyses of the grouped water chemistry data suggest that the study lakes were more similar chemically than they were different, and indirectly support the claim that lake isolation was probably influencing fish assemblage patterns. These analyses indicated that the chemical differences among lake groups (with group membership determined by assemblage pattern) were not significant. Lack of significance among group chemistry is likely due to the high within group variability. For example, Deep Lake and Lake Suggs, the two highly colored study lakes (> 250 Pt-Co units) were grouped with Deep Lake, a clear lake (< 5 Pt-Co units), resulting in high within group variability for color values. Graphical representation of the results of the canonical discriminant analysis (i.e., canonical variates 1 vs. canonical variate 2) shows some chemical differentiation among the lake groups. However, the high within group variability suggests that lake water chemistry was not a major factor influencing fish assemblage patterns in the groups.

Reproduction

Many of Florida's native fishes seem capable of maintaining reproducing populations at very low pH levels. The values reported should not be interpreted to be the actual minima for a particular species; instead, they represent the presence of naturally occurring reproducing populations at the minimum value reported.

At least sixteen species successfully reproduced in the range of acid conditions (i.e., 4.1 - 5.7) found in the study lakes. Adult and YOY largemouth bass, a major sportfish in Florida, were collected from study lakes with pH $\geq$ 4.5. Lamia (1987) documented reproduction and recruitment of this species at a pH of 4.1 in Cue Lake, Florida. Rahel and Magnuson (1983), however, did not collect largemouth bass from northern Wisconsin lakes with pH below 4.6. Haines (1981) listed pH 4.4 - 5.2 as the threshold for reproduction of largemouth bass. During this study, reproducing golden shiners were collected at a pH of

4.6. Other golden shiner populations have been reported from Florida lakes with pH values down to 4.1 (Keller 1984). These values are below the previous minimum pH threshold of 4.8 to 5.3 reported this species (Haines 1981; Rahel and Magnuson 1983; Smith et al. 1986). Esocidae in Florida (i.e., redfin pickerel) occurred at pH 4.1, but in northern Wisconsin pike did not occur below pH 5.5 (Rahel and Magnuson 1983). Catostomidae (i.e., lake chubsucker) occurred in the present study at pH 4.1, but in Nova Scotia and northern Wisconsin white sucker was not found below a pH level of 4.7 (Smith et al. 1986, Rahel and Magnuson 1983). Ictaluridae (i.e., yellow bullhead) also had reproducing populations at pH 4.1 in this study, whereas brown bullhead has not been reported to occur below 4.5 (Haines 1981, Rahel and Magnuson 1983, and Smith et al. 1986). The existence of reproducing fish populations in the study lakes, many of which are well below published values for the species suggests that these species are adapted to these environments.

Fish in naturally acid waters are probably adapted to the acid conditions in these systems (Patrick et al. 1981). For example, acid tolerance in salmonids can be selected for under hatchery conditions (Schofield 1976), and selective breeding drastically improved the survival rate of brown trout in acid waters (Gjedrem 1980). Additionally, yellow perch from naturally acid lakes survived longer than perch from neutral waters when both were exposed to lethal pH levels (Rahel 1982). Because acclimation did not change the survival times, the differences were thought to be genetically based (Rahel 1982). Canfield et al. (1985) found significantly lower plasma electrolyte and osmotic concentration in largemouth bass from naturally acid Florida lakes, as compared to bass from neutral Florida lakes, and suggested that lower electrolyte and osmotic concentrations lakes may be a non-stressful physiological adaptation to low pH waters. Schulze (1980) attributed the success of fish populations in naturally acid Florida lakes to the long term adaptation by the fish to the very acid conditions found in these systems.

It is unclear if fish populations in Florida's acid lakes survive and reproduce because of genetic adaptations to the environment. However, the existing evidence suggest that genetic adaptation of "acid tolerant" species can and does occur, thereby allowing such species to survive and successfully recruit new members under very acid (i.e., pH <5.0) conditions.

Conclusions

The ecological assessment of fish communities in the study lakes provided support for the hypothesis that Shannon-Weaver index, and fish species richness were not related to lake pH in the range of 4.1 to 5.7. These two measures of species diversity were more closely related to correlates of lake trophic state and habitat availability.

The classification and ordination procedures used to evaluate fish assemblage patterns, and their relationship to lake water chemistry suggested four distinct types of assemblages which were not related to lake water chemistry. The observed fish assemblage patterns could be explained by the degree of isolation or connectedness of the respective group of study lakes.

Based on the findings of these analyses, fish species diversity and assemblage patterns in the study lake appear to be related to lake trophic state, historical fish biogeography, and the interaction of these two factors. Although there are conflicting literature accounts of fish species richness and assemblage patterns in other acid systems, many agree with the conclusions drawn from this investigation.

At least 16 of the 21 species large enough for reproduction to be documented successfully reproduced in the range of acid conditions (4.1 - 5.7) found in the study lakes. Another 12 species may have also successfully reproduced in the study lakes, but their small size at sexual maturity and the sampling gear used precluded definitive assessment. The existence of reproducing fish populations in the study lakes, many of which reproduced well below published values for the species, suggests that these species are not adversely affected by the acid conditions in the lakes, and that genetic adaptations to these environments may have occurred.

CHAPTER 4
SUMMARY AND CONCLUSIONS

Project Summary

The 12 study lakes were small, shallow, very dilute, and highly acid. They also varied substantially in trophic state, ranging from oligotrophic to eutrophic, and supported extensive growths of aquatic macrophytes. Fifteen fish species from seven families were captured during mark-recapture sampling, almost half of which were from the family Centrarchidae. This family also had the only cosmopolitan species, warmouth, in the 12 study lakes. Other widely distributed species included bluegill, largemouth bass and lake chubsucker, collected from 11, 10, and 9 lakes, respectively.

The mark-recapture procedure used to estimate population size, density, and abundance was a limited success. In many instances, large numbers of fish were marked, but insufficient numbers of individuals of a given species were marked and/or recaptured to accurately estimate population size, density or biomass for these species. Consequently, only three species, largemouth bass, bluegill, and lake chubsucker were included in the correlation analyses of fish density and biomass to lake morphoedaphic parameters.

Density and biomass estimates of two recreationally important species, largemouth bass and bluegill, were not related to lake pH, total alkalinity, or other morphoedaphic parameters measured. Fish abundance and biomass, as indexed from experimental gillnetting, were not related to lake pH or total alkalinity, but were related to chlorophyll a concentrations. The total abundance and biomass of fish (i.e., all fish species) as determined by rotenone and block-net sampling were not related to lake pH, total alkalinity, or any of the traditional measures of lake trophic state such as total phosphorus, total nitrogen, chlorophyll a, and secchi disc transparency.

The condition factors for fish in this study were generally comparable to the values presented in Carlander (1977) and other published studies. Condition factors of the sportfishes bluegill and largemouth bass were not related to lake pH or total alkalinity.

Daily growth rates of Age I and older largemouth bass in all the study lakes except Lake Barco, were equivalent to literature values for Florida systems with pH values > 5. However, back-calculated length at Age I, and months to adult recruitment were generally below published values for the species. First year growth was slower than other values reported for Florida, and was the cause of the longer than average time to reach adult size (250 mm TL). The occurrence of YOY largemouth bass and their subsequent growth to adult stocks in the study lakes with indigenous bass populations indicate that these systems were sustaining reproducing populations at pH values from 4.5 to 5.7. The below average daily growth rate of largemouth bass in Lake Barco, and the reduced first year growth in the remaining study lakes probably reflects the scarcity of prey for juveniles in these lakes.

Neither fish species richness nor species diversity as measured by the Shannon-Weaver index (H'), were related to lake pH. Rather, these parameters were significantly correlated with total nitrogen concentrations, and to the areal coverage of aquatic macrophytes, respectively.

The cluster analysis of the presence/absence data suggested four distinct fish assemblages, with each having consistent patterns of species composition. The general trend in the four assemblage types encountered was that of a species richness gradient, from relatively species poor to relatively species rich.

Discriminant analyses of the grouped water chemistry data indicated that differences among lake groups were not significant. Three derived canonical variates explained 100% of the statistical variation among the four groups of lakes. The first and second canonical variates, which accounted for 97% of the variation along those two axes, were most heavily influenced chloride and water color, and sulfate concentrations, respectively. Lake pH was not identified as a major factor influencing fish assemblage patterns in the study lakes.

At least sixteen fish species successfully reproduced in the range of acid conditions (i.e., 4.1 - 5.7) found in the study lakes, including the sportfishes largemouth bass and bluegill. The existence of reproducing fish populations in the study lakes, many of which are well below published pH values for the species, suggests that these species are not adversely affected by the acid conditions in the lakes, and that genetic adaptation to these environments may have occurred.

The results of this study and the other published accounts with which comparisons were made suggest that lake pH was not and is not a major factor influencing fish population dynamics in Florida's naturally acid lakes (Table 4-1). In many instances, the fisheries parameters measured were directly related to accepted trophic state indices such as total nitrogen and chlorophyll *a* concentrations. In other instances, factors such as prey availability, and habitat availability and/or complexity, also appeared to be important, though these were not measured directly. At the community level, fish species diversity and assemblage patterns were also not related to lake pH. Instead, these parameters were either strongly related to accepted indices of lake trophic state, or could be explained by factors known to affect fish biogeography.

Table 4.1. Summary of the major parameters measured for fish populations in the study lakes and the environmental factor(s) implicated as strongly influencing each parameter.

DISSERTATION SUMMARY

Parameter	pH Related	Other environmental factor(s) implicated
Largemouth bass:		
density and biomass	No	None
condition factor	No	Nitrogen concentrations, and littoral zone width
daily growth rate	No	Prey availability, esp. for juvenile fish
length at Age I	No	Prey availability, esp. for juvenile fish
months to 250 mm TL	No	Prey availability, esp. for juvenile fish
Bluegill:		
density and biomass	No	None
condition factor	No	Nitrogen concentrations, and littoral zone width
Fish abundance and biomass (gillnets)	No	Chlorophyll *a* concentrations
Fish abundance and biomass (block-nets)	No	None
Species Richness	No	Nitrogen concentrations
Shannon-Weaver diversity index (H')	No	Percent lake area covered with aquatic vegetation

Table 4-1. Continued.

Fish assemblage patterns	No	Degree of lake isolation (or connectedness)
Fish reproduction	No	None (gear and technique limited)

Conclusions

There are many published accounts of fish population response to low acid conditions; however, very few are as comprehensive as this present investigation (but see Gunn et al. 1988). This study is different from past studies of fish populations in acid waters because many methods were used to assess the fish populations, which were then related to many possible influencing environmental variables. Therefore, the results reported herein probably closely reflects the actual response of fish populations to the low pH conditions found in Florida's naturally acid lakes.

The fish populations investigated during this study seem to be unaffected by the low pH conditions in the study lakes. The lakes in this study represent a small fraction of Florida's 7700-plus lakes, and extrapolating the results of this investigation to other Florida lakes should be done with caution. However, the available evidence does suggest that for lakes with conditions similar to those in this study, pH may not be the primary factor influencing fish populations. Additionally, if fish populations have been adversely affected by low lake pH, the effects were probably small and localized. Whether these findings also hold for culturally acidified systems is unknown. There is, however, a growing body of literature which recognizes that there are other factors such as lake trophic state, ecological interactions, genetic adaptation, and historical fish biogeography which can also influence fish populations in acid systems, whether culturally or naturally acid.

The findings of this study differ markedly from studies conducted on culturally acidified lakes in the northeastern United State, Canada, and Scandinavia (hereafter, other affected areas). Many of these reports, which are reviewed in chapter one, have reported extensive losses of fish populations. Regional climate, genetic adaptations, and the interpretation of research results may explain the apparent differences in fish population response to low acid conditions in Florida, as compared to other affected areas.

Sudden mortality of adult fish in riverine environments, and gradual reproductive and recruitment failure in lake environments are the mechanism suspected of causing the fish population losses in the other affected areas. Acute mortality of fish in acid waters occurs primarily in streams, usually in association with episodic events (i.e., heavy autumn rains or snow melt) which rapidly reduce stream pH (Haines 1981). Spring thaw, and concomitant acid meltwaters, are products of the temperate zone climate. Florida lies in the subtropic and tropic zones, and its precipitation follows a seasonal pattern. Convectional precipitation (i.e., thunderstorms) occurs in the summer, and frontal system precipitation occurs in the late fall, winter and early spring. Power plant emissions in Florida also increases during the summer in response to higher demands for electricity (e.g., air conditioner usage increases dramatically during summer months)(Brezonik et al. 1983). Therefore, it is unlikely that Florida receives acid rain in the fall, as most of the sulfate and nitrate emissions occur during the summer months. Accordingly, one would not expect the state's streams and rivers to experience sudden losses of adult fish in response to episodic events such as low pH snow melt or heavy autumn rains.

Genetic adaptations may also help explain the apparent differences between the results of this study and reports from other affected areas. Gradual recruitment failure over a long period of time is the cause often given for losses of fish populations from culturally acidified lakes (see review in chapter one). Because adult fish are more resistant to the effect of low pH than any of the other life history stages (Haines 1981), it is likely that population losses in acid waters are due to reproductive and recruitment failure rather than direct mortality of adult fish (Beamish and Harvey 1972; Beamish et al. 1975; Fritz 1980; Haines 1981; Harvey 1982).

Lakes in the other affected areas often became acid as a direct result of anthropogenic activity, whereas lakes in Florida became acid from natural processes, and have been acid for as long as 40,000 years (Crisman 1984). The length of time a lake has been acid is important because of potential biotic adaptations to the low pH conditions. Many authors have suggested that fish are capable of genetically adapting to low pH conditions (Schofield 1976; Gjedrem 1980; Schulze 1980; Patrick et al. 1981; Rahel 1982; Canfield et al. 1985). The lakes in this study are naturally acid; therefore, fish in these lakes probably evolved under, and have adapted to, the low pH conditions. On the other hand, lakes in other affected areas have only recently become acid, with acidification occurring too rapidly for fish populations to adapt enough to survive in the "new" environment (Schofield 1976). Therefore, genetic adaptations to low pH conditions may be one reason why fish populations in this study appear to respond differently (i.e., did not appear to be affected) than fish populations in other affected areas (i.e., reportedly showed very adverse effects).

Undoubtedly, some fish populations have been lost as a direct result of cultural acidification. There are, however, some aspects of the population losses that appear to be related to natural cycling of wild populations. In such instances, interpretation of research results may be a third factor that can help explain the apparent differences between the results of this study and those from other affected areas. This factor is more difficult to assess, but the available data suggest that some alternative interpretations can be made which do not implicate lake pH as a factor affecting fish populations. This point is well illustrated in papers by Wiener (1983) and Mills et al. (1987).

Wiener (1983) reported that species richness was lower in the acid lakes as compared to circumneutral lakes of similar size and physical characteristics. Because the two groups of lakes were equally productive (based on chlorophyll a concentrations), he attributed the differences in species richness to lake pH and calcium concentrations. This interpretation is questionable because Wiener (1983) presented chlorophyll a data for only two of the six circumneutral lakes. The chlorophyll a concentration for these lakes was 2.74 and 8.74 μg/L, respectively (mean = 5.74 μg/L). The range of chlorophyll a concentration in the acid lakes ranged from 1.4 to 3.9 μg/L (mean = 3.0 μg/L). Two of six samples was not adequate to determine if differences existed in the productivity of the two lake groups, especially since the range was so large for the non-acid group. Therefore, it is possible that lake productivity may have influenced the species assemblage patterns that Wiener (1983) observed.

In the second example, Mills et al. (1987) described the effects of eight years of experimental acidification on a 27 hectare lake. At the beginning of the acidification experiment (1976; pH 6.49), lake trout, white suckers, fathead minnows (Pimephales promelas), and slimy sculpin (Cottus cognatus) were abundant. By 1979 (pH 5.64), the abundance of fathead minnow and slimy sculpin decreased rapidly (pH 5.64), followed by an increase in the abundance of pearl dace (Semotilus margarita) in 1980 (pH 5.59), and then a rapid decline in pearl dace abundance in 1982 (pH 5.09). Lake trout and white sucker abundance increased during the early years of acidification, but declined following consecutive years of recruitment failure beginning in 1980 for lake trout and 1981 for white suckers. Growth of lake trout and white sucker remained constant during the initial stages of acidification, but growth of white sucker increased in 1979 and growth of lake trout slowed in 1982. Condition factors (K) of lake trout increased from the fall of 1975 to the spring of 1977, then gradually declined until 1983. Condition factors of white sucker increased from 1976 until 1978, declined in 1979, then remained relatively stable from 1979 to 1983. By 1982, recruitment had ceased for all species in the lake. Mills et al. (1987) mentioned food availability may have affected growth rates, and population densities may have affected condition factors. However, they related population losses to recruitment failures, and concluded that the recruitment failure of all fish species in lake the lakes were due to low pH conditions in the lake.

The presence of large numbers of predatory fish has been known to affect fish assemblages in Canadian lakes (Robinson and Tonn 1989). Therefore, Mills et al.'s (1987) results may be reflecting the presence of large numbers of predatory fish (i.e., lake trout) which were influencing the abundance of the prey species like fathead minnow, slimy sculpin, and pearl dace. During the first six years of lake acidification phytoplankton primary productivity increased 250% (Shearer et al. 1987). During this first two years of increased primary productivity, the lake trout population expanded (from 400 in 1977 to approx. 850 in 1979), thereby reducing not only the numbers of fathead minnow and pearl dace, but also the number of smaller lake trout. If the lake trout exhibited a preference for fathead minnows and pearl dace (or avoidance of slimy sculpins), then one would expect the former to decline in abundance and the latter to increase in abundance. The eventual decline in slimy sculpin abundance can be attributed to a switch in the diet of lake trout, as pearl dace and fathead minnows became scarce. As all slimy sculpins become scarce, one would expect the larger lake trout to consume larger numbers of small lake trout, leading to eventually recruitment failure. Surviving lake trout would then exhibit slow growth in response to a very diminished food supply.

The piscivory scenario presented above may or may not reflect what actually happened in this lake. However, given the data, it is a reasonable explanation for the results presented. It is also possible that such community dynamics may explain, in part, the losses of fish populations reported from culturally acidified lakes.

Future Research Needs

Cultural acidification of formerly circumneutral waters and the resulting loss of fishery resources is scientific fact. However, lake pH was probably not as culpable as the existing literature suggests. Conflicting reports of fish population responses to low pH conditions underscores this point. Resolution of this problem, or at least a better of how the process work, can only come from rethinking future research strategies.

Florida

Indications are, that fish populations in Florida's acid lakes are not affected by the low pH conditions in these lakes. Instead, fish populations seem to be responding to lake trophic state, habitat availability and degree of isolation. Therefore, future research on Florida's acid lakes should address these assertions directly.

For example, enclosure experiments should be conducted to see how fish populations in the same lake (i.e., same pH levels) respond to artificially manipulated nutrient levels. Similar experiments could also be conducted with habitat availability or combinations of these two factors. Future surveys of fish populations in acid lakes should also consider the degree of isolation (i.e., distance from streams or wetlands) of the lakes. Lakes should be chosen so the effects of lake isolation on fish populations could be addressed directly. The question of fish response to acidification can also be addressed by intentionally acidifying non-acid lakes and observing fish population response. As there are only a few studies of fish populations in Florida's acid lakes, all aspects of fish populations, including physiological response and possible genetic adaptations, should be included in these evaluations.

Other affected areas

The current scientific literature offers conflicting reports of fish population response to cultural acidification in other affected areas. Therefore, a careful review of the existing literature is a necessary first step in any future research project. In doing so, one might be able to present a case for alternative interpretations of earlier work, which may help define or redefine the existing problem. During this process, secondary factors (e.g., genetic adaptation, isolation, and ecological interactions) not as obvious as lake pH may come to light, and present meaningful avenues for further exploration.

Another important step toward resolving any current problem is to look at the lake in a historical context. For example, are current conditions different from past conditions, and have current conditions existed in the past. Although historical perspective are not easily obtainable because past limnological data for most lakes are often unavailable, paleolimnological techniques are now available which allow for a qualitative reconstruction of past lake conditions, including lake water chemistry (Crisman 1988).

This historical perspective is useful in assessing a lake's current state of affairs, specifically in regards to environmental perturbations, and future management needs.

APPENDIX

Table A-1. THE PHYSIOGRAPHIC DISTRICTS AND SUBDIVISIONS WHERE THE 12 STUDY LAKES ARE LOCATED.

Lake	District	Subdivision
Suggs	Central Lake	Interlachen Hills
Barco	Central Lake	Interlachen Hills
McCloud	Central Lake	Interlachen Hills
Deep	Central Lake	St. Johns Offset
Lawbreaker	Central Lake	Ocala Scrub
Gobbler	Central Lake	Ocala Scrub
Crooked	Central Lake	Ocala Scrub
Tomahawk	Central Lake	Lynne Karst
Moore	Appalachicola Delta	Lake Munson Hills
Lofton	Appalachicola Delta	Lake Munson Hills
Turkey Pen	Appalachicola Delta	Betts Delta
Brock	Dougherty Karst	Bonifay Karst

LITERATURE CITED

Aggus, L.R., and G.V. Elliott. 1975. Effects of cover and food on year-class strength of largemouth bass. pp. 317-322 In H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Institute, Washington, D.C., USA.

Almer, B., W. Dickson, C. Ekstrom, and E. Hornstrom. 1978. Sulfur pollution and the aquatic ecosystem. pp. 273-311 In J. Nriagu, ed. Sulfur in the Environment. Part II. Ecological Impacts, John Wiley and Sons, New York.

American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater, 16th ed. American Public Health Association, Washington, D.C.

Anderson, R.O., and S.J. Gutreuter. 1983. Length, weight, and associated structural indices. pp. 283-300 In L.A. Nielsen and D.L. Johnson, eds. Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Bagenal, T.B., and F.W. Tesch. 1978. Age and growth. pp. 101-136 In T. Bagenal, ed. Methods of Assessment of Fish Production in Fresh Waters. Blackwell Scientific Publications, London.

Baker, J.P. 1982. Effects on fish of metals associated with acidification. pp. 165-176 In R.E. Johnson, ed. Acid Rain/Fisheries, Proceedings of an International Symposium on Acidic Rain and Fisheries Impacts on Northeastern North America. Northeastern Division. American Fisheries Society, Bethesda, MD.

Baker, J.P., and C.L. Schofield. 1982. Aluminum toxicity to fish. Water, Air, and Soil Pollution 18:289-309.

Barbour, C.D., and J.H. Brown. 1974. Fish species diversity in lakes. American Naturalist 108:473-489.

Beamish, R. 1972. Lethal pH for the white sucker, Catostomus commersoni. Transactions of the American Fisheries Society 101:355-358.

Beamish, R.J., and H.H. Harvey. 1972. Acidification of the La Cloche Mountain Lakes, Ontario, and resulting fish mortalities. Journal of the Fisheries Research Board of Canada 29:1131-1143.

Beamish, R.J., W.L. Lockhart, J.C. Van Loon, and H.H. Harvey. 1975. Long term acidification of a lake and resulting effects on fish. Ambio 4:98-102.

Bell, H.L. 1971. Effect of low pH on the survival and emergence of aquatic insects. Water Research 5:313-319.

Brezonik, P.L., C. Hendrey, E. Edgerton, R. Schulze, and T. Crisman. 1983. Acidity, nutrients, and minerals in atmospheric precipitation over Florida: Deposition patterns, mechanisms, and ecological effects. EPA 600/S3-83-004. U.S. Environmental Protection Agency, Corvalis, OR.

Brown, D.J.A. 1982. The effect of calcium on fish and fisheries. Water, Air and Soil Pollution 18:343-351.

Brown, R.A. 1981. Lakes as islands: Biogeographic distributions, turnover rates, and species composition in the lakes of central New York. Journal of Biogeography 8:75-83.

Canfield, D.E., Jr. 1983a. Prediction of chlorophyll a concentrations in Florida lakes: The importance of phosphorus and nitrogen. Water Resources Bulletin 19:255-262.

Canfield, D.E., Jr. 1983b. Sensitivity of Florida lakes to acidic precipitation. Water Resources Research 19:833-839.

Canfield, D.E., Jr., and M.V. Hoyer. 1988. Regional geology and the chemical and trophic state characteristics of Florida lakes. Lake and Reservoir Management 4:21-31.

Canfield, D.E., Jr., C.A. Jennings, and D.E. Colle. 1989. A characterization of fish populations in some acid Florida lakes. Final Report. Florida Department of Environmental Regulation, Tallahassee, FL, 181 pp.

Canfield, D.E., Jr., K.A. Langeland, M.J. Maceina, W.T. Haller, and J.V. Shireman. 1983a. Trophic state classification of lakes with aquatic macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 40:1713-1718.

Canfield, D.E., Jr., S.B. Linda, and L.M. Hodgson. 1984. Relations between color and some limnological characteristics of Florida lakes. Water Resources Bulletin 20:323-329.

Canfield, D.E., Jr., M.J. Maceina, L.M. Hodgson, and K.A. Langeland. 1983b. Limnological features of some northwestern Florida lakes. Journal of Freshwater Ecology 2(1):67-79.

Canfield, D.E., Jr., M.J. Maceina, F.G. Nordlie, and J.V. Shireman. 1985. Plasma osmotic and electrolyte concentrations of largemouth bass from some acid Florida lakes. Transactions of the American Fisheries Society 114:423-429.

Carlander, K.D. 1969. Handbook of Freshwater Fishery Biology. Volume 1. Iowa State University Press, Ames, IA, 752 pp.

Carlander, K.D. 1977. Handbook of Freshwater Fishery Biology. Volume 2. Iowa State University Press, Ames, IA, 431 pp.

Chew, R.L. 1974. Early life history of the Florida largemouth bass. Fishery Bulletin 7. Florida Game and Fresh Water Fish Commission, Tallahassee, FL, 76 pp.

Clugston, J.P. 1964. Growth of the Florida largemouth bass, _Micropterus_ _salmoides_ _floridanus_ (LeSueur), and the northern largemouth bass, _M_. _s_. _salmoides_ (Lacepede), in subtropical Florida. Transactions of the American Fisheries Society 93:146-154.

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 5:521-531.

Cope, E.D. 1896. Fishes in isolated pools. The American Naturalist 1896:943-944.

Cowling, E.B. 1982. Acid precipitation in historical perspective. Environmental Science and Technology 16:110-123.

Crisman, T.L. 1984. Temperate and subtropical biotic responses to lake acidity: A preliminary assessment of the importance of direct and indirect pH effects. pp. 139-157 _In_ M.E. Vittes and H. Kennedy, eds. Proceedings of the Conference on Acid Rain: Impact on Florida and the Southeast. University of Central Florida, Orlando, FL.

Crisman, T.L. 1988. The use of subfossil benthic invertebrates in aquatic resource management. pp. 71-88 In W.J. Adams, G.A. Chapman, and W.G. Landis, eds. Aquatic Toxicology and Hazard Assessment (Volume 10). American Society for Testing Materials, Philadelphia, PA.

Crisman, T.L., R.L. Schulze, P.L. Brezonik, and S.A. Bloom. 1980. Acid precipitation in Florida: The biotic response. pp. 296-297 In D. Drablos and A. Tollan, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Crossman, E.J. 1962. The grass pickerel, Esox americanus vermiculatus LeSueur, in Canada. Royal Ontario Museum Contribution No. 5. Ontario 29 pp.

Crossman, E.J. 1966. A taxonomic study of Esox americanus and its subspecies in eastern North America. Copeia 1:1-20.

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

Crumpton, J.E., and S.L. Smith. 1975. Differences in growth and catchability of natural bass populations in Florida. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 29:330-336.

Daye, P.G., and E.T. Garside. 1975. Lethal levels of pH for brook trout, Salvelinus fontinalis (Mitchill). Canadian Journal of Zoology 53:639-641.

Dickinson, J.C., Jr. 1948. An ecological reconnaissance of the biota of some ponds and ditches in northern Florida. Quarterly Journal of the Florida Academy of Sciences 11:1-28.

Dickinson, R.E., P.L. Brezonik, W.C. Huber, and J.P. Heaney. 1982. Gazetteer of Florida Lakes. Publication No. 63 of the Florida Water Resources Research Center. University of Florida, Gainesville, FL.

Digby, P.N.G., and R.A. Kempton. 1987. Multivariate analysis of ecological communities. Chapman and Hall, New York, 206 pp.

Dillon, P.J., and F.H. Rigler. 1974. The phosphorus-chlorophyll relationship in lakes. Limnology and Oceanography 19(5):767-773.

Dillon, P.J., and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. Journal of the Fisheries Research Board of Canada 32:1519-1531.

DuRant, D.F., J.V. Shireman, and R.D. Gasaway. 1979. Reproduction, growth, and food habits of seminole killifish, Fundulus seminolis, from two central Florida lakes. American Midland Naturalist 102(1):127-133.

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

Eadie, J.M., and A. Keast. 1984. Resource heterogeneity and fish species diversity in lakes. Canadian Journal of Zoology 62:1689-1695.

Eilers, J., G. Lien, and R. Berg. 1984. Aquatic organisms in acidic environments: A literature review. Technical Bulletin No. 150. Department of Natural Resources. Madison, WI.

Fritz, E.S. 1980. Potential impacts of low pH on fish and fish populations. U.S. Fish and Wildlife Service, Biological Services Program, National Power Plant Team, FWS/OBS-80/40.2. 14 pp.

Frosberg, C., and S.O. Ryding. 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Arch. Hydrobiol. 89:189-207.

Fryer, G. 1980. Acidity and species diversity in freshwater crustacean faunas. Freshwater Biology 10:41-45.

Gauch, H.G. Jr., 1982. Multivariate analysis in community ecology. Cambridge University Press, New York, 298 pp.

Germann, J.F., L.E. McSwain, D.R. Holder, and C.D. Swanson. 1974. Life history of warmouth in the Suwannee River and Okefenokee Swamp, Georgia. Proceedings Annual Southeastern Association of Game and Fish Commissioners 28:259-278.

Gilbert, C.R. 1987. Zoogeography of the freshwater fish fauna of southern Georgia and peninsular Florida. Brimleyana 13:25-54.

Gjedrem, T. 1980. Genetic variation in acid tolerance in brown trout. pp. 308 In D. Drablos and A. Tollan, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Gorham, E. 1976. Acid precipitation and its influence upon aquatic ecosystem--An overview. Water, Air and Soil Pollution 6:457-481.

Guillory, V. 1979. Life history of chain pickerel in a central Florida lake. Fishery Bulletin 8. Florida Game and Fresh Water Fish Commission. Tallahassee, FL, 38 pp.

Hach Chemical Company. 1975. Water and Wastewater Analysis Procedures. 3rd Edition. Hach Chemical, Ames, IA.

Haines, B. 1979. Acid precipitation in the Southeastern United States: A brief review. Georgia Journal of Science 37:185-191.

Haines, T.A. 1981. Acidic precipitation and its consequences for aquatic ecosystems. Transactions of the American Fisheries Society 110:669-707.

Haines, T.A., S.J. Pauwels, and C.H. Jagoe. 1986. Predicting and evaluating the effects of acid precipitation on water chemistry and endemic fish populations in the northeastern United States. U.S. Fish and Wildlife Service, Eastern Energy and Land Use Team. Biological Report 80(40.23). 139 pp.

Hall R.J., and G.E. Likens. 1980. Ecological effects of experimental acidification on a stream ecosystem. pp. 375-376 In D. Drablos and A. Tollen, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Hanson, J.M., and W.C. Leggett. 1982. Empirical prediction of fish biomass and yield. Canadian Journal of Fisheries and Aquatic Sciences 39:257-263.

Harvey, H.H. 1975. Fish populations in a large group of acid-stressed lakes. International Association of Theoretical and Applied Limnology 19:2406-2417.

Harvey, H.H. 1980. Widespread and diverse changes in the biota of North American lakes and rivers coincident with acidification. pp. 93-98 In D. Drablos and A. Tollan, eds. Proceedings of an International Conference: Ecological Impacts of Acid Precipitation. Sandefjord, Norway.

Harvey, H.H. 1982. Population responses of fish in acidified waters. pp. 227-242 *In* R.E. Johnson, ed. Acid Rain/Fisheries, Proceedings of an International Symposium on Acidic Rain and Fisheries Impacts on Northeastern North America. Northeastern Division. American Fisheries Society, Bethesda, MD.

Harvey, H.H., and C. Lee. 1982. Historical fisheries changes related to surface water pH changes in Canada. pp. 45-55 *In* R.E. Johnson, ed. Acid Rain/Fisheries, Proceedings of an International Symposium on Acidic Rain and Fisheries Impacts on Northeastern North America. Northeastern Division. American Fisheries Society, Bethesda, MD.

Hastings, R.W. 1979. Fishes of the pine barrens. pp 489-504 *In* R.T. Forman, ed. Pine Barrens: Ecosystem and Landscape. Academic Press, New York.

Hendrey, G.R., K. Baalstrud, T. Traaen, M. Laake, and G. Raddum. 1976. Acid precipitation: Some hydrobiological changes. Ambio 5:224-227.

Hendrey, G.R. and R.F. Wright. 1976. Acid precipitation in Norway: effects on aquatic fauna. Journal of Great Lakes Research 2(Suppliment 1):192-207).

Herke, W.H. 1959. Comparison of the length-weight relationship of several species of fish from two different, but connected habitats. Proceedings Annual Southeastern Association of Game and Fish Commissioners 13:299-313.

Hoyer, M.V., J.V. Shireman, and M.J. Maceina. 1985. Use of otoliths to determine age and growth of largemouth bass in Florida. Transactions of the American Fisheries Society 114:307-309.

Huish, M.T. 1954. Life history of the black crappie *Pomoxis nigromaculatus*. Transactions of the American Fisheries Society 83:176-194.

Jensen, K., and E. Snekvik. 1972. Low pH levels wipe out salmon and trout populations in southernmost Norway. Ambio 1:223-225.

Johnson, D., and D. Webster. 1977. Avoidance of low pH in selection of spawning sites by brook trout, *Salvelinus fontinalis*. Journal of the Fisheries Research Board of Canada 34:2215-2218.

Jones, J.R., and M.V. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll a concentrations in midwestern lakes and reservoirs. Transactions of the American Fisheries Society 111:176-179.

Keller, A.E. 1984. Fish communities in Florida lakes: Relationship to physio-chemical parameters. Master of Science Thesis. University of Florida, Gainesville, 107 pp.

Kettle, W.D., M.F. Moffett, and F. deNoyelles, Jr. 1987. Vertical distribution of zooplankton in an experimentally acidified lkae containing a metalimnetic phytoplantkon peak. Canadian Journal of Fisheries and Aquatic Sciences 44(Suppl. 1):91-95.

Kramer, R.H., and L.L. Smith. 1960. First year growth of the largemouth bass (Micropterus salmoides), and some related ecological factors. Transactions of the American Fisheries Society 89(2):223-233.

Lagler, K.F. 1978. Capture, sampling and examination of fish. pp. 7-47 In T. Bagenal ed. Methods for Assessment of Fish Production in Fresh Waters. Blackwell Scientific Publications, London.

Lamia, J.A. 1987. The limnological and biological characteristics of Cue Lake: An acid lake in North Florida. Master of Science Thesis. University of Florida, Gainesville, 119 pp.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. North Carolina Museum of Natural History. Biological Survey Publication 1980. Raleigh, NC, 867 pp.

Lee, S., and J.L. Schnoor. 1988. Reactions that modify chemistry in lakes of the National Surface Water Survey. Environmental Science and Technology 22:190-195.

Leivestad, H., G. Hendrey, I. Muniz, and E. Snekvik. 1976. Effect of acid precipitation on freshwater organisms. pp. 87-111 In F. Braekke, ed. Impact of Acid Precipitation on Forest and Freshwater Ecosystems in Norway. Acid Rain-Effects on Forest and Fish Project Report FR 6176.

Linthurst, R.A., D.H. Landers, J.M. Eilers, D.F. Brakke, W.S. Overton, E.P. Meier, and R.E. Crowe. 1986. Characteristics of lakes in the eastern United States. Volume I: Population descriptions and physico-chemical relationships. EPA/600/4-86/007a. United States Environmental Protection Agency, Washington, D.C.

Maceina, M.J., and J.V. Shireman. 1980. The use of a recording fathometer for determination of distribution and biomass of hydrilla. Journal of the Aquatic Plant Management Society 18:34-39.

Maceina, M.J., and J.V. Shireman. 1982. Influence of dense hydrilla infestation on black crappie growth. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 36:394-402.

Magnuson, J.J., J.P. Baker, and E.J. Rahel. 1984. A critical assessment of effects of acidification on fisheries in North America. Transactions of the Royal Philosophical Society of London B305:501-516.

Matuszek, J.E., and G.L. Beggs. 1988. Fish species richness in relation to lake area, pH, and other abiotic factors in Ontario lakes. Canadian Journal of Fisheries and Aquatic Sciences 45:1931-1941.

McKenna, M., and F. Duerr. 1976. Effects of ambient pH on the gills of <u>Ictalurus</u> <u>melas</u> Raf. American Zoologist 16:224 (abstract).

McKim, J. 1977. Evaluation of tests with early life history stages of fish for predicting long-term toxicity. Journal of the Fisheries Board of Canada 34:1148-1154.

McWilliams, P.G., D.J.A. Brown, G.D. Howells, and W.T.W. Potts. 1980. Physiology of fish in acid waters. pp. 282-283 <u>In</u> D. Drablos and A.Tollen, eds. Proceedings of an International Conference: Ecological Impacts of Acid Precipitation. Sandefjord, Norway.

Meehean, O.L. 1942. Fish populations in five Florida lakes. Transactions of the American Fisheries Society 71:184-194.

Menzel, D.W., and N. Corwin. 1965. The measurement of total phosphorus in seawater based on the liberation of organically bound fractions by persulfate oxidation. Limnology and Oceanography 10:280-282.

Mills, K.H., S.M. Chalanchuk, L.C. Mohr, and I.J. Davies. 1987. Responses of fish populations in Lake 223 to 8 years of experimental acidification. Canadian Journal of Fisheries and Aquatic Sciences 44(Suppl. 1):114-125.

Moyle, J.B. 1946. Some indices of lake productivity. Transactions of the American Fisheries Society 76:322-334.

Muller, P. 1980. Effects of artificial acidification on the growth of periphyton. Canadian Journal of Fisheries and Aquatic Sciences 37(3):355-363.

Muniz, I., and H. Leivestad. 1980. Acidification--Effects on freshwater fish. pp. 84-92 In D. Drablos and A. Tollen, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36.

Nelson, D.W., and L.E. Sommers. 1975. Determination of total nitrogen in natural waters. Journal of Environmental Quality 4:464-468.

Nelson, J.S. 1968. Life history of the brook silverside, Labidesthes sicculus, in Crooked Lake, Indiana. Transactions of the American Fisheries Society 97(3):293-296.

Oglesby, R.T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. Journal of the Fisheries Research Board of Canada 34:2271-2279.

Overrein, L.N., H.M. Seip., and A. Tollan. 1981. Effects of acid water on aquatic life. pp. 143-161 In Acid Precipitation--Effects on Forest and Fish. Final Report. 2nd Edition. SNSF Project, Oslo, Norway.

Parsons, T.R., and J.P. Strickland. 1963. Discussion of spectrophotometric determination of marine plant pigments, with revised equations of ascertaining chlorophylls and carotenoids. Journal of Marine Research 21:155-163.

Patrick, R., V. Binetti, and S.G. Halterman. 1981. Acid lakes from natural and anthropogenic causes. Science 211:446-448.

Patrick, R., B. Matson, and L. Anderson. 1979. Streams and lakes in the pine barrens. pp. 169-193 In R.T.T. Foreman, ed. Pine Barrens: Ecosystem and Landscape. Academic Press, New York.

Pauwels, P.J., and T.A. Haines. 1986. Fish species distribution in relation to water chemistry in selected Maine lakes. Water, Air, and Soil Pollution 30:477-488.

Pollman, C.D., and D.E. Canfield, Jr. in press. Florida Chapter 12 In D.F. Charles, ed. Acid Deposition and Aquatic Ecosystems: Regional Case Studies. Springer-Burlag, New York.

Poole, R.W. 1974. An introduction to quantitative ecology. McGraw-Hill Book Company, New York, 532 pp.

Porak, W., W.S. Coleman, and S. Crawford. 1986. Age, growth, and mortality of Florida largemouth bass utilizing otoliths. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 40:206-215.

Prince, E.D., and O.E. Maughan. 1978. Freshwater artificial reefs: Biology and economics. Fisheries 3:5-9.

Raddum, G.G. 1980. Comparison of benthic invertebrates in lakes with different acidity. pp. 330-331 In D. Drablos and A. Tollen, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Rago, P.J., and J.G. Wiener. 1986. Does pH affect fish species richness when lake area is considered. Transactions of the American Fisheries Society 115:438-447.

Rahel, F.J. 1982. Fish assemblages in Wisconsin bog lakes. Ph.D. Dissertation, University of Wisconsin, Madison, 197 pp.

Rahel, F.J. 1986. Biogeographic influences on fish species composition of northern Wisconsin lakes with applications for lake acidification studies. Canadian Journal of Fisheries and Aquatic Sciences 43:124-134.

Rahel, F.J., and J.J. Magnuson. 1983. Low pH and the absence of fish species in naturally acidic Wisconsin lakes: Inferences for cultural acidification. Canadian Journal of Fisheries and Aquatic Sciences 40(1):3-9.

Richards, F.A., and T.G. Thompson. 1952. The estimation and characterization of plankton populations by pigment analyses: II A spectrophotometric method for the estimation of plankton pigments. Journal of Marine Research 11:156-171.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Fisheries Research Board of Canada. Ottwa, Ontario, Canada, 382 pp.

Robinson, C.L.K., and W.M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblage of small Alberta lakes. Canadian Journal of Fisheries and Aquatic Sciences 46:81-89.

Roff, J., and R. Kwiatkowski. 1977. Zooplankton and zoobenthos communities of selected northern Ontario lakes of different acidities. Canadian Journal of Zoology 55:899-911.

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator--A review and evaluation. Journal of the Fisheries Research Board of Canada 31:663-688.

SAS Institute Inc. 1988. SAS/STAT User's Guide Version 6.03 Edition. SAS Institute, Inc., Cary, NC, 1028 pp.

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

Scheider, W.A., and P.J. Dillon. 1976. Neutralization and fertilization of acidified lakes near Sudbury, Ontario. Water Pollution Research in Canada 11:93-100.

Schindler, D. 1980. Experimental acidification of a whole lake: A test of the oligotrophication hypothesis. pp. 370-374 In D. Drablos and A. Tollen, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Schofield, C.L. 1976. Acid precipitation: Effects on fish. Ambio 5:228-230.

Schofield, C.L. 1982. Historical fisheries changes in the United States related to decreases in surface water pH. pp. 57-67 In R.E. Johnson, ed. Acid Rain/Fisheries, Proceeding of an International Symposium on Acidic Rain and Fisheries Impacts on Northeastern North America. Northeastern Division. American Fisheries Society, Bethesda, MD.

Schramm, H.L., J.V. Shireman, D.E. Hammond, and D.M. Powell. 1985. Effect of commercial harvest of sport fish on black crappie population in Lake Okeechobee, Florida. North American Journal of Fisheries Management 5:217-226.

Schulze, R.L. 1980. The biotic response to acid precipitation in Florida lakes. Master of Science Thesis, University of Florida. 146 pp.

Shannon, E.E., and P.L. Brezonik. 1972. Relationships between lake trophic state and nitrogen and phosphorus loading rates. Environmental Science and Technology 6:719-725.

Shearer, J.A., E.J. Fee, E.R. DeBruyn, and D.R. DeClercq. 1987. Phytoplankton primary production and light attenuation responses to the experimental acidification of a small Canadian sheild lake. Canadian Journal of Fisheries and Aquatic Sciences 44(suppl. 1):83-90.

Shireman, J.V., D.E. Colle, and D.F. DuRant. 1981. Efficiency of rotenone sampling with large and small block nets in vegetated and open-water habitats. Transactions of the American Fisheries Society 110:77-80.

Shireman, J.V., R.L. Stetler, and D.E. Colle. 1978. Possible use of the lake chubsucker as a baitfish. Progressive Fish Culturist 40(1):33-34.

Smith, D.L., J.K. Underwood, J.G. Ogden III, and B.C. Sabean. 1986. Fish species distribution and water chemistry in Nova Scotia Lakes. Water, Air, and Soil Pollution 30:489-496.

Smith, F.E. 1972. Spatial heterogeneity, stability, and diversity in ecosystems. Transactions of the Connecticut Academy of Arts and Sciences 44:309-335.

Smith, V. 1982. The nitrogen and phosphorus dependence of algal biomass in lakes: An empirical and theoretical analysis. Limnology and Oceanography 27:1101-1112.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry. Second edition. W.H. Freeman and Company, New York, 859 pp.

Somers, K.M., and H.H. Harvey. 1984. Alteration of fish communities in lakes stressed by acid deposition and heavy metals near Wawa, Ontario. Canadian Journal of Fisheries and Aquatic Sciences 41:20-29.

Sutcliffe, D.W., and T.R. Carrick. 1973. Studies on mountain streams in the English Lake District I: pH, calcium, and the distribution of invertebrates in the River Duddon. Freshwater Biology 3:437-462.

Tonn, W.M., and J.J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin lakes. Ecology 63:1149-1166.

Tonn, W.M., J.J. Magnuson, and A.M. Forbes. 1983. Community analysis in fisheries management: An application with northern Wisconsin lakes. Transactions of the American Fisheries Society 112:368-377.

Traaen, T. 1980. Effects of acidity on decomposition of organic matter in aquatic environments. pp. 340-341 In D. Drablos and A. Tollen, eds. Proceedings of an International Conference: Ecological Impact of Acid Precipitation. Sandefjord, Norway.

Wales, D.L., and G.L. Beggs. 1986. Fish species distribution in relation to lake acidity in Ontario. Water, Air, and Soil Pollution 30:601-609.

Wiener, J.G. 1983. Comparative analyses of fish populations in naturally acidic and circumneutral lakes in northern Wisconsin. United States Fish and Wildlife Service. Eastern Land Use Team. FWS/OBS-80/40.16. 107 pp.

Wilbur, R.L. 1969. The redear sunfish in Florida. Fishery Bulletin 5. Florida Game and Fresh Water Fish Commission. Tallahassee, FL, 64 pp.

Williams, V.P., D.E. Canfield, Jr., M.M. Hale, W.E. Johnson, R.S. Kautz, J.T. Krummrich, F.H. Langford, K. Langeland, S.P. McKinney, D.M. Powell, and P.L. Shafland. 1985. Lake habitat and fishery resources of Florida. pp. 43-119 In W.Seaman, Jr. ed., Florida Aquatic Habitat and Fisheries Resources. Florida Chapter of the American Fisheries Society. Kissimmee, FL, USA.

Wooten, M.C., K.T. Scribner, and M.H. Smith. 1988. Genetic variability and systemics of Gambusia in the southeastern United States Copeia 2:283-289.

Wright, R., and E. Gjessing. 1976. Acid precipitation: Changes in the chemical composition of lakes. Ambio 5:219-223.

Wright, R.F., and E. Snekvik. 1978. Acid precipitation: Chemistry and fish populations in 700 lakes in southernmost Norway. International Association of Theoretical and Applied Limnology 20:765-775.

Yan, N., and P. Stokes. 1978. Phytoplankton of an acidic lake, and its response to experimental alterations of pH. Environmental Conservation 5:93-100.

Yentsch, C.S., and D.W. Menzel. 1963. A method for the determination of phytoplankton chlorophyll and pheophytin by fluorescence. Deep Sea Research 10:221-231.

BIOGRAPHICAL SKETCH

Cecil Andre Jennings was born June 4th, 1958, on Tortola, British Virgin Islands. He is a 1977 graduate of Charlotte Amalie High School, St. Thomas, U.S. Virgin Islands. He obtained his undergraduate education at Carthage College, Kenosha, Wisconsin, from which he graduated in 1981 with a Bachelor of Arts degree in biology, natural science, and conservation.

In 1982, he enrolled in Mississippi State University where he studied fisheries science. During his tenure at Mississippi State, his research focused on recreational fishing and its effects on the population structure of largemouth bass in a large reservoir. Cecil earned his Master of Science degree from Mississippi State in 1985. While at Mississippi State, he also met and married the former Brenda J. Holmes.

After leaving Mississippi State, Cecil worked as a fishery biologist for the U.S. Virgin Islands Division of Fish and Wildlife. His primary duty was the design and implementation of sampling procedures used to gather catch and effort statistics for the commercial reef-fish fishery. He left this position in July 1986 to further his studies.

In the fall of 1986, Cecil enrolled in the doctoral degree program in the Department of Fisheries and Aquaculture at the University of Florida. For the next four years, he worked diligently toward fulfilling the degree requirements as outlined by his major department and the Graduate School. During this time, he was also enrolled in the Cooperative Education Agreement program and worked as a Fisheries Intern for the Florida Cooperative Fish and Wildlife Research Unit (U.S. Fish and Wildlife Service). At the Coop Unit he was part of the administrative team responsible for all aspects of the unit's operations.

Cecil's research interests center on the biology, ecology and management of commercial and recreational fish species. After earning his Ph.D., he plans to continue working as a fisheries scientist.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Wiley M. Kitchens

Wiley M. Kitchens, Chairman
Associate Professor of Forest Resources
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Daniel E. Canfield Jr.

Daniel E. Canfield, Jr.
Professor of Forest Resources and
Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Carter R. Gilbert

Carter R. Gilbert
Professor of Zoology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Frank G. Nordlie
Professor of Zoology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerome V. Shireman
Professor of Forest Resources and
Conservation

This dissertation was submitted to the Graduate Faculty of the School of Forest Resources and Conservation in the College of Agriculture and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May 1990

Director, Forest Resources and
Conservation

Dean, Graduate School