

ANALYSIS OF A BLUE CATFISH POPULATION IN A SOUTHEASTERN
RESERVOIR: LAKE NORMAN, NORTH CAROLINA

By

Joseph Daniel Grist

Thesis submitted to the Graduate Faculty of the Virginia Polytechnic Institute and State
University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Fisheries and Wildlife Sciences

Approved:

Brian R. Murphy, Committee Chairman

John J. Ney, Committee Member

James M. Berkson, Committee Member

Gene Vaughan, Committee Member

Donald J. Orth, Department Head

August 14, 2002

Copyright 2002, Joseph D. Grist

Analysis of a Blue Catfish Population in a Southeastern Reservoir: Lake Norman, North Carolina

Joseph D. Grist

(Abstract)

This investigation examined the diet, growth, movement, population genetics, and possible consumption demands of an introduced blue catfish *Ictalurus furcatus* population in Lake Norman, North Carolina. Clupeids, *Corbicula fluminea*, and *Chara* were the predominant food items (percent stomach contents by weight) found in blue catfish, and varied by season, lake-region, and fish size-class. Lake Norman blue catfish grow at a slower rate than has been reported for other reservoir populations, with fair to poor body conditions ($W_r < 85$) early in life, but improving with increases in length ($W_r > 95$).

Movements and home ranges of blue catfish in Lake Norman were extremely varied, but individual blue catfish did establish specific seasonal home ranges and exhibited site fidelity. A spawning area in the upper region of the lake was identified and data suggested that blue catfish may have segregated populations within Lake Norman.

The Lake Norman blue catfish population exhibited relatively little genetic variability, and was genetically differentiated from populations from Santee-Cooper, SC, and Arkansas. Genetic diversity could have been limited by a population bottleneck at the founding of the population or in subsequent generations.

A consumption model indicated that 5.0 kg/ha to 8.3 kg/ha of clupeid standing stock could be eaten annually by blue catfish in Lake Norman based on percent stomach

contents by weight data, and 21 kg/ha to 42 kg/ha based on percent caloric contribution calculations. This may reduce the possible production of other game fish species, including the put-grow-take striped bass *Morone saxatilis* fishery.

Acknowledgements

It would have been impossible for me to take on the huge task of performing long hours of field research in North Carolina (where the hotel staffs knew me by my first name) while also taking classes, serving as president of the Fisheries and Wildlife Graduate Student Association, and working as a teaching assistant without the support of a large contingent of individuals.

First and foremost, I must thank my parents, Buddy and Brenda Grist, who instilled in me the responsibility, work ethic, and never give up mentality that has helped me to achieve my goals. Though they could not be here in person through this quest, their support and love were always front and center in my heart and mind. To my brother Bill and his wife Nicole, for their encouragement and constant reminder about the lack of oceanview beaches in the mountains of Virginia. And to the late Reverend Arthur Grist, Baptist minister and beloved grandfather, who's teachings about life, fishing, and faith in God kept me focused throughout. To my family, I dedicate this work.

Dr. Brian Murphy, my major professor, advisor, mentor, horseshoe thrower extraordinaire, who lent me invaluable editorial guidance and support while I struggled with my thoughts, hyphens, modifiers, and how to back up and look at the forest, not just the trees. Since 1999 when Dr. Orth introduced us in Charlotte, Dr. Murphy has guided me through our co-operative work with Duke Power, into graduate school, teaching undergraduates, and toward my future role as a fisheries scientist. Thank you.

Drs. John Ney and Jim Berkson, the sometimes fatherly, sometimes humbling faculty members of my graduate committee, who challenged me constantly and kept pushing me to think outside the proverbial box. Through your own unique ways you always kept me on my toes and off my assumptions.

To Gene Vaughan and Duane Harrell, Duke Power Company, I owe thanks for their participation on my committee and constant support of my research efforts. I would be remiss if I did not mention Larry Olmstead, David Coughlan, Hugh Barwick, Kim Baker, Mark Rash, Bob Doby, Mark Knapp, Tim Leonard, Sandy Sherer, James Hall, Judi Lewis and the rest of the staff at Duke Power's environmental staff that dedicated so much time and effort toward my research project.

To Scott Van Horn, North Carolina Wildlife Resources Commission, mentor, banjo picker, gillnet picker, and friend, who was always there to help when I was in need and always willing to take the time to talk out ideas, thoughts, fish politics, or just where we should go fish. Thanks to Fred Harris for your support of this project, and the individual contributions made by Lawrence Dorsey, Doug Bessler, Ken Hodges, and Shari Bryant.

To Tracy Westmoreland, Richard Jones, Doug Brogden, and the J&J Tournament anglers for your willingness to assist in various aspects of the project, insights about blue catfish fishing at Lake Norman (and your favorite fishing spots), and the good stories shared while having breakfast at Midway.

To the faculty, staff, and my fellow graduate students at Virginia Tech. To Drs. Eric Hallerman, Melanie Culver, Dean Stauffer, and Mark Kidd for your individual contributions to my research and development as a fisheries scientist. Linda Boothe, Carol Linkous, Valerie Sutherland, Holly Faville, Ramona Shaver, Arlice Banks, and Peggy Quarterman for getting me through the ‘red-tape’ and for all of the often unappreciated tasks you handle for graduate students behind the scenes. To Brendan O’Neill, Andy Strickland, and Jake Rash for making the trip to Lake Norman. Marcy Anderson for sharing in T/A fun, poster printing, statistical programming, and where to find obscure cal/g information. Darroch, Pat, Mandy, Michelle, and my fellow members of operations, Travis and Tim, for their editorial and statistical guidance. To Jodi, Lora, Colleen, Gabriella, and C. Morgan for their constant support and the numerous others that have shared the Halls of Cheatham with me.

To Dr. Harold Cones, CNU, mentor, friend, fellow flipper chaser and Outer Banks historian, who gave me the push when I most needed it that lead me on my journey to this point in time.

And last but not least, Adrienne (defense coordinator and Deet’s kibitzer) and Josh, Mary and Nelson, Danny and Kathy, and Jess and Ken, Lori, and Jessica for your constant support, wine times, cookouts, Monopoly slugfests, golfing adventures, horseback riding, guitar sharing, country nights, long talks, gripe sessions, and overall friendship that have been and will always be priceless.

Table of Contents

Introduction.....	1
Study Site.....	8
<u>Chapter One:</u> The diet and growth of blue catfish in a southeastern reservoir.	
Introduction.....	11
Methods.....	13
Results.....	17
Discussion.....	39
<u>Chapter Two:</u> Movement and habitat use of blue catfish in Lake Norman, North Carolina.	
Introduction.....	44
Methods.....	47
Results.....	52
Discussion.....	64
<u>Chapter Three:</u> Genetic analysis of introduced blue catfish populations	
Introduction.....	70
Study Site.....	70
Methods.....	71
Results.....	74
Discussion.....	80
<u>Chapter Four:</u> Management of blue catfish.....	83
Literature Cited.....	98
Vita.....	108

List of Figures

Figure 1. Map of Lake Norman, North Carolina.....	10
Figure 1.1. Map of Lake Norman, NC, showing the division of sampling areas into upper (white) and lower (gray) regions.....	15
Figure 1.2. Comparison of seasonal blue catfish percentage-by-weight stomach contents from Lake Norman. The most common food items (Asiatic clams, clupeids, and <i>Chara</i>) are highlighted in bold.....	21
Figure 1.3. Comparison of regional blue catfish percentage-by-weight stomach contents from upper and lower Lake Norman.....	24
Figure 1.4. Comparison of blue catfish percentage-by-weight stomach contents by size-classes.....	25
Figure 1.5. Winter blue catfish diets.....	27
Figure 1.6. Spring blue catfish diets.....	28
Figure 1.7. Summer blue catfish diets.....	29
Figure 1.8. Fall blue catfish diets.....	30
Figure 1.9. Length-frequency histogram with mean lengths-at-age represented for Lake Norman blue catfish.....	32
Figure 1.10. Age-frequency histogram for Lake Norman blue catfish.....	33
Figure 1.11. Length (mm) ranges at age (yr) for Lake Norman blue catfish.....	34
Figure 1.12. Comparison of average growth rates of Lake Norman blue catfish sampled during 1999 and 2000 to four other reservoir blue catfish populations dataset for previous years.....	35
Figure 1.13. Lake Norman blue catfish condition per 25 mm length-classes.....	36
Figure 1.14. Comparison of trendlines for mean condition per 25-mm length classes of Lake Norman ($\log_{10}W = 0.0307 + 69.165 \cdot \log_{10}L$, $r^2=0.59$, $N=205$) blue catfish to four other reservoir blue catfish populations: Santee-Cooper, SC ($\log_{10}W = 0.0253 + 75.651 \cdot \log_{10}L$, $r^2=0.61$, $N=468$); Choke Canyon Reservoir, TX ($\log_{10}W = -0.0069 + 94.501 \cdot \log_{10}L$, $r^2=0.02$, $N=136$); Lake Corpus Christi, TX ($\log_{10}W = 0.0132 + 93.294 \cdot \log_{10}L$, $r^2=0.15$, $N=103$); and Lake Livingston, TX ($\log_{10}W = 0.0321 + 88.201 \cdot \log_{10}L$, $r^2=0.48$, $N=114$).....	37

Figure 2.1. Capture/release locations for blue catfish with external radio-transmitters in Lake Norman, North Carolina.....	50
Figure 2.2. Individual blue catfish mean seasonal home ranges observed in Lake Norman, North Carolina	56
Figure 2.3. Range of temperatures available within Lake Norman per month overlaid by the range of temperatures blue catfish were observed inhabiting.....	59
Figure 2.4. Range of D.O. amounts available within Lake Norman per month overlaid by the range of D.O. blue catfish were observed inhabiting.....	60
Figure 2.5. Range of depths blue catfish were observed inhabiting in Lake Norman per month.....	62
Figure 2.6. Movements of blue catfish 40.121 in Lake Norman, North Carolina over a one-year period from February 2001 to March 2002. During May 2001 50% of the Lake Norman blue catfish in this study were found congregated in a 5.6-km reach of the Catawba River in the upper Lake Norman region (shaded in gray).....	63
Figure 3.1. Genetic distances among individual blue catfish from Lake Norman (2000 series), Santee-Cooper (3000 series), and Arkansas (B series), estimated using data from four microsatellite loci using the kinship coefficient (Dkf) metric.....	78
Figure 3.2. Genetic distances among individual blue catfish from Lake Norman (2000 series), Santee-Cooper (3000 series), and Arkansas (B Series), estimated using data from four microsatellite loci using the proportion of shared alleles (Dps) metric.....	79
Figure 4.1. Condition at length for striped bass ($n=472$) collected by the North Carolina Wildlife Resources Commission from 1994-1997.....	86

List of Tables

Table 1.1. General information on locations where data sets were obtained for direct comparison to Lake Norman’s blue catfish population.....	18
Table 1.2. Sample size and percent stomachs with food of blue catfish collected from Lake Norman, North Carolina.....	19
Table 1.3. Percent stomach contents by weight by season for Lake Norman blue catfish.....	20
Table 1.4. Statistical comparison of food items in the diets of blue catfish within regions, seasons, and size-classes and multiple comparisons between sources. Significant differences highlighted in bold	23
Table 1.5. Statistical results of Lake Norman relative weights compared to Santee-Cooper, SC, and three Texas impoundments.....	38
Table 2.1. Summary information for blue catfish with external radio-transmitters monitored at the Virginia Tech Aquaculture Center and in Lake Norman, North Carolina as of March 7, 2002.....	54
Table 2.2. Seasonal movement comparisons of minimum mean distances moved per season, distance from shoreline, and 95% seasonal home range for blue catfish from Lake Norman, North Carolina, including the high and low distributions for home ranges.....	55
Table 2.3. Seasonal microhabitat comparisons of mean water temperature, dissolved oxygen, and depth for blue catfish from Lake Norman, North Carolina.....	58
Table 3.1. Allele frequencies at four microsatellite loci among blue catfish from Lake Norman, the Santee-Cooper system, and Arkansas	75
Table 3.2. Genetic variability metrics for four microsatellite loci among populations of blue catfish from Lake Norman, Santee-Cooper, and Arkansas	76
Table 4.1. 1995 creel survey data for Lake Norman, NC.....	84
Table 4.2. Consumption model of the annual consumption of clupeid standing stock by blue catfish in Lake Norman using standing stock estimates for catfish in Smith Mountain Lake, VA.....	88

Table 4.3. Model of the annual consumption of clupeid standing stock by blue catfish in Lake Norman assuming blue catfish standing stock of 12.4 kg/ha (see text) using variable annual maintenance costs.....90

Table 4.4. Percent caloric contribution by the three predominant food items in blue catfish identified by stomach contents by weight in Chapter 1.....91

Table 4.5. Model of the annual consumption of clupeid standing stock by blue catfish in Lake Norman using percent caloric contribution instead of percent clupeid mean weights from stomach content data and variable annual maintenance costs.....93

Introduction

Native to the Mississippi, Missouri, and Ohio River basins of the United States, blue catfish *Ictalurus furcatus* have been introduced to North America's Atlantic and Pacific slope basins by various state and federal agencies as well as anglers during the past 40 years (Graham 1999). Reasons for blue catfish introductions have included to increase sportfish diversity and to provide predator control of shad (Clupeidae) and Asiatic clams *Corbicula fluminea* populations (Graham 1999; Richardson et al. 1970). Currently, catfishes (Ictaluridae) are receiving increased attention from anglers and biologists (Michaletz and Dillard 1999; Arterburn et al. 2002). Angling for blue catfish, considered a big-river species capable of reaching large sizes, has become popular and several fishing-related television shows and sporting magazines frequently report about quality blue catfish sportfisheries (Graham 1999). A recent symposium on ictalurids (Irwin et al. 1999) focused specifically on catfish biology and management, including the increasing recognition of blue catfish as a trophy species warranting management (Arterburn et al. 2002). However, a review of the biology and management of blue catfish by Graham (1999) noted that there was a surprising shortage of technical reports discussing the life history and biology of the species. Few researchers have examined the diet, growth, movement, or genetic characteristics of blue catfish populations, or addressed the specific impacts and consequences of introducing this large piscivorous species into reservoir fish communities.

Diet Characteristics

Literature review suggests that catfishes (channel catfish *Ictalurus punctatus*, flathead catfish *Pylodictis olivaris*, and white catfish *Ameiurus catus*) are inclined to

pursue clupeids as forage (Minckley and Deacon 1959; Stevens 1960; Carlander 1969). Cyterski (1999) speculated that clupeids comprised 30% of the diet of catfishes (white, channel, and flathead catfish) in Smith Mountain Lake, and that catfishes consumed more biomass (all food items totalled) on an annual basis than any other predator species.

There are a limited number of published studies on the specific food habits of blue catfish. Studies describe blue catfish as opportunistic and omnivorous feeders (Brown and Dendy 1961; Minckley 1962, Perry 1969; Graham 1999), but preferences for freshwater mussels (Richardson et. al 1970; Graham 1999) and fish (Brown and Dendy 1961; Perry 1969; White 1980) are also reported. Diets of blue catfish <400 mm often included fish and macroinvertebrates in Louisiana, Alabama, and South Carolina (Brown and Dendy 1961; Perry 1969; White 1980), whereas larger blue catfish become primarily piscivorous with predominant fish prey including shad, minnows, and sunfish (Brown and Dendy 1961; Henderson 1972; Davis 1979; White 1980). Larger blue catfish in Oklahoma were reported to suspend under schools of gizzard shad *Dorosoma cepedianum* being fed upon by striped bass *Morone saxatilis*, seeking out and foraging on wounded or dead shad (Graham 1999). However, a comprehensive description of blue catfish diets within a reservoir system, or their potential as forage competitors with other top predators such as striped bass, has not been accomplished.

Growth Characteristics

Blue catfish are the largest catfish in the United States, and only the alligator gar *Lepisosteus spatula*, lake sturgeon *Acipenser fulvescens*, and white sturgeon *A. transmontanus* reach larger maximum sizes among freshwater fishes (Graham 1999). Pre-1900 records report unverified weights of blue catfish from the Mississippi basin as

high as 143 kg (Cross 1967; Pflieger 1975), however current state records throughout the southeastern United States range from 40 to 50 kg. Graham (1999) reported blue catfish growth is rapid, particularly after they become piscivorous. Blue catfish growth rates in Lake Texoma, Oklahoma, were reported to be more rapid than channel catfish and nearly equal to flathead catfish (Jenkins 1956). However, Jenkins (1956) reported that blue catfish growth rates declined with increasing age through age 9+ in Lake Texoma and attributed the decrease to inter-specific competition as the fish community reached carrying capacity. Similar declining growth rates were reported for Kentucky Lake, Tennessee (Porter 1969), but Conder and Hoffarth (1965) concluded that intra-specific competition was the cause. The faster growth rates reported for Kentucky Lake blue catfish were believed to be in areas where intra-specific competition was reduced by high harvest (Hale 1987). No significant differences in growth patterns have been found between sexes for blue catfish or channel catfish (Hale 1987; Hale and Timmons 1990). Growth rates of blue catfish in rivers and reservoirs can be similar if forage is adequate, but Graham (1999) noted that differences in growing seasons and the physical and chemical characteristics of the aquatic environments can hamper comparisons between regions.

Twenty-nine states reported having blue catfish populations within their waters (Graham 1999), but life history studies are extremely limited. Michaletz and Dillard (1999) reported that catch-per-unit effort, size structure, and angler catch information were the most typically used evaluation methods, with ten state agencies using only creel information in lieu of direct population data to evaluate catfish fisheries. Directed studies of blue catfish age structure and growth rates are few. As blue catfish receive increased

attention from anglers and management agencies, information on the length, weight, and age structure of blue catfish populations would enhance the abilities of fisheries biologists to develop sound management plans for current and future blue catfish fisheries.

Movement characteristics

Most freshwater fish species restrict their movement to a small home range, but some fish such as catfishes can exhibit a variety of movement patterns (Ramsey and Graham 1991). Lagler (1961) described blue catfish as the most migratory North American catfish, making long seasonal movements upstream in the spring and downstream in the fall that can span several hundred kilometers (Graham 1999). Movements in response to water temperature, with blue catfish moving down the lower Mississippi River to warmer waters during the winter and upstream to cooler waters in the summer, have been noted (Jordan and Evermann 1920; Pflieger 1997). Complex movements and the use of multiple habitats were also observed in the Mississippi River (Lee 1983). Some researchers suggest blue catfish movement patterns in reservoirs are similar to those of the channel catfish, which migrate into tributaries and river headwaters to spawn in spring and migrate downstream during the summer and winter (Hubert 1999). But Timmons (1999) reported that blue catfish traveled greater distances than channel catfish in Kentucky Lake.; 50% of channel catfish were harvested within a 5.5-km radius of the tagging site, whereas 50% of the blue catfish in the same study were harvested within a 14.4-km radius (Timmons 1999). Furthermore, the radius for 90% of the fish harvested was 14.0 km for channel catfish and 41.5 km for blue catfish (Timmons 1999). Pugh and Schramm (1999) reported that blue catfish were more mobile than flathead

catfish, and long-range movements both upstream and downstream were common. Flathead catfish were found to be generally sedentary with preferred-use areas and home ranges (Hart 1974; Jackson 1999). However, specific information on seasonal movements of catfish throughout a large reservoir system is limited (Ramsey and Graham 1991).

Population Genetics

Though genetic studies of blue catfish have been executed in relation to their development for aquaculture interests (Graham 1999), studies of native or stocked populations are virtually non-existent. A literature review indicated that the population genetics of North American catfishes are not well characterized and, specifically, genetic studies of blue catfishes are lacking. Reasons for this gap in genetic investigation are not clear, but might be explained by blue catfish not previously being a high profile sport fish species.

Understanding the genetic character of fish stocks can be a vital component to the overall management plan for an ecosystem. Description of the genetic character of a species could provide information on whether genetically distinct stocks of a particular fish were stocked within a system or if a fishery stocked decades ago in a singular effort has diverged genetically from the original source stock, and thus lost part of its genetic variability.

Lake Norman, North Carolina

Lake Norman, North Carolina supports intensive sport fisheries for striped bass (a put-grow-take fishery), largemouth bass *Micropterus salmoides*, and crappie *Pomoxis spp.* This 13,159-ha hydroelectric and cooling reservoir was stocked with 4,000 eight-

inch blue catfish (source unreported) by the North Carolina Wildlife Resources Commission (NCWRC) in 1966. The presence of a self-sustaining blue catfish population was not detected during various fisheries-related sampling projects on Lake Norman until 1983. Since 1983 the population has grown rapidly, with anecdotal evidence of concomitant declines of other ictalurid species (white catfish and snail bullhead *A. brunneus*) {H. Barwick, Duke Power Company (DPC), personal communication}. Personal communications have indicated that Lake Norman anglers frequently catch blue catfish while targeting schools of striped bass, and that fishing tournaments specifically for catfish have become a common occurrence on the lake. But the direct impacts of blue catfish on other ictalurids, the extent of interspecific competition between striped bass and blue catfish, and the intraspecific competition of blue catfish within Lake Norman are all unknown.

Due to the apparent increase in blue catfish abundance in Lake Norman, combined with the limited amounts of specific information on the diet, growth, movement, or genetic characteristics of blue catfish populations within large reservoirs, this study was developed in cooperation with DPC and NCWRC to improve the current state of knowledge regarding the ecology of blue catfish in Lake Norman and to contribute to the management of blue catfish fisheries throughout North Carolina and the southeastern United States.

Project Objectives

During the summer of 2000, I initiated a study of the blue catfish population in Lake Norman, North Carolina. The overall goal of this study was to improve the current state of knowledge regarding the ecology of blue catfish in Lake Norman and to

contribute to the management of blue catfish fisheries throughout North Carolina and the southeastern United States. The specific study objectives were: (1) to describe the seasonal diet composition of blue catfish; (2) to determine length, weight and growth characteristics of blue catfish in Lake Norman and compare my results to existing and historical records for other southeastern United States reservoirs; (3) to describe the movement and habitat use of blue catfish within Lake Norman; (4) to determine the level of genetic variability of the introduced blue catfish stock in Lake Norman, and (5) to explore possible impacts on forage supply and describe possible management strategies.

For food habits, I examined blue catfish seasonal stomach contents collected from Lake Norman during 2000 and 2001 and described the diet composition by lake-region, season, and size-class distributions (**Chapter 1**). To determine length and weight distributions and examine growth rates for Lake Norman blue catfish I analyzed previously unexamined data collected from Lake Norman during the spring of 1999 and 2000 by Duke Power Company, and compared these data to existing and historical records for other southeastern reservoirs (**Chapter 1**). Then, I utilized radio-telemetry to assess movements and habitat use by blue catfish located throughout Lake Norman (**Chapter 2**). Next, I conducted a study of blue catfish population genetics to determine the level of genetic variability and to assess whether the populations at Lake Norman, and the Santee-Cooper system, SC, have differentiated from their Mississippi River drainage source stocks (**Chapter 3**). Finally, based on the results of the proceeding chapters (1, 2, and 3) I discuss possible impacts on clupeid forage and future management implications for blue catfish in Lake Norman, North Carolina (**Chapter 4**).

Study Site

Located on the Catawba River and the largest man-made body of freshwater in North Carolina, Lake Norman (Figure 1) was impounded in 1963 to provide water for hydroelectric power and the cooling of steam-electric stations (Siler et al 1986). Lookout Shoals Hydroelectric Station provides the primary input of water into Lake Norman from the Lookout Shoals Reservoir. The waters of Lake Norman drive the turbines of Cowans Ford Hydroelectric Station and cool the condensers that drive the turbines of Marshall Steam Station and McGuire Nuclear Station, generating electricity for Duke Power Company. Lake Norman also provides water for recreation, industrial cooling, as well as drinking water for such communities as Davidson, Mooresville, and Charlotte, North Carolina.

The lake has a mean depth of 10.2 m, surface area of 13,159 ha, 837 km of shoreline, a full pond elevation of 231.7 m, and a retention time of 239 days. Excluding the drainage area of the upstream reservoir, Lake Norman has a drainage area of 131 km² (Harrell 1984). Lake Norman's annual surface temperatures range from 1.6 to 33.0 °C (excluding power plant discharge zones), with minimum temperatures of 1.6 to 8.0 °C occurring in February and maximum temperatures of 29 to 33 °C typically occurring in July and August (Siler et. al 1986). Lake Norman is characterized as a warm-monomictic reservoir with an oligo-mesotrophic status based on primary production and phytoplankton biomass (Weiss and Kuenzler 1976; Rodriguez 1982). Total phosphorous concentrations in Lake Norman are the highest (>30 ug/L) during the winter-spring runoff period and lowest during the summer (<5 ug/L in some areas) (Siler et. al 1986). Mean total phosphorous concentration in Lake Norman is 15 ug/L (Gene Vaughan, DPC,

personal communication), but total phosphorous concentrations are generally higher in uplake than downlake regions (Siler et. al 1986).

Lake Norman supports popular sport fisheries that include striped bass *Morone saxatilis* (put-grow-take fishery), white bass *Morone chrysops*, largemouth bass *Micropterus salmoides*, spotted bass *Micropterus punctulatus*, black crappie *Pomoxis nigromaculatus*, blue catfish *Ictalurus furcatus*, channel catfish *Ictalurus punctatus*, and flathead catfish *Pylodictis olivaris*. Until recently the primary forage base for fisheries in Lake Norman were threadfin shad *Dorosoma petenense* and gizzard shad *Dorosoma cepedianum*, but trawl surveys since 1999 indicate that alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis* have been introduced and are displacing the clupeids during certain years in abundance and biomass (Scott Van Horn, NCWRC, personal communication). Annual fishing pressure equals 50.24 hrs/ha for boat and shore anglers combined, with anglers primarily fishing during the spring and summer months (Duke Power Company 1997).

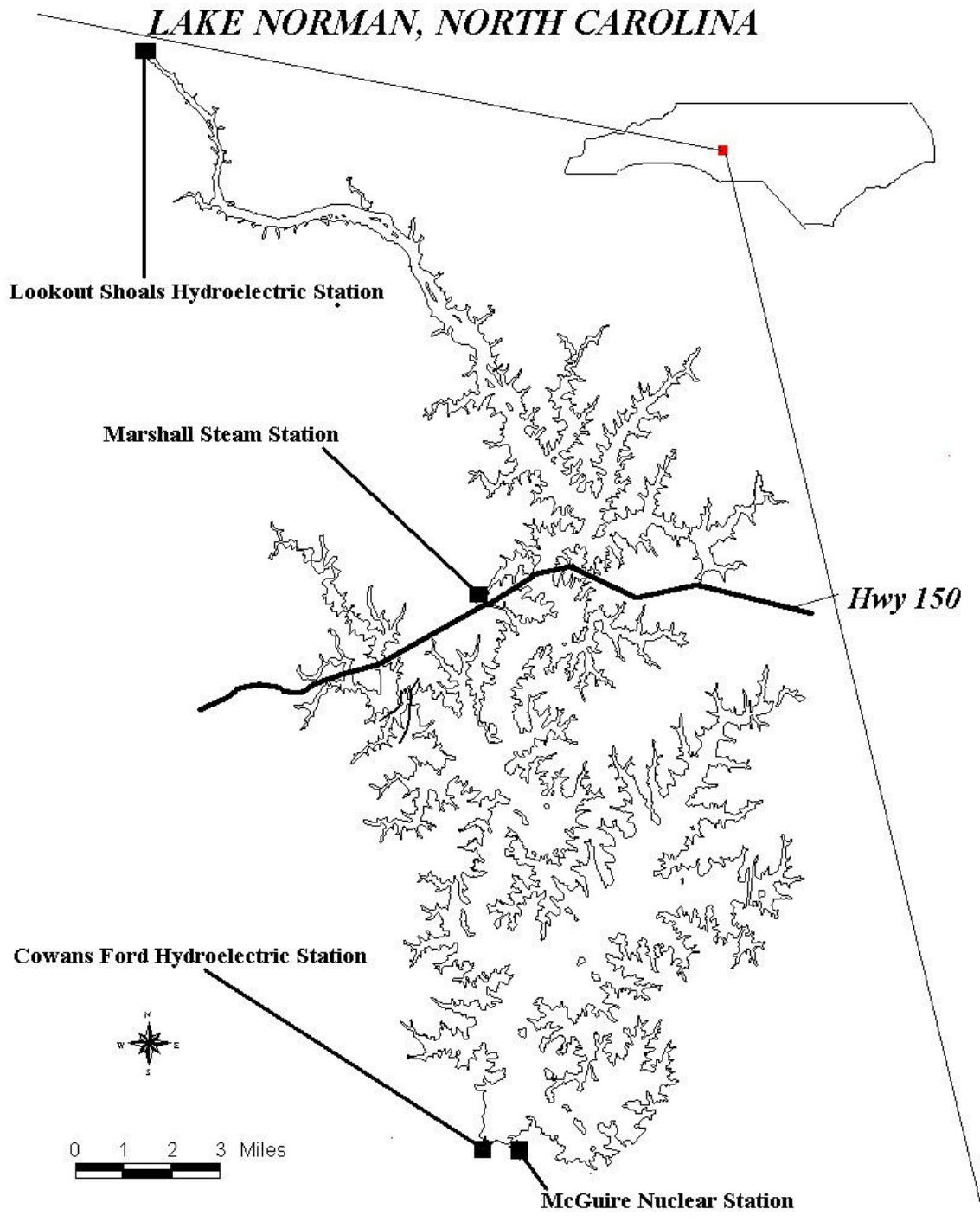


Figure 1: Map of Lake Norman, North Carolina.

Chapter I

The diet and growth of blue catfish in a southeastern reservoir

Introduction

Previous life-history studies of blue catfish *Ictalurus furcatus* are limited and primarily focused on large river and estuary populations. Most published food habit studies suggest that blue catfish are opportunistic and omnivorous feeders, consuming a variety of animal life including fishes, aquatic insects, crayfish, and freshwater mussels (Brown and Dendy 1961; Minckley 1962, Perry 1969; Graham 1999). Richardson et al. (1970) reported that California blue catfish fed heavily upon Asiatic clams *Corbicula fluminea*, and Graham (1999) noted that biologists along the upper Mississippi River in Missouri found blue catfish so full of freshwater mussels that one could see and feel mussel shells protruding from the stomach against the body cavity wall. According to anglers, blue catfish also suspend in deep water below schools of gizzard shad *Dorosoma cepedianum* being fed upon by striped bass *Morone saxatilis*, seeking-out and foraging on wounded or dead shad (Graham 1999). Personal communications have indicated that Lake Norman anglers frequently catch blue catfish in winter while targeting schools of striped bass.

Graham (1999) noted that blue catfish in rivers and reservoirs could have similar growth rates if forage is adequate, but cautioned against comparing age-and-growth data for fish from different regions where growing season, physical and chemical conditions, forage base, and interspecific and intraspecific competition could vary. Blue catfish and channel catfish *Ictalurus punctatus* growth impairment in Kentucky Lake were attributed

to a combination of intra- and interspecific competition (Freeze 1977). Decreased growth rates also were attributed to interspecific competition observed in blue catfish populations from Lake Texoma, OK (Jenkins 1956) and in channel catfish from Reelfoot Lake, TN (Schoffman 1954) and various Iowa waters (Harrison 1957).

North Carolina Wildlife Resources Commission (NCWRC) introduced four-thousand 8-inch blue catfish into Lake Norman in 1966. During the next 17 years, no blue catfish were collected even though gill netting and rotenone samples were conducted annually on Lake Norman (Scott Van Horn, NCWRC, personal communication). However, since 1983 the blue catfish catch has increased noticeably in annual lake samples, with concurrent declines in abundance of other ictalurid species (e.g. white catfish *Ameiurus catus* and snail bullhead *Ameiurus brunneus*) {H. Barwick, Duke Power Company (DPC), personal communication}. Currently, there is a popular fishery for blue catfish in Lake Norman, including recreational, commercial, and tournament-sport anglers. But the direct impacts of blue catfish on other ictalurids, the extent of competition between striped bass and blue catfish for forage, and the intraspecific competition of blue catfish within Lake Norman are all unknown.

The goal of this study is to improve the current state of knowledge regarding the ecology of blue catfish in Lake Norman and to contribute to the management of blue catfish fisheries throughout North Carolina and the southeastern United States. My specific objectives are: (1) to describe the seasonal diet composition of blue catfish; and (2) to determine length, weight and growth characteristics of blue catfish in Lake Norman and compare my results to existing and historical records for other southeastern United States reservoirs.

Methods

Diet

Data Collection

Four seasonal collections of blue catfish for stomach analysis were conducted between spring 2000 and fall 2001. The spring 2000 sample (n=90) was collected by DPC in conjunction with a reservoir fish assemblage project. Stomach contents collected and analyzed for DPC in spring 2000 were used in place of performing a similar sample for spring data in 2001 to prevent additional bycatch mortality to striped bass, which were captured in large quantities during the 2000 gill net sample. In 2001, I collected blue catfish seasonally during the winter (n=98), summer (n=119), and fall (n=88). All blue catfish were captured using experimental gill nets (five 6.1-m panels with bar-mesh sizes of 25, 38, 51, 64 and 76 mm) set for 12 hours overnight. Median in-net time was six hours, except during the summer, when gill nets were checked, blue catfish removed, and re-set after the first six hours, with a median in-net time of three hours. After collection, all blue catfish were immediately transported to the DPC laboratory at Lake Norman where each fish was measured for total length (mm) and weight (g). Stomachs of each blue catfish collected were removed and stored in 10% formalin for later analysis. Stomach contents were identified to lowest taxonomic level possible and weighed to the nearest 0.1 g.

Diet Analysis

I characterized the diet composition for Lake Norman blue catfish as percent stomach contents by weight (Bowen 1996). Percent stomach contents by weight was calculated for blue catfish during each season of Lake Norman as

$$X_i = \frac{\sum_{i=1}^N \frac{wt_i}{wt}}{N}$$

where X_i equals the mean percent composition by weight of item i in the diet, wt_i is the weight of food item i in an individual fish, wt is the total weight of all food items in an individual fish, and N is the total number of fish with food contents (Ney 1990).

Individual food items were classified into one of eight categories for further analysis: clupeids; other fish (non-clupeids); unidentifiable fish remains; Asiatic clams; crayfish; *Chara spp.* (*Chara*), a filamentous algae; aquatic insects; and miscellaneous items (such as chicken bones and corn cobs).

Percent stomach contents by weight were collated by season, lake-region, and size groups. Lake regions were delineated by the production characteristics of Lake Norman, an upper mesotrophic (upper) and lower oligotrophic (lower) region (Siler et al. 1986) (Figure 1.1). Catfish size groups were categorized by stage of maturation, with blue catfish <400 mm (small) considered immature, 400-600 mm (intermediate) considered as transitioning into sexually mature adults, and >600 mm (large) as sexually mature (Carlander 1969; Jenkins and Burkhead 1993). To test for significant differences for each food type found within the stomach contents, I used multivariate analysis of variance (MANOVA) to identify similarities or differences between regions, seasons, and size classes.

LAKE NORMAN, NORTH CAROLINA

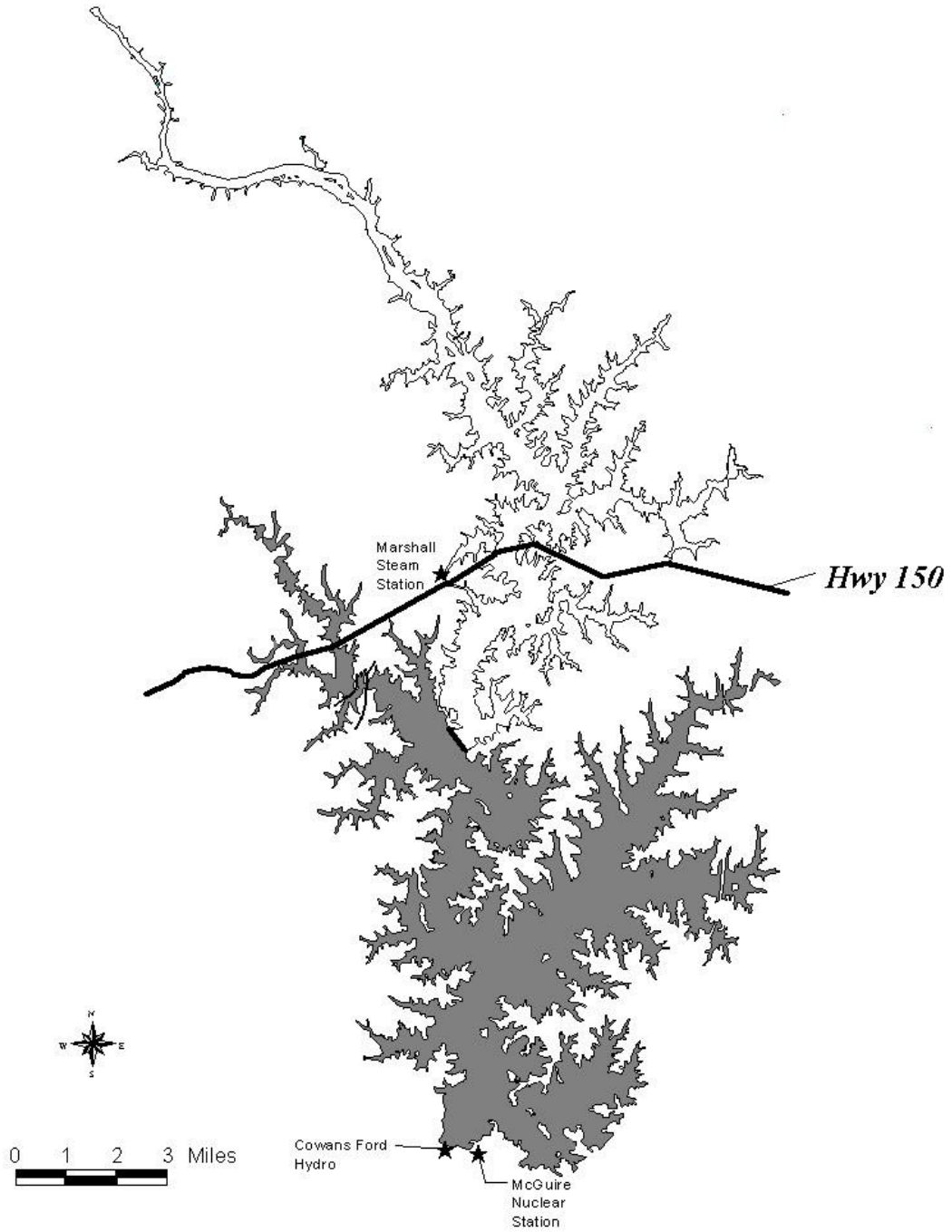


Figure 1.1: Map of Lake Norman, NC, showing the division of sampling areas into upper (white) and lower (gray) regions.

Growth

Data Collection

In the spring of 1999 and 2000, DPC personnel recorded total length (mm) and weight (g) data and collected pectoral spines (Sneed 1951) from 205 blue catfish captured with experimental gill nets (mesh sizes previously described; 30 net nights per year). Spines were placed in numbered coin envelopes and stored for later age analysis. During 2000, I sectioned each individual spine across the basal recess and articulating process using a modified Blouin and Hall (1990) method. I replaced the use of a steel tension pin for mounting each spine onto the weighted saw arm with tightly wrapped paper toweling, which provided more favorable maneuverability of spines when positioning for each individual cut. Spine-sections were cut to 0.12 – 0.15 mm and attached to petrographic slides with Permount histological mounting medium. Spine sections were aged using a compound microscope with 10x magnification, and results were reported as age at capture.

Older catfish can be difficult to age because of ontogenetic changes in spine structure. As catfish grow, their spines grow correspondingly, adding a growth ring and additional length to the spine for each year. But, after the first few years of growth, the central lumen begins to expand and the first year's annulus is lost from the spine (Turner 1977; Nash and Irwin 1999). As catfish increase in age more annuli are lost, making accurate age definition of older catfish by spines difficult. Ages determined for all blue catfish in this study were reported, but comparisons to other populations were limited to blue catfish of age-class 8 or younger in recognition of the loss of annuli and probable under-aging of older blue catfish.

Growth Analysis

Length- and age-frequency histograms were created to examine the sample distribution of blue catfish across size classes (25 mm increments) and age classes. The age distribution of Lake Norman blue catfish was examined and compared to length-at-age datasets for blue catfish from four southeastern impoundments. The additional datasets were provided by the South Carolina Department of Natural Resources and the Texas Parks and Wildlife Department (Table 1.1).

Individual relative weights (W_r) were calculated for each fish as

$$W_r = \frac{W}{W_s} \cdot 100$$

where W is the observed weight of each fish and W_s is the length specific standard weight [as determined by the formula $\log_{10} W_s = -6.067 + 3.400 \log_{10} TL$; (Muoneke and Pope 1999)]. Mean relative weights were calculated for 25-mm size classes, and compared to the datasets from South Carolina and Texas. Statistical analyses were conducted using the statistical analysis SAS version 8.1e (SAS Institute Inc., 1999) software.

Satterthwaite's t-test was used to compare differences between mean total lengths-at-age between Lake Norman blue catfish and the additional blue catfish populations.

Results

Diet

A total of 395 blue catfish stomachs from Lake Norman were evaluated over four seasons, with at least 51% (varied by season) containing food (Table 1.2). The most common prey items (percent stomach contents by weight) identified in winter blue catfish stomachs were *Chara* (49%) and fish (33%) throughout Lake Norman (Table 1.3) (Figure 1.2).

Table 1.1: General information on locations where data sets were obtained for direct comparison to Lake Norman’s blue catfish population.

<i>Reservoir</i>	<i>Date impounded</i>	<i>Size (hectares)</i>	<i>Pool elevation (m)</i>	<i>Dataset year(s)</i>
Santee-Cooper, SC ^a	1941	64,752	22.9	2000-2001
Choke Canyon Reservoir, TX ^b	1982	10,518	67.2	1995
Lake Corpus Christi, TX ^b	1958	8,863	28.7	1996-97
Lake Livingston, TX ^b	1969	36,423	40.0	1995

^aSouth Carolina Department of Natural Resources

^bTexas Parks and Wildlife Department

Table 1.2: Sample size and percent stomachs with food of blue catfish collected from Lake Norman, North Carolina.

Length Classes	Winter		Spring		Summer		Fall	
	Stomachs (n)	With food (%)	Stomachs (n)	With food (%)	Stomachs (n)	With food (%)	Stomachs (n)	With food (%)
<400 mm	54	72	39	51	55	67	42	57
400-599 mm	35	74	14	79	44	55	24	67
>600 mm	9	67	37	62	20	75	22	83

Table 1.3: Percent stomach contents by weight by season for Lake Norman blue catfish.

Classification	Family	Genus	Winter 2001 n=71	Spring 2000 n=54	Summer 2001 n=76	Fall 2001 n=59
Aquatic Plants						
	Charophyta	<i>Charaphytin</i>	49%	0%	0%	17%
Aquatic Invertebrates (other)						
	Phylactolaemate	<i>Pectinatella spp.</i>	1%	0%	0%	0%
Aquatic Insects						
	Diptera	<i>Unidentified</i>	1%	0%	0%	0%
	Trichoptera	<i>Unidentified</i>	6%	0%	0%	0%
Crayfish						
	Unidentified	<i>Unidentified</i>	3%	6%	0%	3%
Fish						
	Catostomidae	<i>Unidentified</i>	0%	2%	0%	0%
	Clupeidae	<i>Dorosoma cepedianum</i>	1%	3%	3%	3%
		<i>Dorosoma petenense</i>	1%	0%	0%	7%
		<i>Dorosoma spp.</i>	24%	0%	0%	0%
	Cyprinidae	Unidentified	0%	0%	3%	0%
	Percichthyidae	<i>Morone Americana</i>	0%	0%	0%	11%
		<i>Morone spp.</i>	1%	0%	0%	0%
	Unidentifiable Fish		6%	16%	1%	3%
Freshwater Clams						
		<i>Corbicula fluminea</i>	1%	60%	87%	48%
Miscellaneous Items (i.e.chicken bones)						
			6%	13%	7%	7%

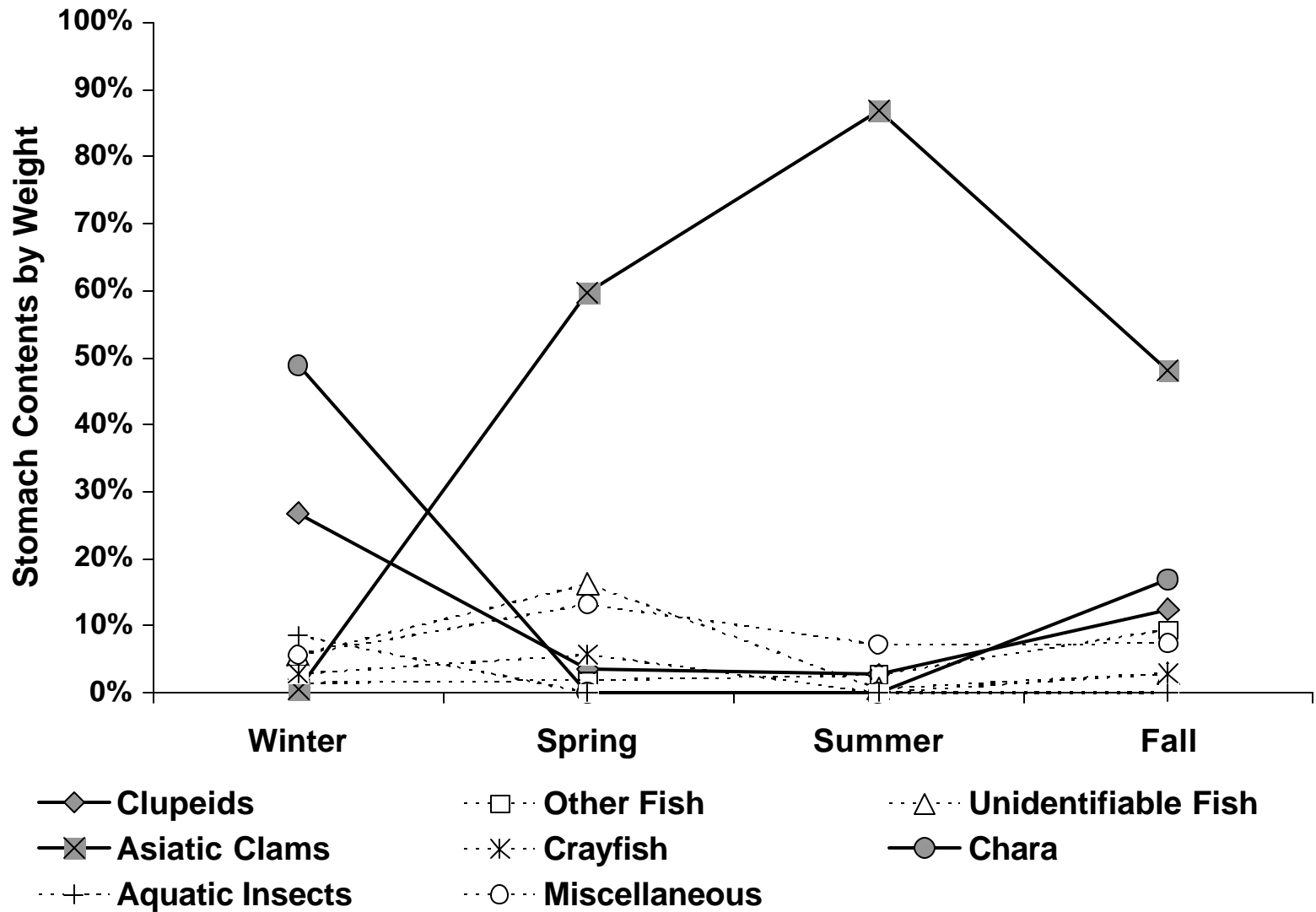


Figure 1.2: Comparison of seasonal blue catfish percentage-by-weight stomach contents from Lake Norman. The most common food items (Asiatic clams, clupeids, and *Chara*) are highlighted in bold.

Chara was identified in the diets of winter and fall blue catfish, but absent during the spring and summer. Clupeids were the most prevalent fish (26%), however I was unable to consistently differentiate between threadfin shad *Dorosoma petenense* and gizzard shad due to the poor condition of the remains. Asiatic clams were the predominant prey item for the spring (60%), summer (87%), and fall (48%), with fish contributing 19%, 7%, and 24%. Identifiable fish included gizzard shad, threadfin shad, and white perch. Seasonal differences were significant for most diet items, including Asiatic clams (df=3; $F=53.72$; $P<0.0001$), *Chara* (df=3; $F=32.18$; $P<0.0001$), and clupeids (df=3; $F=17.38$; $P<0.0001$) (Table 1.4).

In addition to seasonal differences, the diets of Lake Norman blue catfish also varied regionally. *Chara* (29%) was more common in the diets of lower Lake Norman blue catfish, whereas clupeids (24%), aquatic insects (6%), and crayfish (6%) were primarily found in the diets of upper lake blue catfish (Figure 1.3). Asiatic clams were found in the diets of blue catfish from both regions (57% lower; 37% upper). Aquatic insects (diptera, tricoptera, and unidentified remains) were found only in the diets of upper lake blue catfish. The regional differences were statistically significant for clupeids (df=1; $F=27.73$; $P<0.0001$), clams (df=1; $F=4.55$; $P=0.0339$), *Chara* (df=1; $F=73.41$; $P<0.0001$), and crayfish (df=1; $F=5.01$; $P=0.0262$) (Table 1.4).

There were fewer obvious differences in diet among size groups of blue catfish. Larger blue catfish (>600 mm) consumed more fish (41%) than intermediate (23%) and small (9%) blue catfish (Figure 1.4). *Chara* was more common in small (21%) and intermediate (19%) blue catfish than in the diets of larger fish (6%). Clams, while predominant in the diets of all size groups of blue catfish, were more common in the diets

Table 1.4: Statistical comparison of food items in the diets of blue catfish within regions, seasons, and size-classes and multiple comparisons between sources. Significant differences highlighted in bold.

Source	df	Value	Clupeids	Other Fish	Unidentified Fish	Clams	Crayfish	<i>Chara</i>	Aquatic Insects	Miscellaneous
Region	1	F	27.73	1.33	0.11	4.55	5.01	73.41	N/A	1.22
		P	<0.0001	0.2508	0.74	0.0339	0.0262	<0.0001	N/A	0.2706
Season	3	F	17.38	1.57	4.5	53.72	2.22	32.18	2.37	0.84
		P	<0.0001	0.197	0.0043	<0.0001	0.087	<0.0001	0.0712	0.4731
Size	2	F	11.24	0.64	4.61	7.31	1.68	3.6	2	0.24
		P	<0.0001	0.5262	0.0108	0.0008	0.1881	0.0289	0.1377	0.7902
Region*Season	3	F	10.86	0.13	1.29	7.34	2.7	28.79	N/A	1.04
		P	<0.0001	0.9419	0.2769	0.0001	0.0465	<0.0001	N/A	0.3768
Region*Size	2	F	2.96	0.23	0.63	1.31	2.22	3.56	N/A	0.78
		P	0.0538	0.7923	0.5347	0.2705	0.1379	0.03	N/A	0.4578
Season*Size	6	F	3.96	1.89	2.28	5.63	4.28	3.34	2.07	2.62
		P	0.0008	0.0841	0.0371	<0.0001	0.0004	0.0036	0.057	0.0176
Region*Season*Size	6	F	1.06	1.97	3.32	4.54	3.34	2.76	N/A	1.93
		P	0.3847	0.0706	0.0037	0.1657	0.0036	0.0131	N/A	0.0769

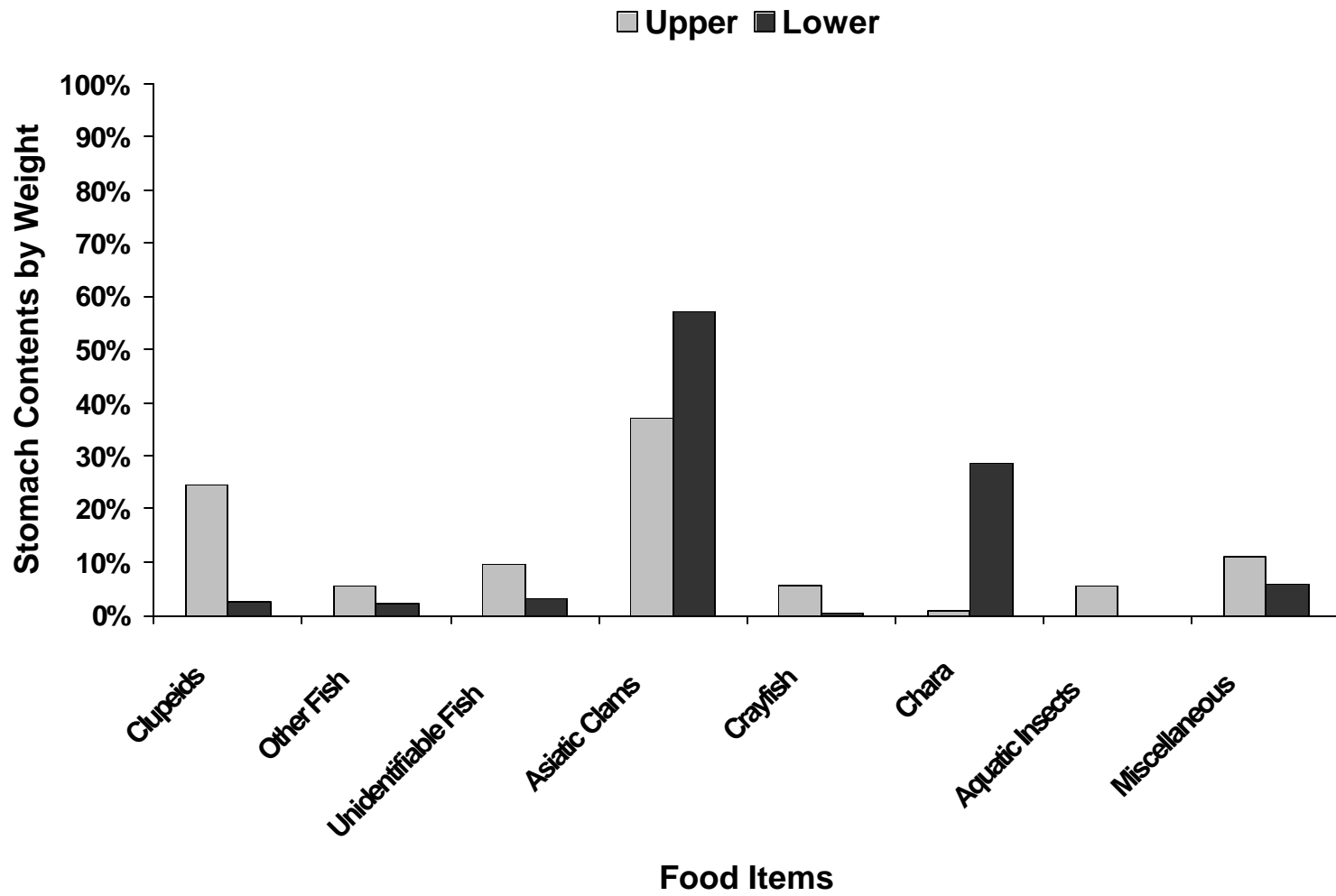


Figure 1.3: Comparison of regional blue catfish percentage-by-weight stomach contents from upper and lower Lake Norman.

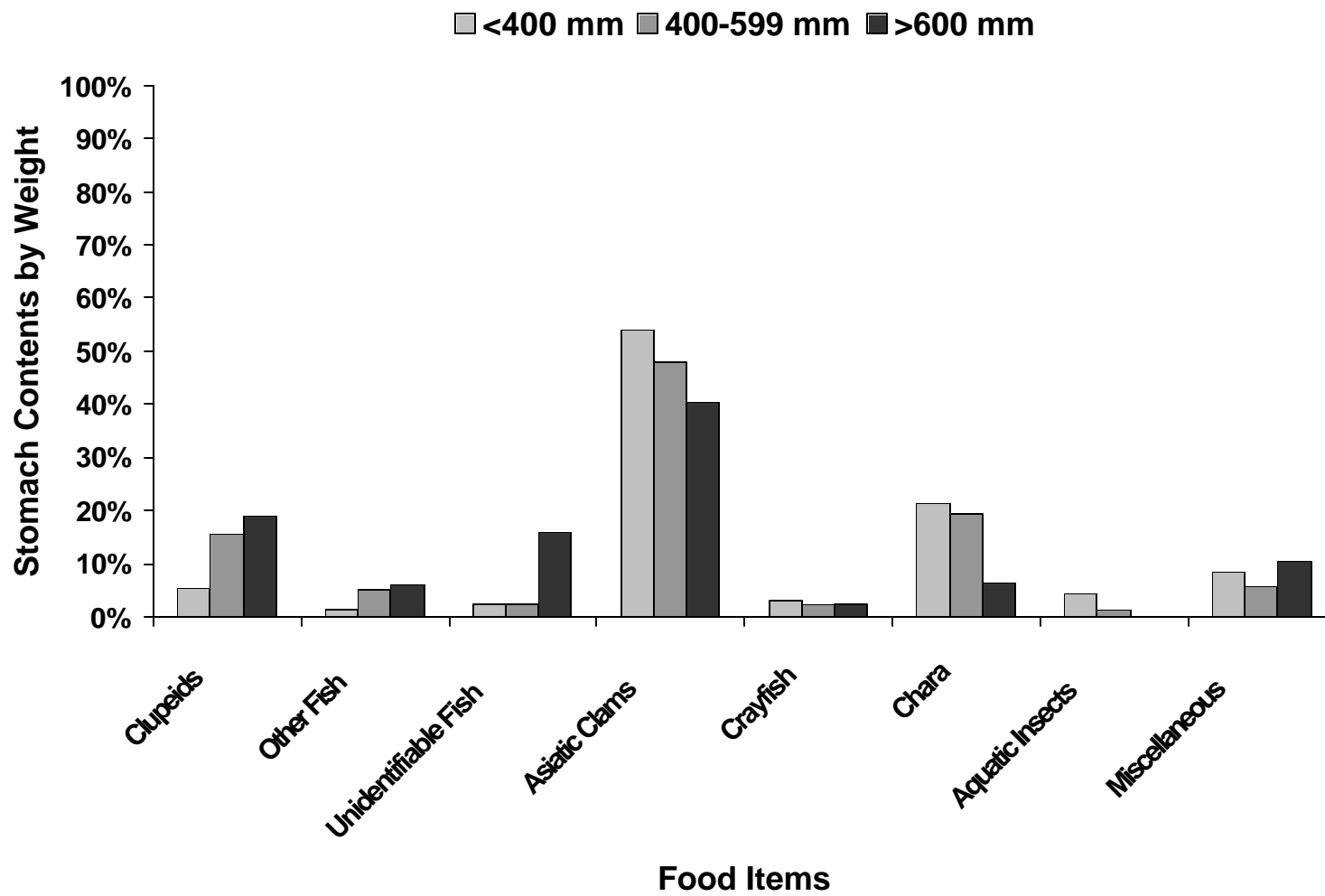


Figure 1.4: Comparison of blue catfish percentage-by-weight stomach contents by size-classes.

of small fish (54%) than intermediate (48%) and large fish (40%). Stomach-contents-by-weight were significantly different between size groups (Table 1.4) for *Chara* (df=2; $F=3.6$; $P=0.0289$), clams (df=2; $F=7.31$; $P=0.0008$), unidentifiable fish (df=2; $F=4.61$; $P=0.0108$), and clupeids (df=2; $F=11.24$; $P<0.0001$).

The relationships defined by analyzing the data separately by seasons, regions, and size groups imply a simpler food-habits dynamic than may be actually occurring within the lake. By adding regional and size group information to the analysis the overall description of diets is more refined. For example, the general analysis shows that *Chara* and fish predominated during the winter. However, during this season, fish were more common in the diets of large fish than small fish, and *Chara* was more dominant in the lower lake region while fish were more dominant in the upper lake region (Figure 1.5). The spring analysis shows that Asiatic clams were more common, whereas fish and *Chara* had declined since the winter. Asiatic clams were most common in the diets of smaller fish and in the lower lake, while fish were more common in intermediate and larger blue catfish in the upper lake (Figure 1.6). The summer analysis shows Asiatic clam as the predominant food item; unlike the winter and spring, there were no regional or size-group diet differences (Figure 1.7). In the fall there was a diet transition, from clams back to fish and *Chara*. Fish are the predominant item in the diets of larger blue catfish in both regions, but Asiatic clams are still the predominant item of small and intermediate catfish (Figure 1.8). *Chara* reappears in the diets of all size groups in the lower region during the fall.

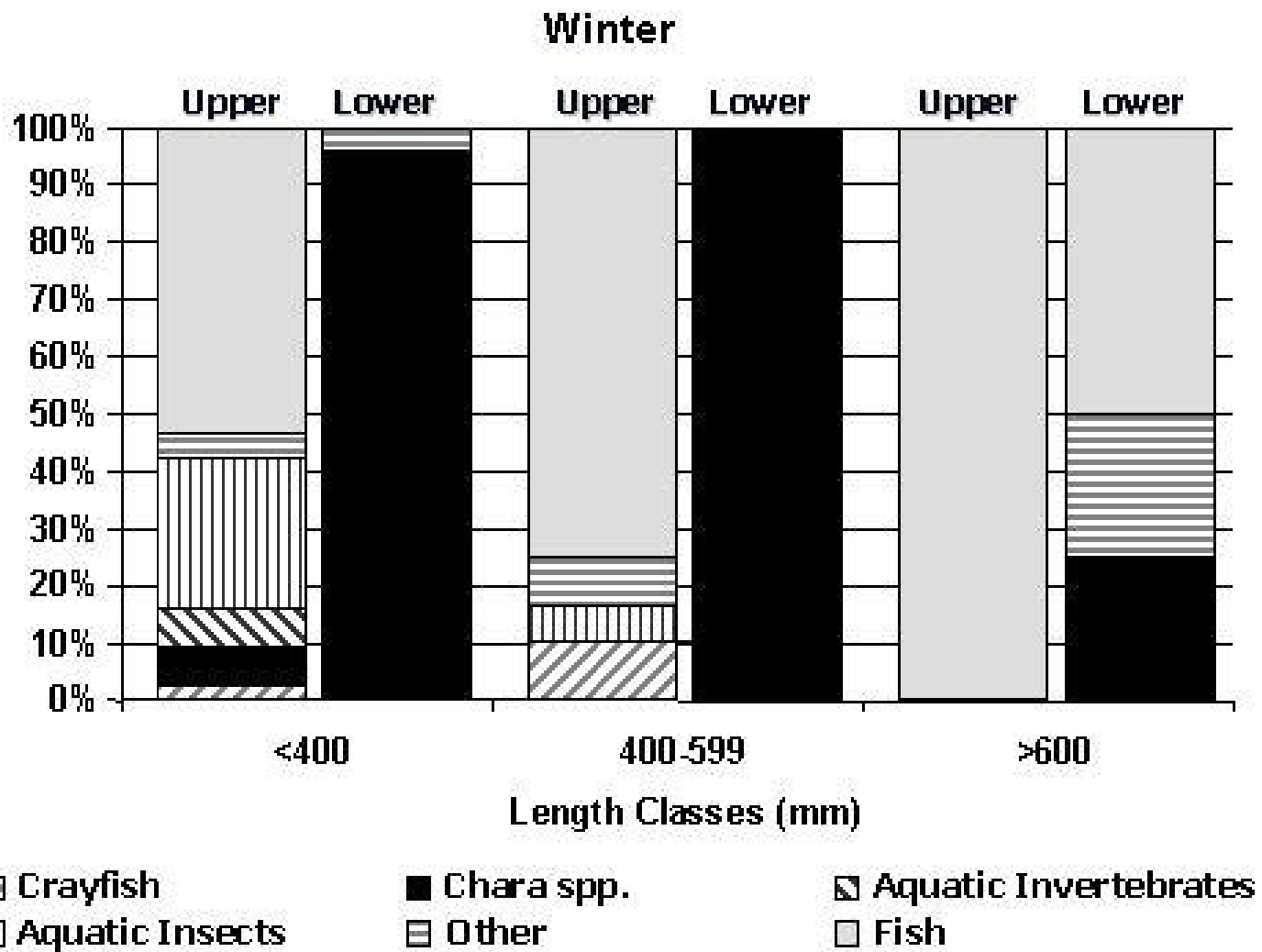


Figure 1.5: Winter blue catfish diets.

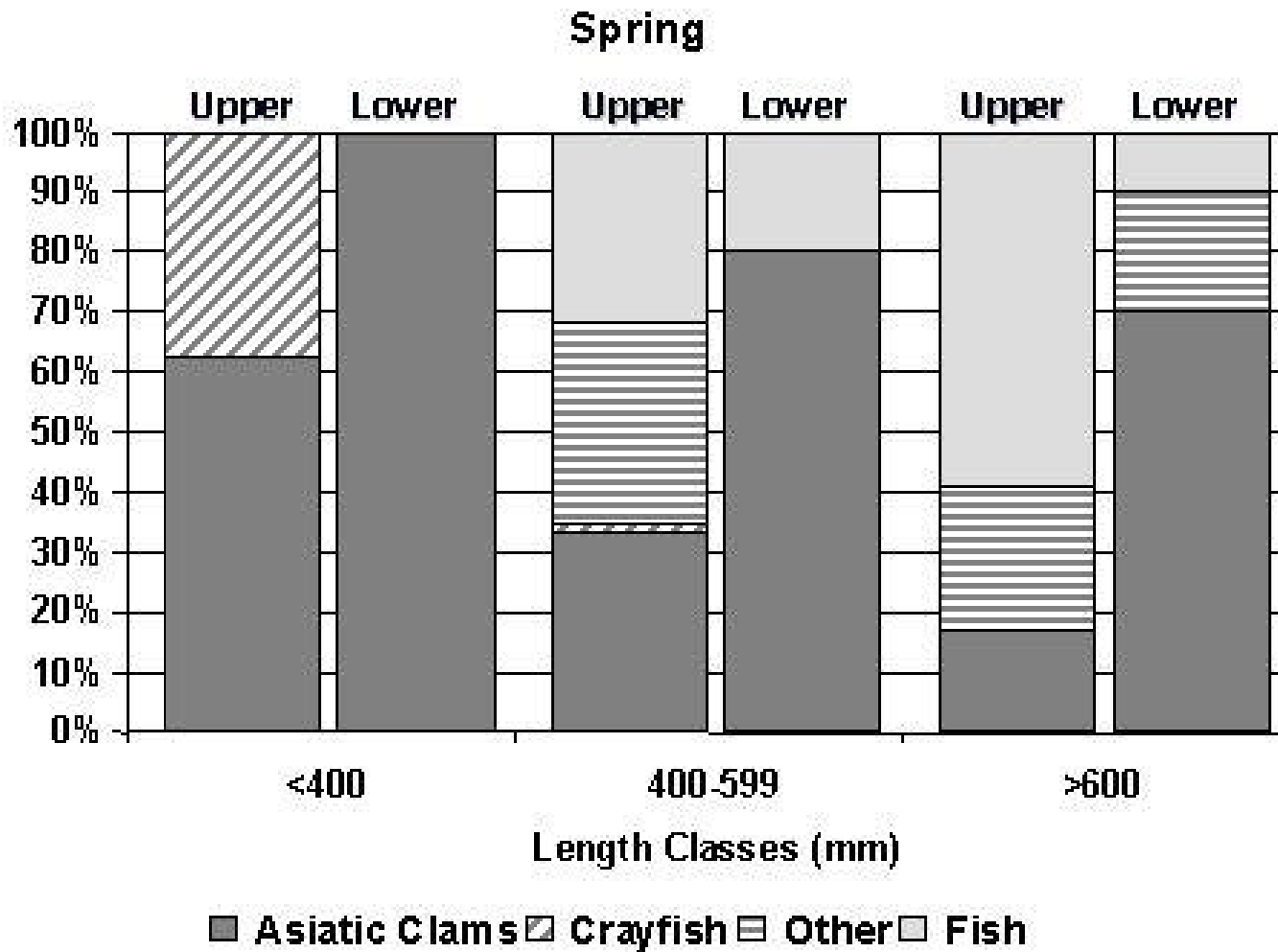


Figure 1.6: Spring blue catfish diets.

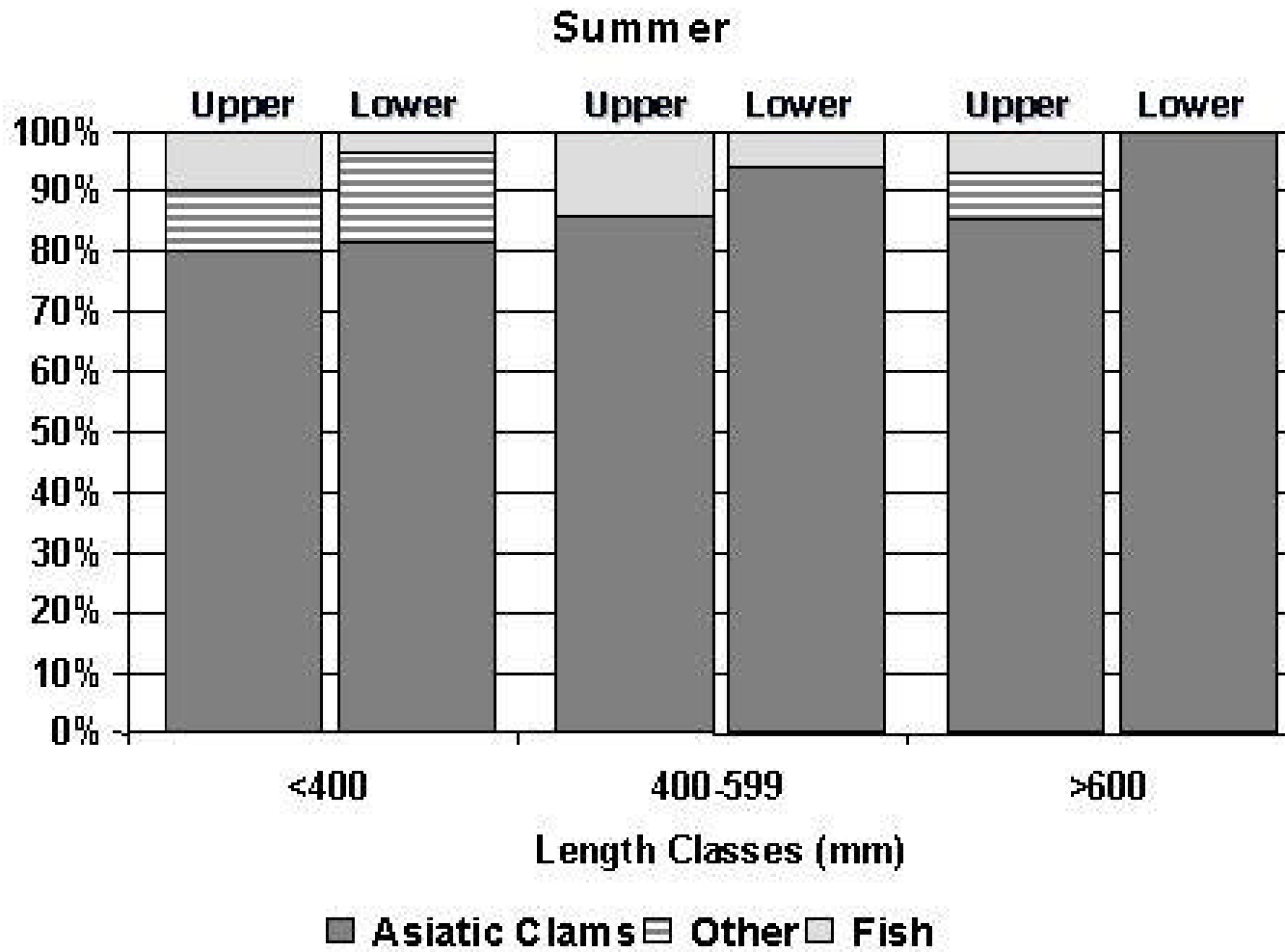


Figure 1.7: Summer blue catfish diets.

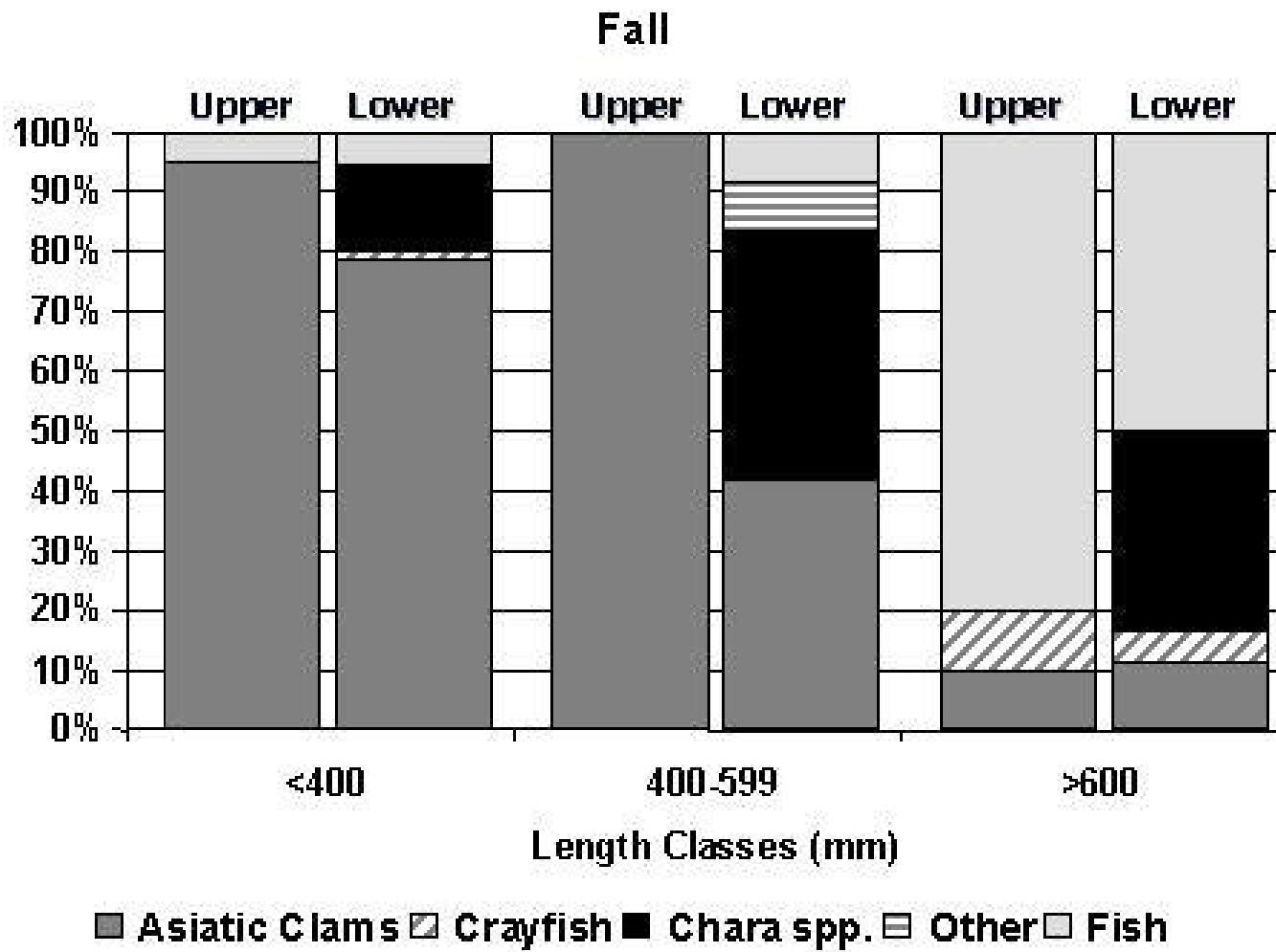


Figure 1.8: Fall blue catfish diets.

Growth

A total of 215 blue catfish were captured during the spring months of 1999 (n=93) and 2000 (n=112). Length and age frequencies, as well as relative weights were not significantly different between years or lake-regions in Lake Norman, so the annual datasets were combined to increase the sample size for analysis. The sample size was low (n<4) for blue catfish size-classes <200 mm, 500-525 mm, and >750 mm (Figure 1.9). The size distribution was tri-modal, with peaks at 325, 450, and 625 mm.

An age-frequency histogram (Figure 1.10) indicated that blue catfish < 3+ were absent from the collection, and the maximum recorded age was 15+. The age-distribution was also tri-modal, with peaks at ages 5+, 8+, and 10+. Blue catfish exceeded 400mm by 7+ and 600 mm by 9+ (Figure 1.11). Lake Norman mean growth rates were slower than those for blue catfish from Santee-Cooper and three Texas impoundments (Figure 1.12). The 1977-79 dataset for Santee-Cooper blue catfish represented the highest growth rates, while Lake Norman represented the lowest.

Lake Norman blue catfish are in poor condition (relative weight < 85) up to approximately 600mm. Lake Norman blue catfish mean relative weights increase with length, with body condition ranging from a mean of 73 for 200-224 mm fish to 102 for 900 mm fish (Figure 1.13). Body condition for Lake Norman blue catfish <600 mm were lower than those reported for Santee-Cooper and the three Texas impoundments (Figure 1.14). Body condition was similar to Santee-Cooper, but significantly less than Choke Canyon Reservoir ($df=269$; $T=5.74$; $P=<0.0001$), Lake Corpus Christi ($df=289$; $T=12.46$; $P=<0.0001$) and Lake Livingston ($df=253$; $T=13.34$; $P=<0.0001$) (Table 1.5).

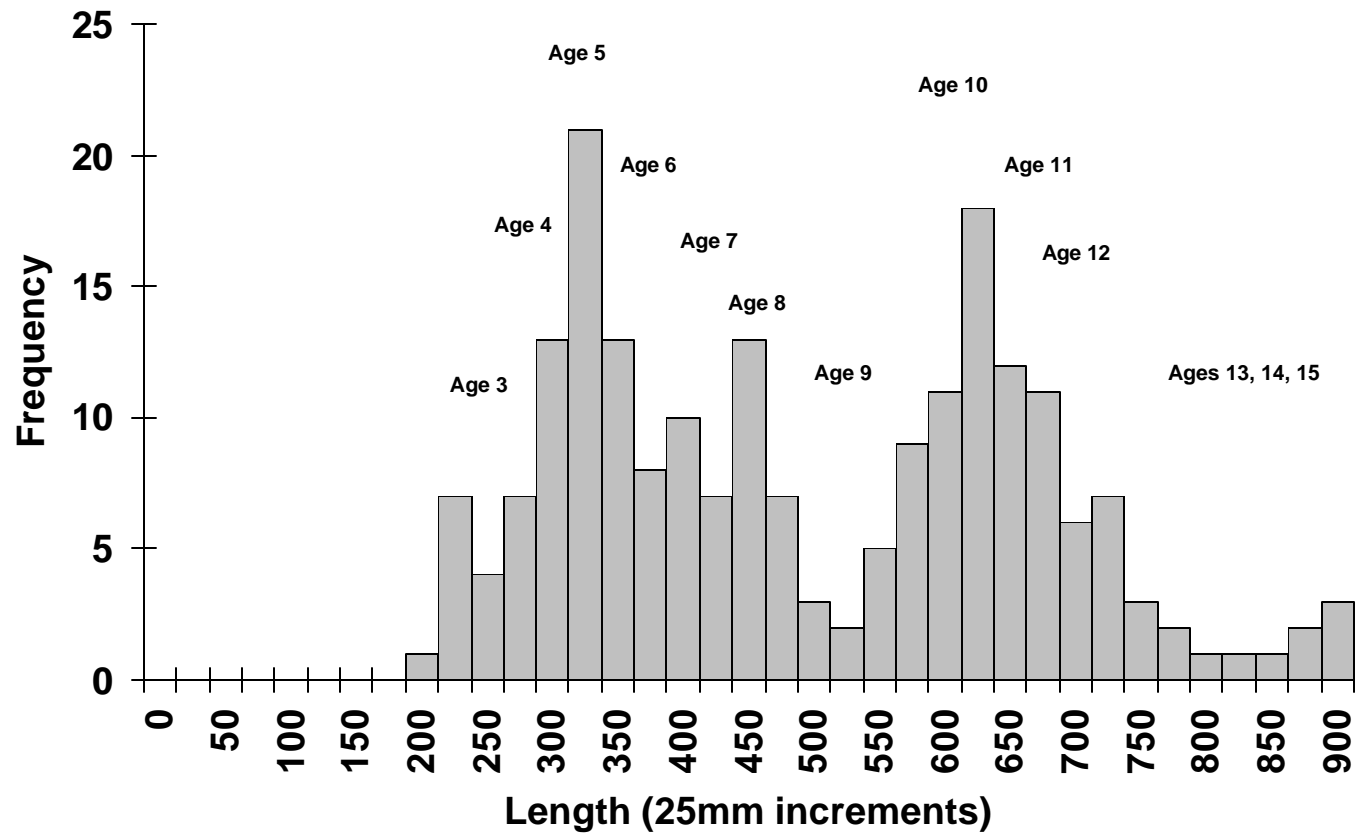


Figure 1.9: Length-frequency histogram with mean lengths-at-age represented for Lake Norman blue catfish.

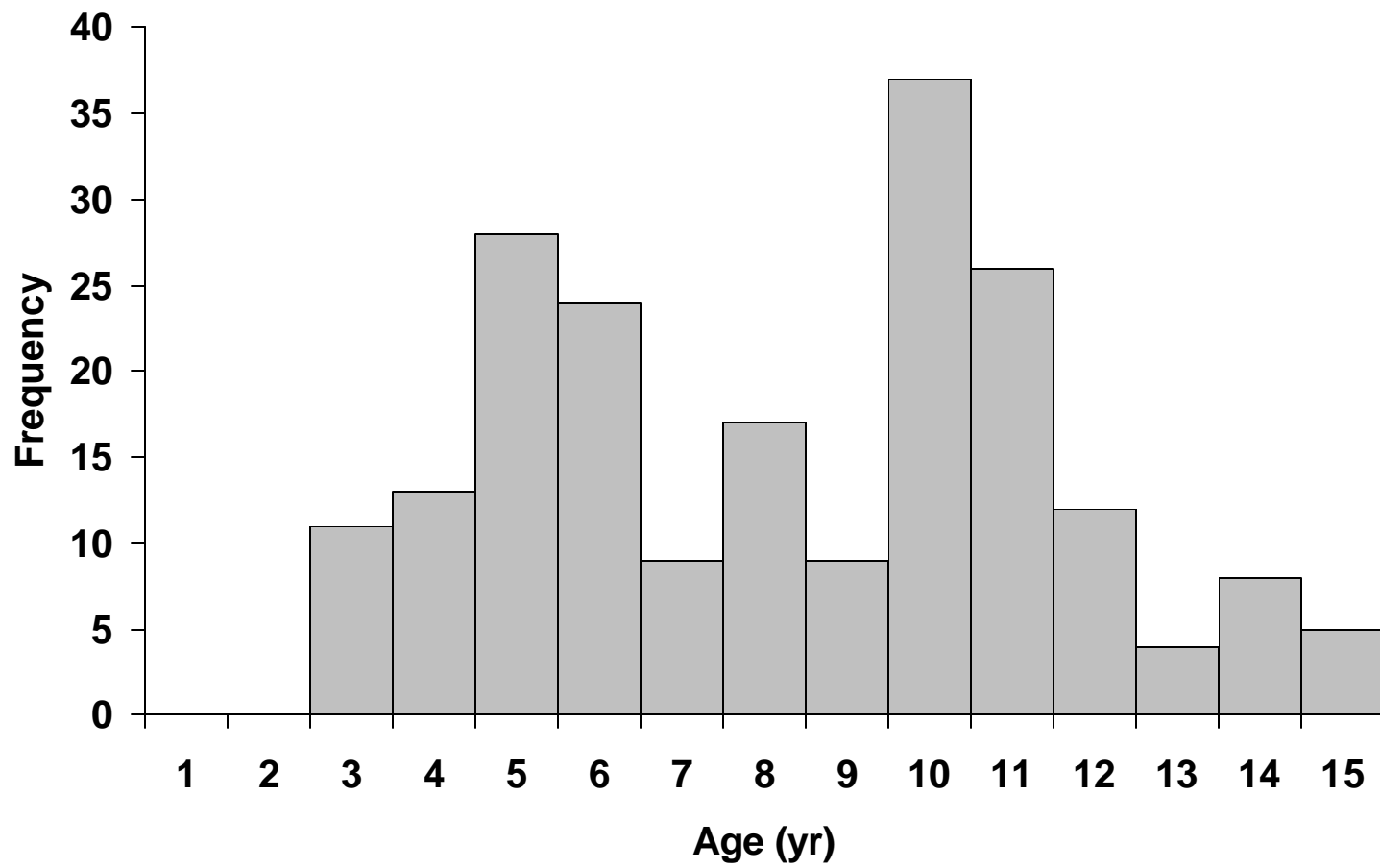


Figure 1.10: Age-frequency histogram for Lake Norman blue catfish.

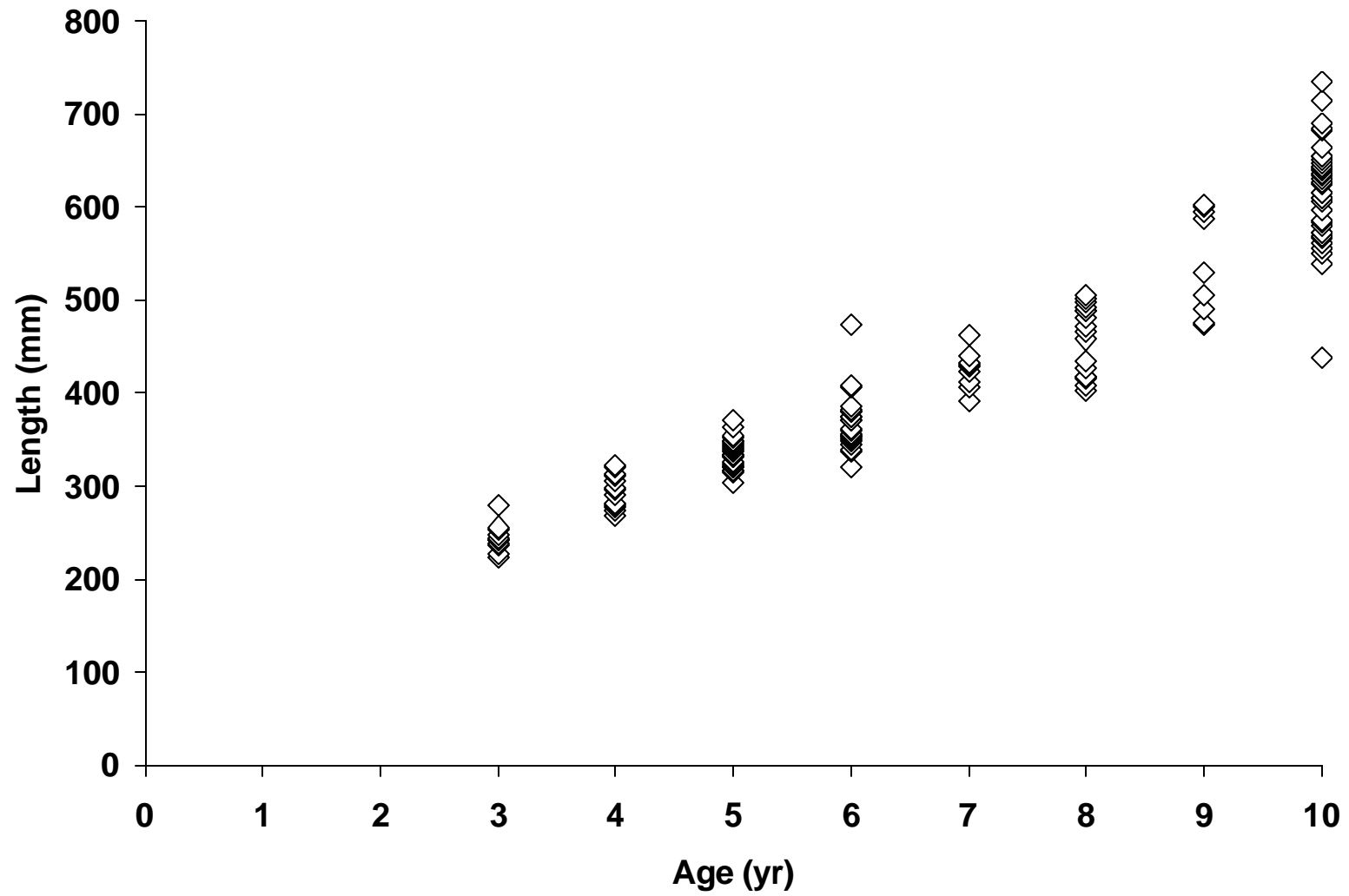


Figure 1.11: Length (mm) ranges at age (yr) for Lake Norman blue catfish.

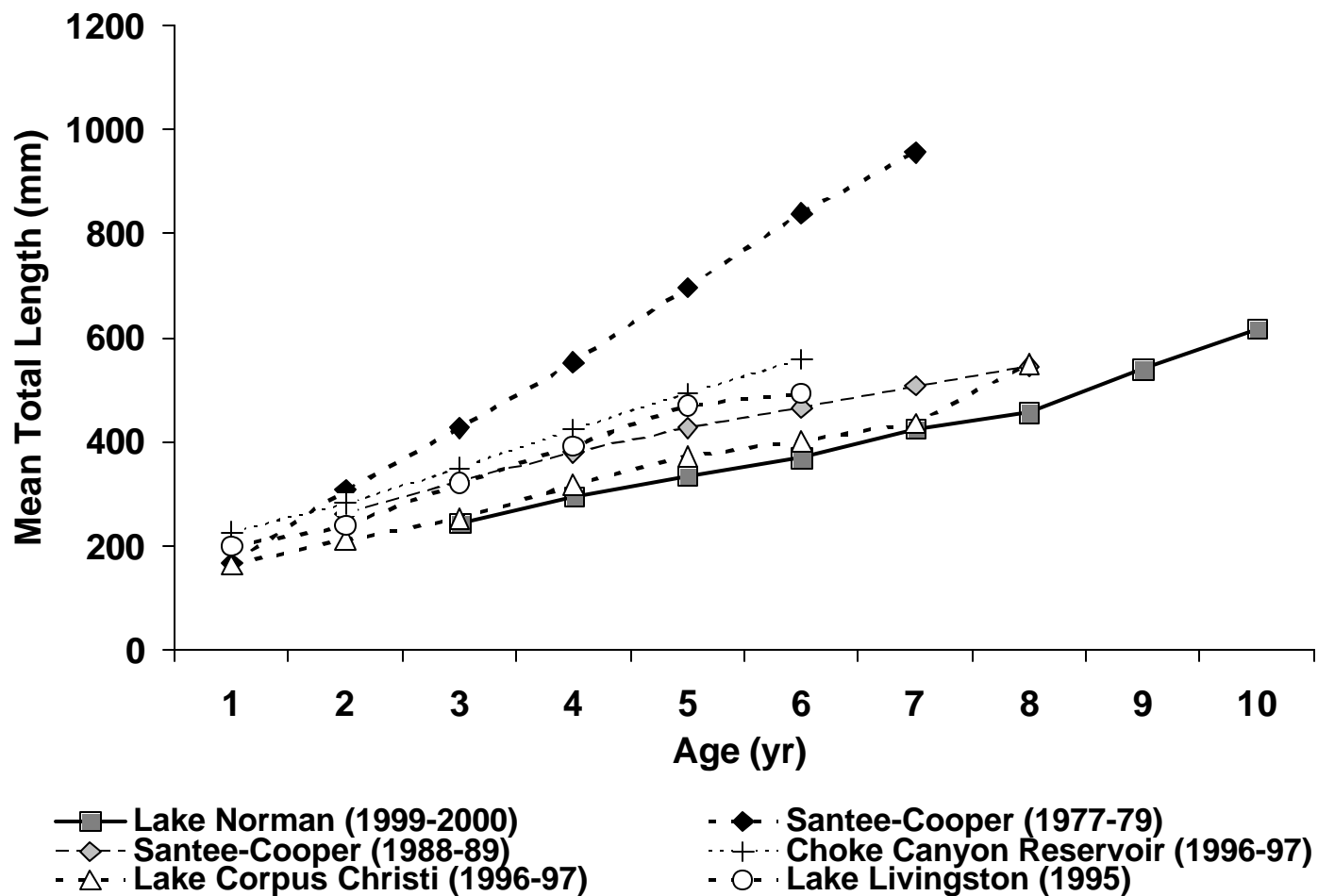


Figure 1.12: Comparison of average growth rates of Lake Norman blue catfish sampled during 1999 and 2000 to four other reservoir blue catfish populations dataset for previous years.

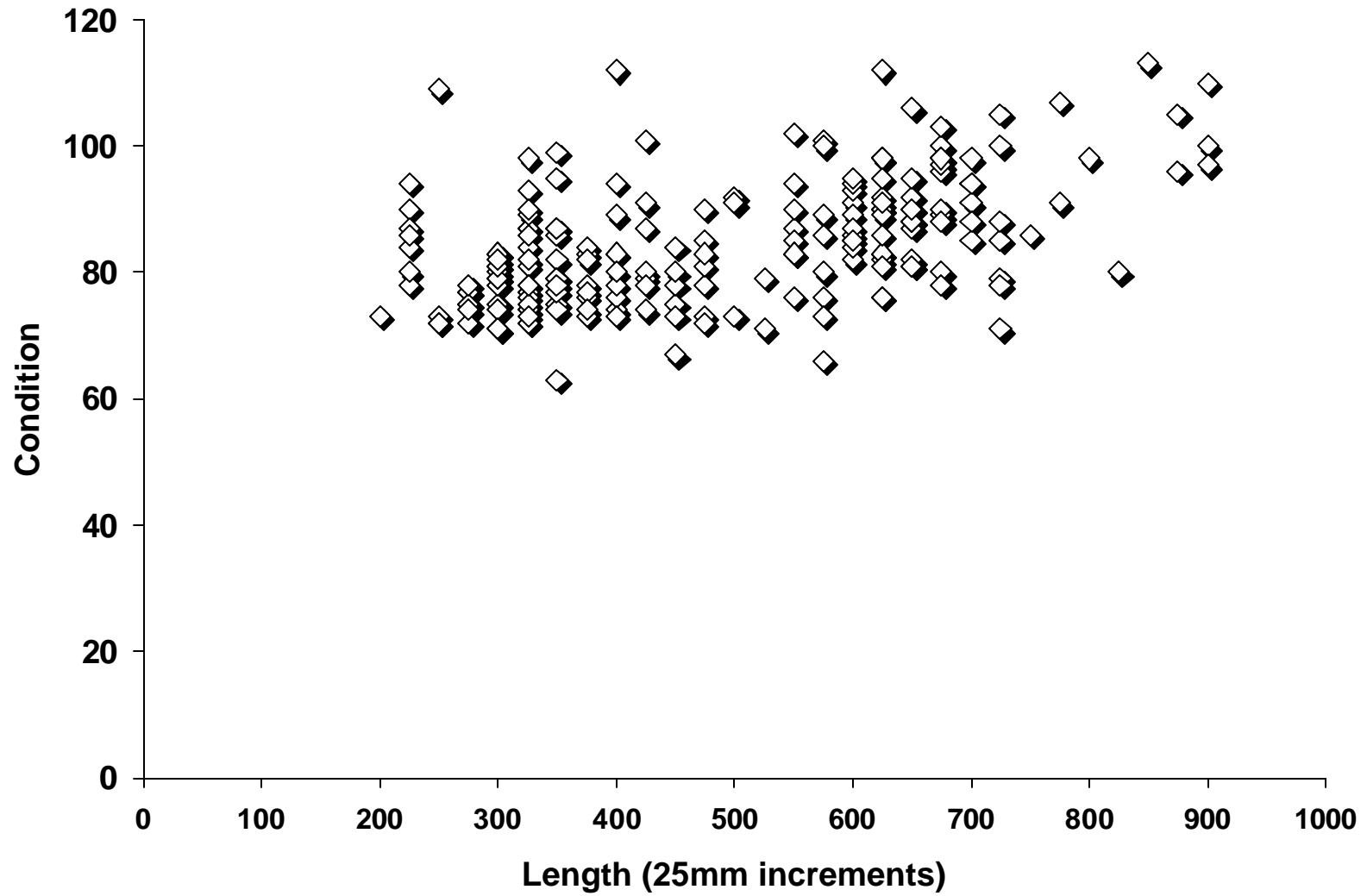


Figure 1.13: Lake Norman blue catfish condition per 25 mm length-classes.

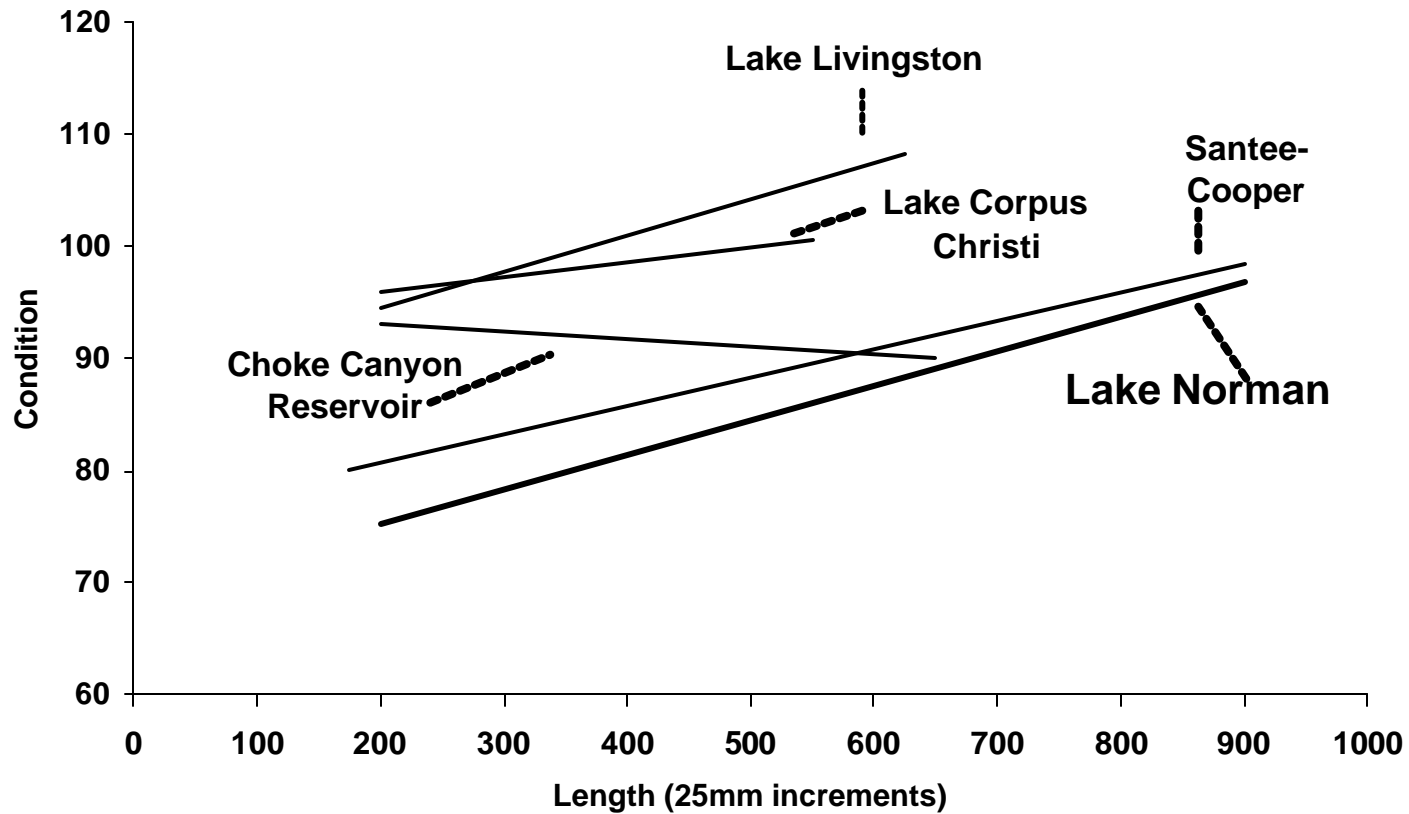


Figure 1.14: Comparison of trendlines for mean condition per 25-mm length classes of Lake Norman ($\log_{10}W = 0.0307 + 69.165 \cdot \log_{10}L$, $r^2=0.59$, $N=205$) blue catfish to four other reservoir blue catfish populations: Santee-Cooper, SC ($\log_{10}W = 0.0253 + 75.651 \cdot \log_{10}L$, $r^2=0.61$, $N=468$); Choke Canyon Reservoir, TX ($\log_{10}W = -0.0069 + 94.501 \cdot \log_{10}L$, $r^2=0.02$, $N=136$); Lake Corpus Christi, TX ($\log_{10}W = 0.0132 + 93.294 \cdot \log_{10}L$, $r^2=0.15$, $N=103$); and Lake Livingston, TX ($\log_{10}W = 0.0321 + 88.201 \cdot \log_{10}L$, $r^2=0.48$, $N=114$).

Table 1.5: Statistical results of Lake Norman relative weights compared to Santee-Cooper, SC, and three Texas impoundments.

<i>Reservoir</i>	<i>df</i>	<i>T</i>	<i>P</i>
Santee-Cooper, SC ^a	356	-0.06	0.9549
Choke Canyon Reservoir, TX ^b	269	5.74	<0.0001
Lake Corpus Christi, TX ^b	289	12.46	<0.0001
Lake Livingston, TX ^b	253	13.34	<0.0001

^aWhite and Lamprechet (1992)

^bTexas Department of Parks and Wildlife

Discussion

Diet

Blue catfish in Lake Norman would best be described as opportunistic and omnivorous feeders, similar to the results of the limited number of additional studies within the southeastern United States (Brown and Dendy 1961; Minckley 1962; Perry 1969; Graham 1999). The diets of Lake Norman blue catfish were dominated during most seasons by Asiatic clams, with fish and *Chara* also common items during certain seasons. A literature review demonstrated that blue catfish diets frequently contain large quantities of freshwater mussels (Richardson et. al 1970; Graham 1999), with researchers often finding blue catfish with distended stomachs full of clam shells (Graham 1999).

Blue catfish were also observed to be more piscivorous at larger sizes (Brown and Dendy 1961; Perry 1969; White 1980), which corresponds with my findings for Lake Norman where blue catfish >600 mm consumed the largest quantity by weight of fish of the three size classes studied. Smaller Lake Norman blue catfish fed primarily on Asiatic clams and insects, along with smaller quantities of fish. These findings were similar to those reported for blue catfish <400mm in Louisiana (Perry 1969), Alabama (Brown and Dendy 1961), and the Santee-Cooper system, South Carolina (White 1980).

Differences between blue catfish diets in the upper and lower regions of the lake were notable. In lower Lake Norman, large amounts of *Chara* were found in all size classes blue catfish during the winter, whereas fish were the most common food item in upper lake blue catfish. My literature review failed to find evidence of *Chara*, a filamentous algae, or other aquatic plants in blue catfish diets in any other rivers or reservoir systems. Though the importance or role of *Chara* in the diets of Lake Norman

blue catfish is unclear, the nutritional value of *Chara* is lower (415 cal/g; Cummins and Wuycheck 1971) than a diet composed primarily of fish (clupeids 1350 cal/g; Moore 1988).

An explanation for the differences in winter diet between the upper and lower lake is not clear. The upper lake is considered mesotrophic, or higher in nutrient concentrations than the lower lake, which is classified as oligotrophic (Siler et. al 1986). One could deduce that forage densities would be higher in the upper lake, since literature suggests that a strong relationship between total phosphorus concentrations and fishery productivity exists (Hanson and Leggett 1982). In northern natural lakes, standing stock was found to be highly correlated to total phosphorus concentrations in Smith Mountain Lake and other southern Appalachian reservoirs (Yurk and Ney 1989; Ney et al. 1990). In southeastern reservoirs, such as the Santee-Cooper system, phosphorus is considered a limiting nutrient (M. White, South Carolina Department of Natural Resources, personal communication). However, forage fish estimates from hydroacoustic surveys during December 2000 indicated that densities of forage fish in lower Lake Norman were slightly higher (2032 fish/ha) than the upper lake (1850 fish/ha) (David Coughlan, DPC, personal communication). And although densities can be variable between years, seasons, and even regions, the December 2000 hydroacoustic survey was within 6 weeks of the winter 2001 diet collection and should be considered a representative sample of forage fish availability during that period. Another possible explanation would be that a winter shad kill contributed to the large amounts of clupeids found within blue catfish stomachs within the upper region of Lake Norman during winter 2001. The waters of upper Lake Norman, especially upstream of the Marshall Steam Station, are not

influenced directly by the thermal discharges of either the Marshall Station, or McGuire Nuclear Station. During an extremely cold winter, when water temperature approaches or drops below freezing in the upper lake region, threadfin shad kills are a common occurrence. Such a scenario may have occurred and contributed to the large amounts of clupeids observed in the stomachs of blue catfish during the winter of 2001.

The other noticeable variable in the diet of Lake Norman blue catfish is Asiatic clams. Cummins and Wuycheck (1971) reported that clams contained approximately 550 cal/g, which is more than *Chara* (415 cal/g) but lower than clupeids (1350 cal/g). Though the diet data does not provide a conclusive reason for the large occurrences of non-fish in the diet of Lake Norman blue catfish, I speculate that high incidence of Asiatic clams throughout the majority of the year (except winter), as well as *Chara* in the lower lake region, is the result of limited fish forage availability of Lake Norman.

Growth

The lack of statistical differences between the 1999 and 2000 length and age frequencies did not allow for back-to-back year comparisons to delineate out defined year classes of blue catfish in Lake Norman. This left the data inconclusive on whether the low sample size for 500-525 mm fish was evidence of a year-class failure, a function of gear bias, or some difference in life-history strategies and movement for the year classes within that size range.

Lake Norman blue catfish did exhibit slower growth characteristics than other southeastern populations, specifically those from Texas. However, Lake Norman blue catfish were similar in body condition and growth to blue catfish from the Santee-Cooper system, a trophy blue catfish fishery in South Carolina. These differences between

population characteristics could be attributed to a variety of geographic and regionally specific factors but are most likely the result of differences in nutrient inputs and overall forage densities of each reservoir. As reported previously, a strong relationship between total phosphorus concentration and productivity of a fishery has been demonstrated (Hanson and Leggett 1982). High total phosphorus concentrations for both Choke Canyon Reservoir and Lake Corpus Christi, Texas {200.0 ug/L each (Barbara Hinojosa, City of Corpus Christi Water Utilities Laboratory, personal communication)} corresponded with the high blue catfish relative weights in those systems. In contrast Lake Norman's total phosphorus concentration (15.0 ug/L) and blue catfish relative weights were the lowest when compared to other reservoirs. Total phosphorus concentrations for each lake of the Santee-Cooper system, Lake Marion (47.5 ug/L) and Lake Moultrie (33.4 ug/L), were more than twice the concentrations for Lake Norman, and mean relative weight-to-length ratios were also higher than Lake Norman.

I would speculate that high incidence of Asiatic clams in the diets of Lake Norman blue catfish throughout the majority of the year (except winter), and especially in size classes <600 mm, is the primary reason for low initial relative weights early on in the life-history of Lake Norman blue catfish. Inferences can be made that the low initial body condition of blue catfish in Lake Norman is partially due to low total phosphorus concentrations in the reservoir. Low total phosphorus can act as a limiting factor on the amount of forage available, especially fish standing stock (Ney 1996). With limited amounts of forage fish available, Lake Norman blue catfish are foraging on higher quantities of Asiatic clams and *Chara*.

Despite limitations in forage fish abundance in the diet and nutrient inputs to the reservoir, the blue catfish population of Lake Norman, North Carolina has developed into a self-sustaining and popular fishery. Previously, only anecdotal biological or ecological information existed about the overall blue catfish population's structure or role within the reservoir's fish community. Furthermore, a literature review of previous blue catfish studies supports the conclusions of Graham (1999) that there is a shortage of technical reports discussing the overall life history and biology of blue catfish populations throughout the United States. My study of the diet composition and growth characteristics of Lake Norman blue catfish provides a baseline of life-history data needed for fishery managers to develop future management plans for blue catfish. Management implications will be discussed in Chapter 4.

Further research should focus on whether the results reported here are consistent among years. Currently, catfishes (Ictaluridae) are receiving increased attention from anglers and biologists throughout the United States (Michaletz and Dillard 1999; Arterburn et al. 2002). In North Carolina a multi-reservoir catch-and-release catfish tournament series has developed in recent years, and includes seven stops at Lake Norman between January and August. Local catfish anglers have created the Carolinas Catfish Club to increase public support for catfish management throughout North Carolina. In view of this increased attention to the biology and management of catfishes, especially within the North Carolina region, management strategies for catfish in general, and blue catfish in Lake Norman specifically, should be examined.

Chapter II

Movement and habitat use of blue catfish in Lake Norman, North Carolina

Introduction

Knowledge of seasonal fish movement and habitat use are key components to management plans being developed by fisheries managers. By defining the migration patterns of individual populations and the habitat they utilize, fisheries managers can develop suitable sampling regimes to perform additional stock assessments (Hubert 1999; Millspough and Marzluff 2001). Literature review suggests that blue catfish *Ictalurus furcatus* are the most migratory of all ictalurid catfishes (Lagler 1961) capable of long distance seasonal migrations (Graham 1999; Pugh and Schramm 1999). But the overall knowledge of seasonal or yearly movements or home ranges in a reservoir system, as well as blue catfish habitat preferences, are limited (Ramsey and Graham 1991).

Movement

Blue catfish are considered more mobile than flathead catfish *Pylodictis olivaris* (Pugh and Schramm 1999) but similar in movement and habitat use to channel catfish *Ictalurus punctatus* (Ramsey and Graham 1991; Graham 1999). Flathead catfish were found to be generally sedentary with small home ranges (Hart 1974; Jackson 1999). Channel catfish were found to be more mobile, with recent tagging and telemetry studies documenting movements from winter areas to spawning areas and then to summer feeding areas (Hubert 1999). Pellett et al. (1998) observed channel catfish in the Wisconsin River occupying small summer home ranges, migrating downstream into the Mississippi River during the fall, back upstream to spawn in the Wisconsin River in the

spring, and then returning to the same small summer home range used the previous summer. Similar movements for blue catfish have been reported in reservoirs; migrations upstream to tributaries and headwater rivers for spawning and downstream to the reservoirs to overwinter (Pflieger 1997; Graham 1999).

Habitat use

Blue catfish prefer open waters of large reservoirs and main channels, as well as flowing rivers, where water is normally turbid and substrate varies from sand-gravel to silt-mud (Burr and Warren 1986; Graham 1999). Blue catfish breed in sheltered nests when water temperatures reach 21-24 °C (Jordan and Evermann 1920; Harlan and Speaker 1956). Both sexes share in the brooding (Jones 1965), with about 2,000 eggs laid per pound of female (Pelzman 1971). The specific habitat preferences of blue catfish are relatively unknown (Lagler 1961), but are believed to be similar to those of channel catfish (Pflieger 1997; Hubert 1999). The maximum water temperature at which channel catfish can survive for long periods is 37°C (Moss and Scott 1961), with a minimum requirement of 1 mg/L of dissolved oxygen at 25-35° to survive and greater than 4 mg/L to spawn. Channel catfish are considered habitat generalists (Layher and Maughan 1985) being found in a variety of water velocities and structure (Hubert 1999). There is evidence of differential habitat use by adult channel catfish in rivers as a function of fish size. Large channel catfish (>500 mm TL) utilized faster water areas where forage fish were more abundant, while smaller channel catfish (<500 mm TL) were in areas of slower water velocity where aquatic insects were abundant (Macdonald 1990; Hubert 1999). Segregation in reservoirs of habitat use by channel catfish of different size classes was also observed (Klaasen and Marzolf 1971). Most studies of fish movement and

habitat use within a larger water body (i.e. reservoirs) use telemetry, but this approach is problematic when applied to catfish.

Telemetry studies

Transintestinal transmitter expulsion has been reported as a potential obstacle to telemetry studies of channel catfish (Marty and Summerfelt 1986; 1988; Siegwarth and Pitlo 1999). Summerfelt and Mosier (1984) offered evidence that internally implanted transmitters can be lost by absorption into the intestinal tract and expulsion through the anus. Other losses of internal transmitters were attributed to ruptures of the original implant incision, thereby allowing the transmitters to pass through the original point of entry. Siegwarth and Pitlo (1999) developed a modified surgical procedure for implanting transmitters and attaching them to the pectoral girdle. Though this modified procedure resulted in higher retention rates of transmitters, a mortality rate of 32% and a missing rate of 29% were noted. It was undetermined if the mortality rate was a result of blocking the natural expulsion process of foreign objects by channel catfish (Siegwarth and Pitlo 1999). It is also unknown whether the reported problems with transmitter expulsion in channel catfish would also occur in blue catfish.

Studies of external transmitters on other fish species have shown no significant differences in survival or growth between fish with and without transmitters (Ross and McCormick 1981; Herke and Moring 1999). In addition, external transmitters record the movement into differing water temperatures more quickly than internal transmitters (Winter 1996). Concerns against using external transmitters include the increased chance of entanglement and possible interference with swimming behavior and speed (Winter 1996; Mellas and Haynes 1985).

Lake Norman, North Carolina

Currently, there is a popular fishery for blue catfish in Lake Norman, including recreational, commercial, and tournament-sport anglers. However, the movement, home range, and habitat use by blue catfish in Lake Norman are unknown. To improve the overall knowledge of blue catfish ecology within a large reservoir, I utilized radio telemetry to: (1) determine the seasonal movement and home range of blue catfish in Lake Norman; and (2) to determine seasonal habitat use by blue catfish. Due to the well documented methods for expulsion of internal radio transmitters by catfish, I chose to use externally attached radio transmitters for this study and examine overall survival rates for this method.

Methods

Radio-Telemetry

Laboratory Study

During November 2000, I collected sixteen blue catfish (500-900 mm) by hook-and-line sampling techniques. Blue catfish were transported to the Virginia Tech Aquaculture Center in Blacksburg, VA, where they were divided into two groups of eight and placed in separated 540-gallon tanks (6 ft. x 30 in.) with a recirculating tube sump and trickling biofilter. A variety of minnows, sunfish, and shad were used to feed all sixteen blue catfish during the duration of the lab study.

On December 1, 2000, I attached a waterproof hysol-coated dummy radio transmitter (Advanced Telemetry Systems, Isanti, MN) externally to the dorsal musculature of eight lab study blue catfish (four from each tank). Dummy transmitters were 4.3 cm long with two 0.9-mm attachment wires set 60 mm apart, a 1.5-mm x 432-

cm trailing external antenna, and weighed 26 grams. A 6.4-mm neoprene pad was attached to the attachment side of dummy transmitter to reduce abrasions to the dorsal surface of each blue catfish. I anaesthetized blue catfish using 350 ppm sodium bicarbonate (Booke et al. 1978; Post 1979; Stefan 1992; Prince et al. 1995; Peake 1998) before recording individual length (m, TL) and weight (g).

My procedure for attaching the external radio transmitters to blue catfish was as follows:

1. I inserted a 16-gauge non-coring-point spinal needle through the dorsal musculature perpendicular to the lateral line and posterior to the dorsal spine. I then passed the forward attachment wire through the needle and removed the needle, leaving only the forward attachment wire running through the dorsal musculature.
2. I inserted a second needle 60 mm anterior to the original needle insertion and repeated the preceding step for the rear attachment wire.
3. I secured each transmitter with two 6.25-mm plastic discs attached to each wire on the opposite side of the body, and placed a 6.4-mm neoprene between the plastic discs and blue catfish body to reduce abrasions.

After completing the transmitter attachment, I placed the blue catfish into a holding tank until recovery from the anesthetic was observed, and then released the blue catfish back into their respective holding tank. The maximum time to complete each individual transmitter attachment, from introducing blue catfish to anesthetic to releasing back into their respective tanks after recovery, was 20 minutes (maximum time to attach each external transmitter was 5 minutes). Blue catfish, with their respective attached

dummy transmitters, was observed for four months in water temperatures of 10-16° C, after which time I sacrificed and individually examined fish for dorsal musculature tissue damage due to attachment wire abrasion.

Field Study

During February and March 2001, I collected twenty-nine blue catfish >2000-grams from throughout Lake Norman, using hook and line sampling techniques, to outfit with external radio transmitters. Each transmitter was identical in dimensions to the dummy transmitters used in the lab test, with the following added features:

1. Saft AA 3.6 lithium battery
2. magnetic ON/OFF switch
3. microprocessor program controlled
 - a. duty cycle (2 weeks on and 2 weeks off, repeat)
 - b. 4° - 40° C temperature sensor with pulse indicator
 - c. 24-hour mortality switch with a duty cycle override.

An individual temperature-versus-pulse-rate calibration curve for each transmitter was developed using calibration guidelines provided by Advanced Telemetry Systems (Isanti, MN). Individual calibration curves provided specific references to compare timed pulse rates at known intervals so as to determine the water temperature at depth for individually transmitted blue catfish.

I brought the captured blue catfish to a centralized processing station on Lake Norman, measured them for length and weight, and then attached a radio-transmitter with an individual specific 40.071 – 40.841 MHz radio frequency. Each blue catfish was returned to their individual collection sites and released (Figure 2.1).

LAKE NORMAN, NORTH CAROLINA

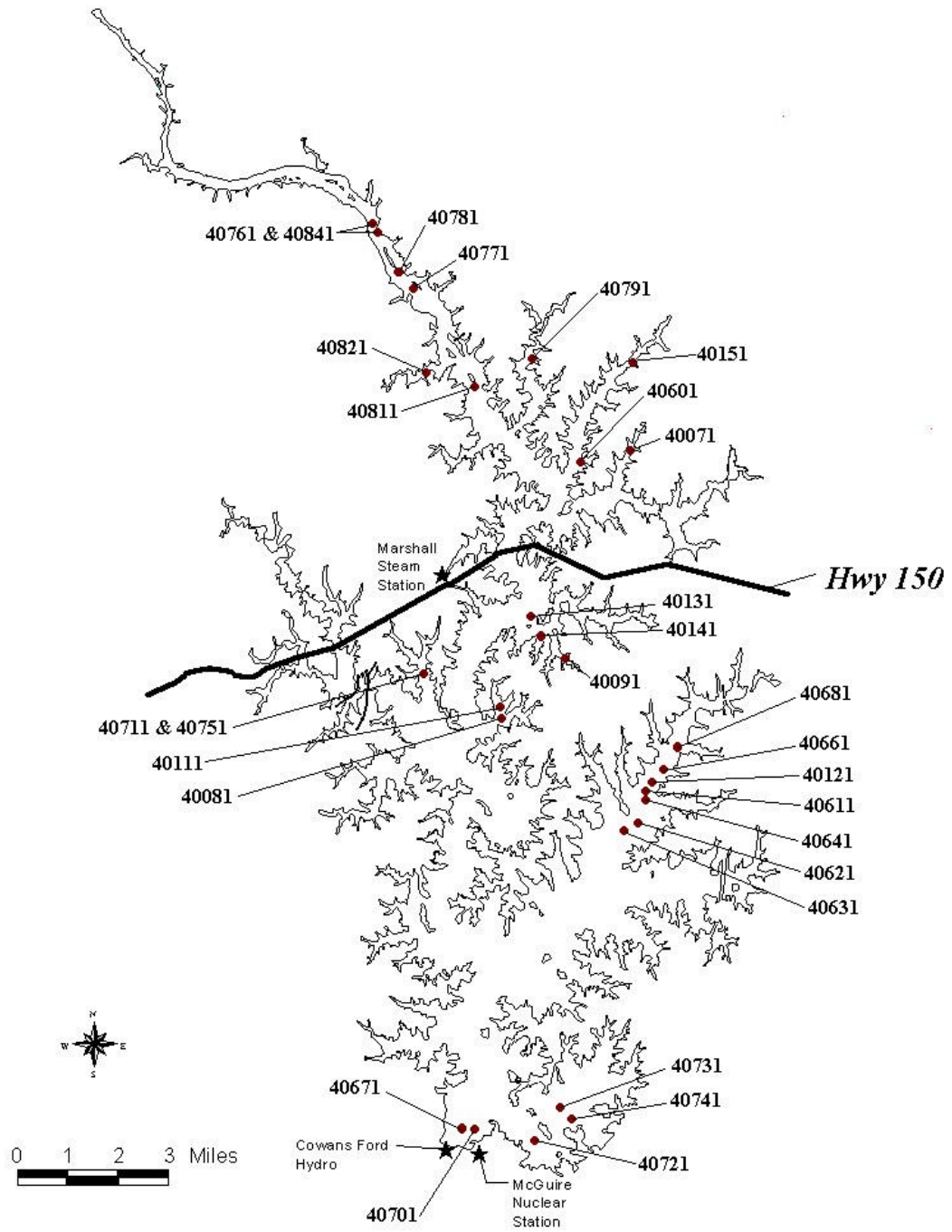


Figure 2.1: Capture/release locations for blue catfish with external radio-transmitters in Lake Norman, North Carolina.

Radio telemetry

Beginning in April 2001, and continuing until March 2002, I located transmittered Lake Norman blue catfish with a boat-mounted directional Yagi antenna (Advanced Telemetry Systems, Isanti, MN) with a ¼-mile range. I used a Global Positioning System (GPS) receiver (Globalmap 100, Lowrance Electronics Inc., Tulsa, Oklahoma) to record the latitudinal and longitudinal locations for each blue catfish. I used a stopwatch to record the transmitter pulse frequency to determine water temperature-at-depth at each individual's locations. I attempted to locate each fish at least once during each two-week duty-cycle.

Movement

I used a Geographic Information System (GIS) program (ArcView GIS version 3.2, Environmental Systems Research Institute, Inc., Redlands, California) to analyze movement patterns, determine distance moved between locations by date, and the distance from the nearest shoreline. I calculated individual seasonal home ranges using the kernel home range method (Silverman 1986; Worton 1989) of the animal movement program extension (Hooge and Eichenlaub 1997) only if the location and status for each individual blue catfish was known throughout a season. Kernel methods estimate the area containing a specified percentage of the utilization distribution volume of an animal's home range, the boundary of which is estimated from a set of locations that are assumed to be independent of each other. Kernel home range incorporates methods with several desirable qualities, including: (1) they are nonparametric and more adaptable to estimating densities of variable shapes; (2) they produce a density direct estimate; and (3) they are not influenced by grid size or placement (Silverman 1986). Least-squares cross

validations (Silverman 1986) were utilized at the 95% confidence interval to determine the fixed home range utilization distribution (Worton 1989) for seasonal kernel home range for blue catfish that survived an entire season. Analysis of variance (ANOVA) was used to determine significant differences ($\alpha=0.05$) in blue catfish movements and home ranges between seasons (winter, spring, summer, fall).

Habitat

I collected water column temperature and dissolved oxygen (DO) profiles at least once during each two-week duty cycle using a HydrolabTM Surveyor 3, except during the months of October through December 2001 when the unit was unavailable. During October through December 2001, monthly lake-profile data provided by Duke Power Company was utilized. Depth (m) of each catfish, and DO (mg/L) at depth, were estimated from the temperature sensitive pulse rates of each transmitter as compared to the current temperature depth profile. ANOVA was used to determine significant differences ($\alpha=0.05$) in the temperature, dissolved oxygen and depth preferences between seasons (winter, spring, summer, fall).

Results

External radio-transmitters

Laboratory study

After 120 days at the Virginia Tech Aquaculture Center, seven (87%) of the blue catfish with dummy transmitters were alive and feeding, with one recorded mortality after 58 days (Table 2.1). Observational necropsies of each laboratory blue catfish did not indicate any internal erosion of muscle tissue by the transmitter attachment wires, and wire exit locations exhibited only minor tissue damage. A reduction in overall body

condition was observed for the one recorded mortality fish, and cause of death was attributed to malnutrition due to the fish failing to feed.

Field Study

External radio-transmitters were successfully attached to 29 blue catfish throughout Lake Norman during February and March 2001. After 120 days, 48% of the blue catfish released in Lake Norman were recorded as mortalities based on transmitter response (mortality signal over-riding the normal duty cycle) and lack of observable movements (Table 2.1). Lake Norman water temperatures were 6-12° C during the release period rising up to 34° C during the summer. After one year, five (17%) of the original 29 blue catfish with external transmitters released into Lake Norman were still alive, four (14%) were missing, and the remainder (69%) presumed dead.

Radio-telemetry

Movement

Blue catfish movements were significantly different between seasons ($df=3$; $F=13.02$; $P<0.0001$). The largest mean minimum distance traveled (minimum distances traveled by each individual per season were combined and a mean seasonal distance reported) by blue catfish in Lake Norman was during the spring (5225 m) while the shortest was during the winter (763 m) (Table 2.2). Blue catfish distances from the shoreline were significantly different between seasons ($df=3$; $F=24.65$; $P<0.0001$). Blue catfish mean distances to the shoreline were closest during the spring (76 m) and furthest during the fall (180 m) (Table 2.2).

Table 2.1: Summary information for blue catfish with external radio-transmitters monitored at the Virginia Tech Aquaculture Center and in Lake Norman, North Carolina as of March 7 2002.

Fish ID	Capture/Release Date	Length (mm)	Weight (g)	Status	
				D=dead A=alive M=missing	Days observed
lab001	12/1/00	580	2144	A*	120
lab002	12/1/00	587	2303	A*	120
lab003	12/1/00	645	2672	D	58
lab004	12/1/00	665	3010	A*	120
lab005	12/1/00	573	1795	A*	120
lab006	12/1/00	872	7892	A*	120
lab007	12/1/00	554	1475	A*	120
lab008	12/1/00	650	3085	A*	120
40.071	2/17/01	930	11567	D	223
40.091	2/17/01	643	2725	D	275
40.121	2/24/01	835	7310	A	376
40.131	2/24/01	700	4002	M	110
40.141	2/24/01	660	2778	A	376
40.151	2/24/01	690	3838	D	158
40.601	2/24/01	800	8210	D	81
40.611	2/24/01	698	3724	A	376
40.621	2/24/01	748	5006	D	81
40.631	2/24/01	712	3859	A	376
40.641	2/24/01	825	8670	D	76
40.661	2/24/01	698	3470	A	376
40.681	2/24/01	630	2370	M	157
40.721	3/22/01	810	7370	D	217
40.731	3/22/01	930	12160	D	50
40.741	3/22/01	875	10150	M	260
40.711	3/23/01	798	5550	D	83
40.751	3/23/01	1102	18570	D	84
40.761	3/23/01	766	5159	M	319
40.771	3/23/01	975	11400	D	49
40.781	3/23/01	910	11460	D	111
40.791	3/23/01	762	4960	D	288
40.811	3/23/01	829	6507	D	76
40.821	3/23/01	791	6030	D	54
40.841	3/23/01	910	10498	D	49
40.081	3/24/01	789	5963	D	81
40.111	3/24/01	770	5124	D	83
40.671	3/30/01	731	3926	D	42
40.701	3/30/01	812	5994	D	69

*Fish sacrificed at end of laboratory study

Table 2.2: Seasonal movement comparisons of minimum mean distances moved per season, distance from shoreline, and 95% seasonal home range for blue catfish from Lake Norman, North Carolina, including the high and low distributions for home ranges.

Movement	Minimum distance moved (m)			Distance from shoreline (m)			95% Home range (hectares)			
	N ¹	Mean	SE ²	N	Mean	SE	N	Mean	SE	Distribution
Winter	57	763	163	48	171	26	6	154	73	13-291
Spring	51	5225	1202	66	76	8	-	-	-	-
Summer	119	981	229	269	123	5	12	323	153	7-1854
Fall	67	1906	442	106	180	17	9	1670	534	7-4391

¹ Number of individual samples per season.

² Standard error.

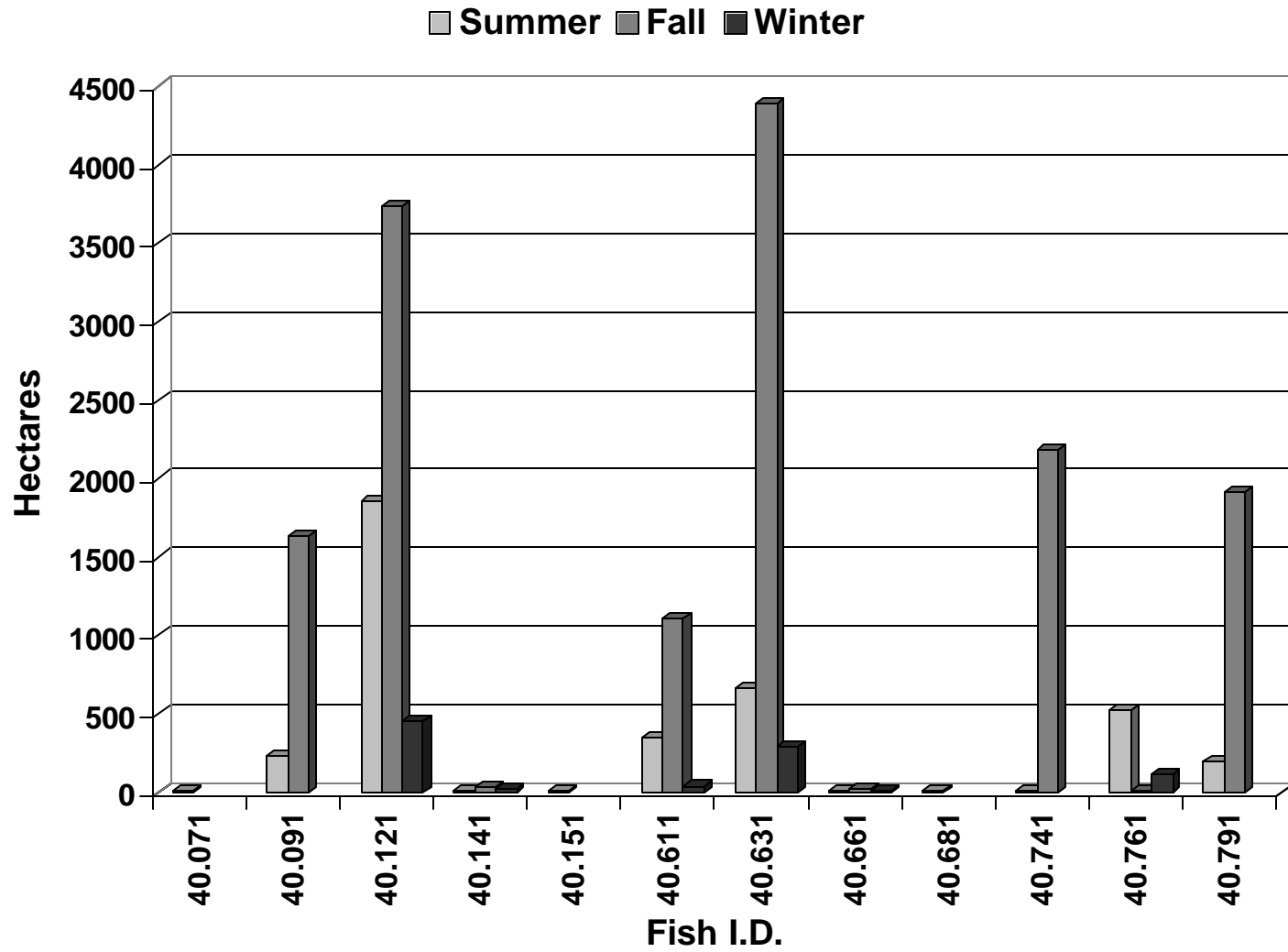


Figure 2.2: Individual blue catfish mean seasonal home ranges observed in Lake Norman, North Carolina.

Blue catfish home ranges were significantly different between seasons ($df=3$; $F=10.30$; $P=0.0030$). The winter home ranges for blue catfish were the smallest (mean = 154 ha), ranging from 13-to-291 ha (Table 2.2). Fall home ranges were the largest (mean=1670), ranging from 7-to-4391 ha. Seasonal home ranges were extremely variable between individuals (Figure 2.2), with some fish exhibiting large seasonal home ranges across all seasons {i.e. Fish 40.121: summer (1854 ha); fall (3742 ha); and winter (452 ha)}, while others exhibiting very small home ranges {i.e. Fish 40.661: summer (14 ha); fall (21 ha); and winter (13 ha)}. Fish 40.631 exhibited the largest observed seasonal home range of 4391 ha and fish 40.761 exhibited the smallest of 6.5 ha, both during the fall.

Habitat

Water temperatures selected by Lake Norman blue catfish were significantly different by season ($df=3$; $F=1794.94$; $P<0.0001$). Temperature selection was consistent with local conditions, the lowest selected mean temperatures occurred during the winter (mean = 12.0° C) and the highest during the summer (26.5° C) (Table 2.3). Blue catfish were found predominantly in the higher temperature ranges available in Lake Norman from March to August, but in the lower range available from October to February (Figure 2.3).

D.O. amounts at each location per season were also significantly different ($df=3$; $F=36.93$; $P<0.0001$). Mean D.O. amounts for winter and spring were the highest (9.0 mg/L), while summer and fall were the lowest (7.1 and 7.2 mg/L) (Table 2.3). Blue catfish mean depth selection per season were also significantly different ($df=3$; $F=18.08$; $P<0.0001$). Blue catfish were predominantly found in the higher concentrations of D.O.

Table 2.3: Seasonal microhabitat comparisons of mean water temperature, dissolved oxygen, and depth for blue catfish from Lake Norman, North Carolina.

Habitat	Water Temperature (°C)			Dissolved Oxygen (mg/L)			Depth (m)		
	N ¹	Mean	SE ²	N	Mean	S.E.	N	Mean	S.E.
Winter	48	12.0	0.4	14	9.0	0.4	13	13.5	2.5
Spring	64	19.0	0.6	40	9.0	0.2	40	5.4	0.9
Summer	126	26.5	0.2	100	7.1	0.1	106	5.3	0.4
Fall	72	18.9	0.4	26	7.2	0.2	23	9.0	1.0

¹ Number of individual samples per season.

² Standard error.

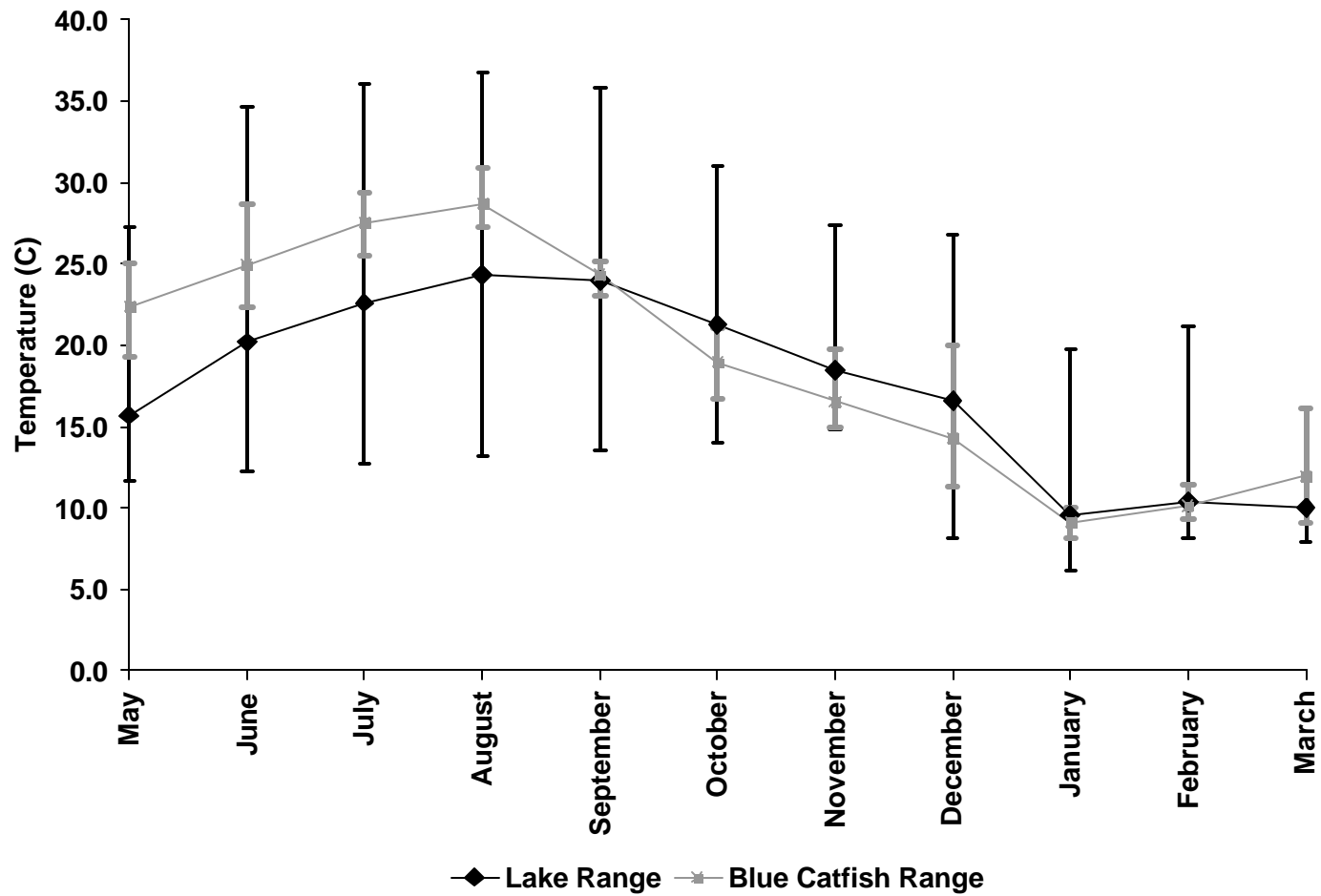


Figure 2.3: Range of temperatures available within Lake Norman per month overlaid by the range of temperatures blue catfish were observed inhabiting.

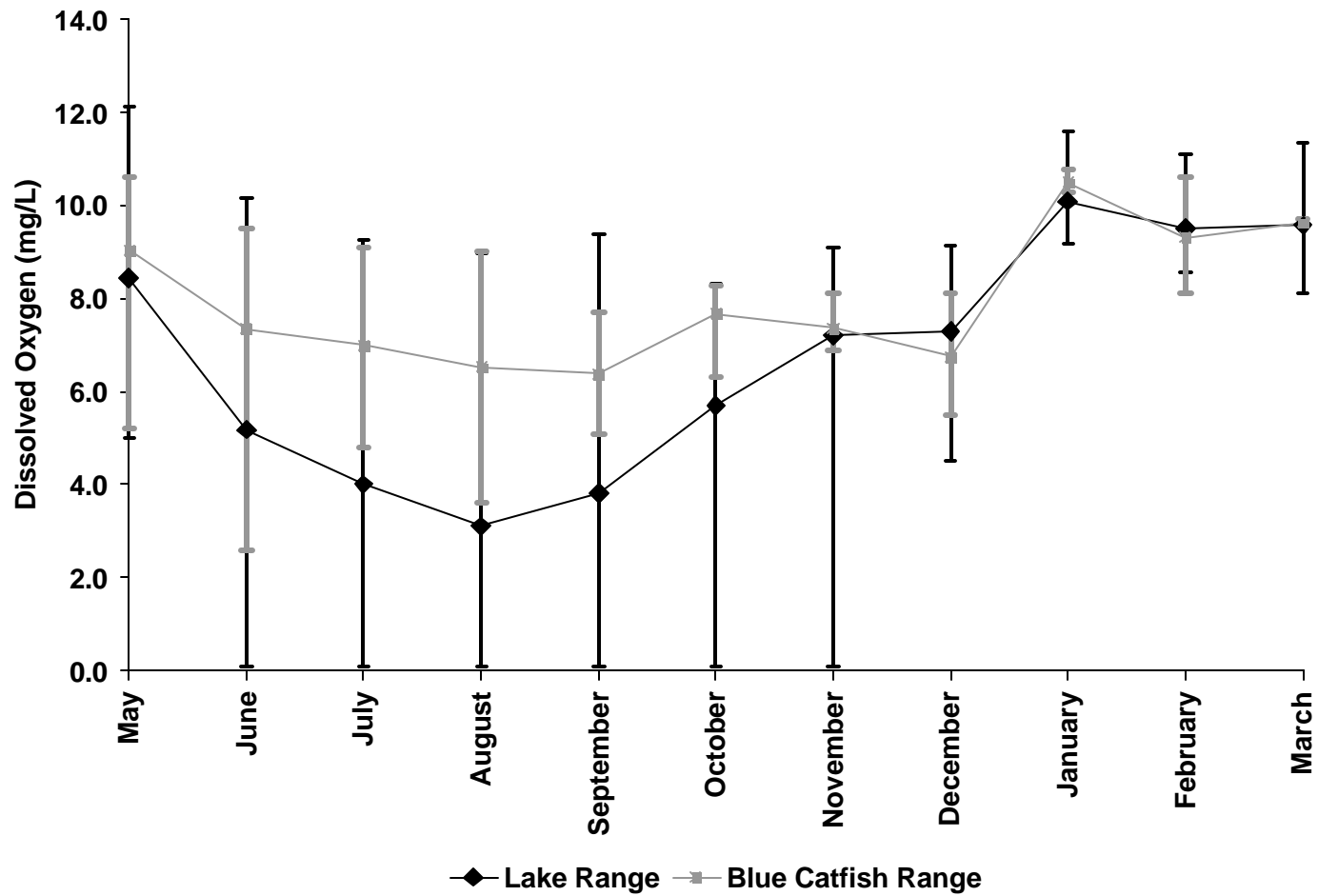


Figure 2.4: Range of D.O. amounts available within Lake Norman per month overlaid by the range of D.O. blue catfish were observed inhabiting.

throughout the lake year-round, and were rarely located in the areas of low D.O. concentrations observed from June through November in Lake Norman (Figure 2.4).

Mean depths for blue catfish were shallower during the spring and summer (5.4 and 5.3 m) and deeper during the winter (13.5 m) (Table 2.3). Ranges of depths were greater in the months of May, June, and February but smaller during November, January, and December (Figure 2.5).

Spawning movements and habitat

During May 2001 50% of the Lake Norman blue catfish in this study were found congregated in a 5.6-km reach of the Catawba River in the upper Lake Norman region (Figure 2.6). Blue catfish were located in mean water temperatures of 22.0° C, DO levels of 9.5 mg/L, and at mean depths of 5.0 m during May, in habitat similar to spawning site descriptions described in the literature (Jordan and Evermann 1920; Harlan and Speaker 1956; Jenkins and Burkhead 1993). Extreme movements were observed for four blue catfish (40.121, 40.641, 40.701, and 40.721), which were captured and released in the lower region of the lake and traveled a minimum of 34.5 km to upper Lake Norman between April 19 and May 10 2001. Additional examples of large seasonal movements were exhibited by blue catfish 40.121 (Figure 2.6). After traveling to the upper Lake Norman region in May, blue catfish 40.121 remained in the upper lake region until October 2001, and then returned to its original capture-release site in lower Lake Norman to overwinter. However, the remaining 50% did not exhibit large movements during the spring and remained in their specific regions of the reservoir throughout the remainder of the study. One group of catfish remained in the lower lake region, and another in the

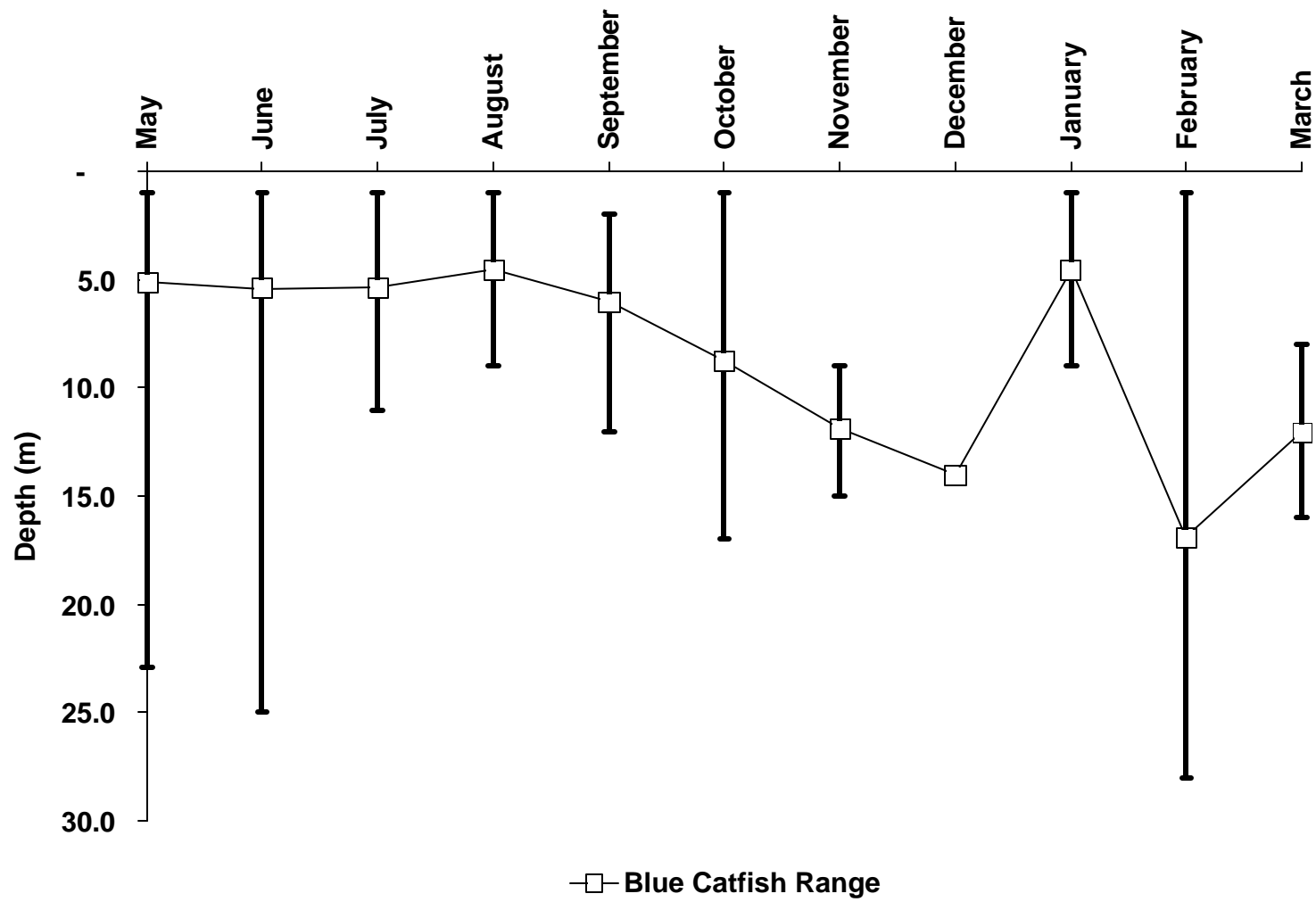


Figure 2.5: Range of depths blue catfish were observed inhabiting in Lake Norman per month.

LAKE NORMAN, NORTH CAROLINA

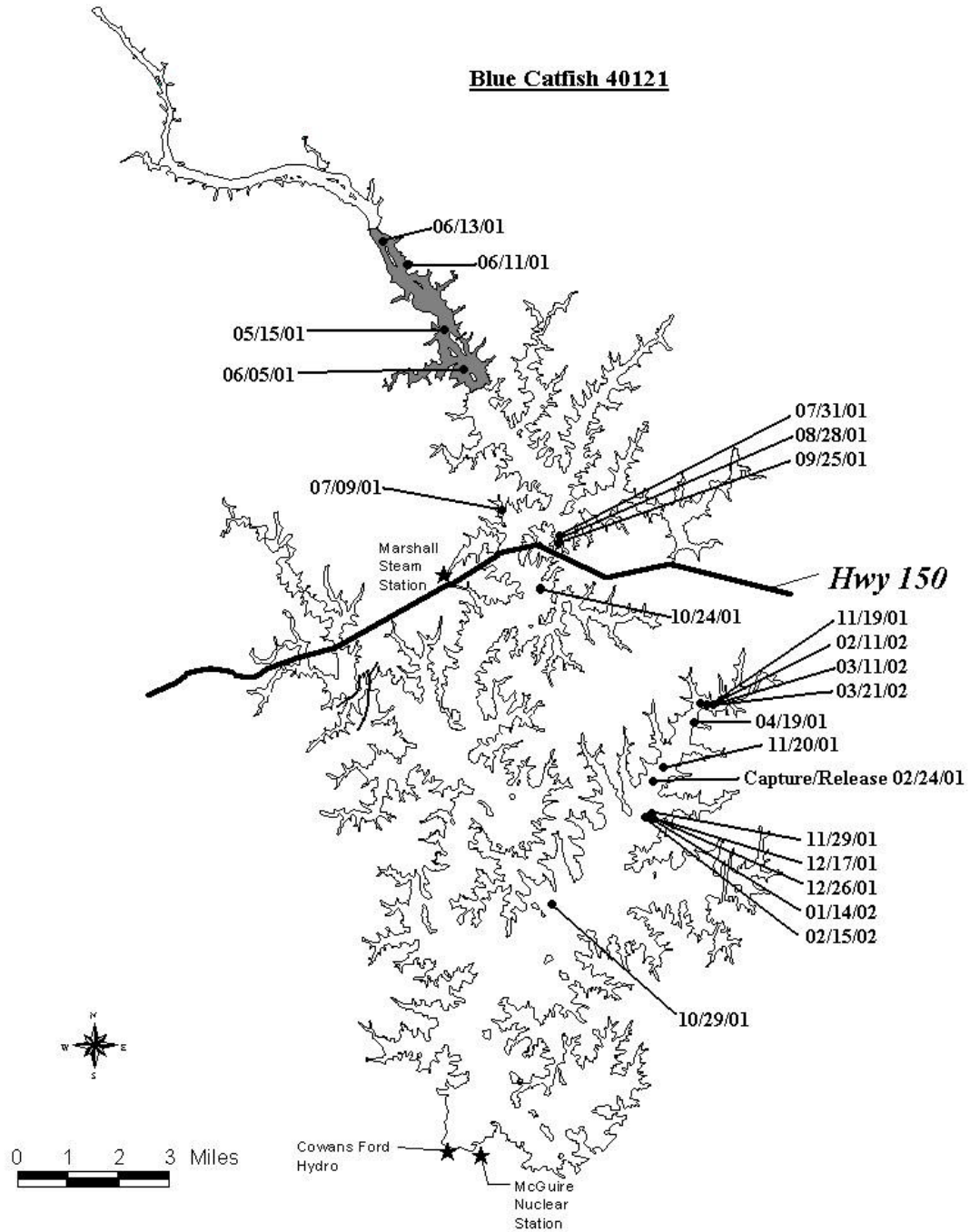


Figure 2.6: Movements of blue catfish 40.121 in Lake Norman, North Carolina over a one-year period from February 2001 to March 2002. During May 2001 50% of the Lake Norman blue catfish in this study were found congregated in a 5.6-km reach of the Catawba River in the upper Lake Norman region (shaded in gray).

upper lake region's riverine section, year-round. It was not apparent if the non-migrating blue catfish, especially those in the lower lake region, were utilizing other areas within their home ranges as reservoir spawning sites in lieu of moving into the riverine portions of Lake Norman to spawn.

Discussion

Previous studies have shown that blue catfish are extremely mobile and capable of making long distance migrations during the spring and fall seasons (Lagler 1961; Ramsey and Graham 1991; Graham 1999). Although radio telemetry studies of blue catfish populations are limited, most researchers suggest that blue catfish are similar in their movements and habitat preferences to channel catfish (Ramsey and Graham 1991; Pflieger 1997; Graham 1999; Hubert 1999). Recent studies have noted channel catfish making purposeful movements to spawning locations, to seek out forage, avoid competition, and establish specific home ranges (Van Eeckhout 1974; Hubert 1999; Wendel and Kelsch 1999).

My study indicated that the movements and home ranges of blue catfish in Lake Norman are extremely varied. However, individual blue catfish did establish specific seasonal home ranges and exhibited site fidelity. Some blue catfish in lower Lake Norman moved long distances (>34 km) during the spring to the upper lake's riverine section. These same blue catfish then remained in the region for the summer, and eventually returned to the lower lake during fall to their original winter capture-and-release sites. Other Lake Norman blue catfish, both in the upper and lower regions of the lake, did not exhibit long-range movements or large home ranges, but still exhibited site fidelity to a particular region of the lake year-round. In many reservoirs, channel catfish

migrate upstream into headwater or tributary waters to spawn and return to the reservoirs during the summer and over the winter (Wahtola 1969; Elrod 1974; Van Eeckhout 1974; Hubert and O'Shea 1991). Evidence of site fidelity by channel catfish in reservoirs has been observed (Houser 1960; Duncan and Meyers 1978), though Hesse et al. (1982) suggests that some random individual movements may correspond with attempts to find more abundance food resources and avoid competition. Differences in individual home range and movement could be explained by a number of factors, including food and habitat availability.

Food availability is one possible component to the movement strategies I observed of individual blue catfish within Lake Norman. In Chapter One, I discussed the seasonal food habits of blue catfish in Lake Norman and the possibility that forage may be a limiting factor to overall blue catfish growth within the lake. Through communication with tournament catfish anglers, I determined that sites where I observed limited seasonal home ranges and movements were often over areas of known beds of Asiatic clams *Corbicula fluminea* or stoneworts *Chara spp.*, both of which are predominant items in the overall diets of Lake Norman blue catfish. Likewise, areas where I saw frequent movements and larger home ranges for some individual blue catfish were also considered areas of larger concentrations of forage fish by local anglers, who often reported catching blue catfish intermixed with striped bass *Morone saxatilis* foraging on schools of clupeids. Graham (1999) noted similar observations in Oklahoma and Missouri of blue catfish suspending below schools of clupeids and foraging on wounded or dead shad.

Another component of blue catfish movement involves habitat availability and use. Blue catfish breed in sheltered nests when water temperatures reach 21-24°C, and in areas where dissolved oxygen is >4 mg/L, anytime between April and June depending on geographic location (Jordan and Evermann 1920; Harlan and Speaker 1956; Jenkins and Burkhead 1994). Both sexes share in brooding and guarding of spawning sites.

Correspondingly long distance movements are often observed during the spring months as blue catfish and channel catfish migrate to suitable spawning habitat (Graham 1999; Hubert 1999). During May 2001, 14 blue catfish (50%) from my study were located in a 5.6-km riverine section of upper Lake Norman. Mean water temperatures in this section was 22° C, dissolved oxygen 9 mg/L, and blue catfish were estimated to be at depths averaging 5 meters. Four blue catfish in this study migrated 34.5 km during a three-week period (April 19 – May 10 2001) from lower Lake Norman to this upper riverine section. Though direct evidence was not available, these movements suggest that this riverine area of Lake Norman is a primary spawning site for Lake Norman blue catfish. In addition, I speculate that the lack of movement by the remainder of my study fish to this spawning site (the majority of these fish were located in the lower reservoir region and exhibiting much smaller movements) indicates that the possibility of separate unidentified spawning areas exist within the lower reservoir region.

Seasonal mean water temperatures and dissolved oxygen amounts at each blue catfish location were well within the literature's reported natural habitat regime for blue catfish. Blue catfish habitat requirements are considered similar to those for channel catfish, where channel catfish can survive for long periods at temperatures up to 35° C and at DO levels as low as 1 mg/L (Moss and Scott 1961; Dunham et al. 1983). Through

numerous individual observations of temperature and DO profiles of Lake Norman throughout the year, and corresponding examinations of monthly profiles provided by DPC, it was apparent that habitat is not a limiting factor to blue catfish movements throughout Lake Norman.

Mean seasonal depths and distances to shoreline of Lake Norman blue catfish corresponded with reported literature values, thus supporting the contention that blue catfish prefer the open waters of reservoirs (Fisher et al. 1999; Graham 1999). Fisher et al. (1999) reported seasonal habitat segregation between blue and channel catfish in a small Missouri impoundment (<100 ha), with blue catfish occupying deeper (>4.5 m) and more-open waters seasonally, while channel catfish were shallower (<4.5 m) and more associated with shoreline brush and underwater snags. Lake Norman's blue catfish were observed at depths >5.0 m year-round, and >120 m from the shoreline during all seasons except spring (mean distance from shoreline = 76 m). Lake Norman's 837 km of shoreline, including numerous coves and creek channels, combined with a mean depth of 10.2 m and large areas of open water offers a large variety of habitats for blue catfish to occupy. Consequently, mean seasonal depths and distances to shoreline of blue catfish in Lake Norman are more likely a function of habitat selection rather than a lake induced habitat limitation.

Previously (Chapter 1), I reported finding limited amounts of forage fish in the diets of blue catfish within Lake Norman. I speculate that the variety of home range and movement patterns observed of blue catfish correlated to the forage limitations of Lake Norman, excluding blue catfish spawning movements.

Any inferences I make from this study have to meet the normal assumptions for all radio telemetry studies that the attached transmitters do not affect the behavior of the fish and that the number of fish tracked is sufficiently large to be representative of the behavior of the general population (Diana 1995). My telemetry study did suffer from a high initial rate of blue catfish mortalities in Lake Norman, resulting in a large reduction in individuals and observations on which to base my results. Only 45% of the original 29 blue catfish with attached external radio transmitters survived the first 120 days in Lake Norman, whereas 87% of 8 catfish survived the first 120 days at the Virginia Tech Aquaculture Center. Attempts by scuba divers to locate transmitters (and fish) sending mortality signals were unsuccessful due to low visibility, so I have no direct evidence of the causes of mortality. Stress from temperature variations or bacteria may have contributed to mortalities of tagged catfish. Blue catfish are currently unpopular with the aquaculture industry due to beliefs that blue catfish are more easily stressed than channel or flathead catfish and more susceptible to bacterial diseases after handling (Graham 1999). Water temperatures at the Virginia Tech Aquaculture Center only ranged between 10-and-16°C during the 120-day period, whereas water temperatures were 6-12°C at release to as high as 34°C at the end of the 120-day period in Lake Norman. In addition, the water used at the Virginia Tech Aquaculture Center is managed through an array of bio-filtration units that reduces the likelihood of disease or infection, unlike the natural waters of Lake Norman. A combination of physiological stress by the attachment of an external transmitter and an increase in water temperatures during the initial study period may have provided favorable conditions for bacterial infection of the attachment wire insertion points, possibly contributing to the high initial mortality of blue catfish in my

study. Other contributing factors may have included fishing mortality (with transmitters removed from captured blue catfish and thrown overboard) or transmitter programming failures, but I have no evidence to support either possibility.

Despite the initial high mortality rates reported, the present radio telemetry study of blue catfish in Lake Norman provided some useful information. I was able to identify a likely blue catfish spawning area in the upper region of the lake, present observations of variable seasonal movements and home ranges, and conclude that habitat availability is not a probable limiting factor to the overall life history of blue catfish in Lake Norman. Furthermore, the data suggests that blue catfish may have segregated populations within Lake Norman, within one group traversing from the lower region to the upper region of the lake during the year, a second group remaining in the upper region year-round, and a third group remaining in the lower region year-round.

Chapter III

Genetic analysis of introduced blue catfish populations

Introduction

Native to the Mississippi drainage of the United States, blue catfish *Ictalurus furcatus* Lesueur have been introduced to North America's Atlantic and Pacific slope basins by various state and federal agencies and anglers during the past 40 years (Graham 1999). Reasons for blue catfish introductions have included increasing sportfish and trophy species diversity for anglers and providing a predator to control shad (Clupeidae) and Asiatic clam *Corbicula fluminea* populations (Graham 1999, Richardson et al. 1970). Catfishes (Ictaluridae) are receiving increased attention from anglers and fisheries biologists (Michaletz and Dillard 1999; Arterburn et al. 2002); however, there are few technical reports discussing the life history and biology of blue catfish (Graham 1999). Genetic studies of introduced blue catfish populations are lacking, leaving fisheries managers without knowledge of the genetic composition of introduced populations, often established by single stockings more than three decades ago.

Blue catfish in Lake Norman, NC and the Santee-Cooper system, SC have become valuable fisheries for recreational anglers and commercial fishermen in the southeastern United States. The purpose of this study was to determine the level of genetic variability and to assess whether the blue catfish populations at Lake Norman and Santee-Cooper have differentiated from their Mississippi River drainage source stocks.

Study Sites

The largest man-made body of freshwater in North Carolina, Lake Norman was formed in 1963 when Cowans Ford Dam was completed and dammed the Catawba River.

Lake Norman has a surface area of 13,159 ha and 837 km of shoreline, with a full pond elevation of 231.7 m and a retention time of 239 days. The waters of Lake Norman drive the turbines of Cowans Ford Hydroelectric Station and cool the condensers that drive the turbines of Marshall Steam Station and McGuire Nuclear Station. Blue catfish from Arkansas were stocked once into Lake Norman in 1966 (S. Van Horn, North Carolina Wildlife Resources Commission, personal communication).

The Santee-Cooper system consists of two reservoirs and three canals: Lake Marion, adjacent to the Santee River; Lake Moultrie, adjacent to the headwaters of the Cooper River; a 12.1-km diversion canal connecting the two major bodies of water; a 6.4-km tail race emptying into the Cooper River; and an 18.5-km rediversion canal draining to the Santee River. The two reservoirs are held in check by the use of 67.6 km of dams and dikes. There are approximately 605 km of accessible natural shoreline. A 1036-meter spillway is used to control the flow of waters into the Santee River and as a flood control device. The total surface area of the two reservoirs is approximately 69,202.7 hectares (J. Inabinet, Santee-Cooper Power, personal communication). Blue catfish from Arkansas were stocked into Santee-Cooper once in 1964 (M. White, South Carolina Department of Natural Resources, personal communication).

Methods

Sample Collection

Fin clips were collected from blue catfish in Lake Norman and Santee-Cooper reservoirs during January 2001. Lake Norman blue catfish were collected by gillnets. Santee-Cooper blue catfish were obtained from anglers during a catfish fishing tournament. Forty-one pectoral fin clips ($n=20$ from Lake Norman, $n=21$ from Santee-

Cooper) were stored individually upon collection, frozen, and transported to the laboratory. DNA samples of 12 individuals from an Arkansas-derived population were provided by Dr. John Liu of Auburn University.

DNA Extraction

I extracted DNA from fin tissue of 41 blue catfish using the Puregene DNA isolation kit (Gentra, Minneapolis, MN). The manufacturer's protocol for extraction of DNA from animal tissue involved an overnight digestion of 10-20 mg of finely chopped fin tissue with Proteinase K. The sample was treated with RNase A solution, followed by Protein Precipitation Solution, and then centrifuged. The supernatant was combined with 100% isopropanol, centrifuged, and the precipitated DNA was washed with 70% ethanol. Finally, the DNA was resuspended in 50-500 µl of DNA Hydration Solution. A DNA Fluorometer (Model TKO 100, Hoefer Scientific Instruments, San Francisco, CA) was utilized to quantify DNA concentrations.

Microsatellite Amplification and Data Collection

Polymerase chain reaction (PCR) primers amplifying loci containing microsatellite DNA tracts from channel catfish *Ictalurus punctatus* (Liu et al. 1999) were used in attempts to amplify corresponding loci in blue catfish. Of the ten primer pairs tested on blue catfish DNA (*Ip383*, *Ip385*, *Ip393*, *Ip394*, *Ip396*, *Ip397*, *Ip466*, *Ip554*, *Ip555*, *Ip557*), the four yielding repeatable, scoreable results (*Ip383*, *Ip394*, *Ip396*, *Ip554*) were used to screen blue catfish populations.

DNA was amplified with a PCR Express (Hybaid, Franklin, MA) thermocycler using the following PCR protocol: 2.5 µl of DNA (100ng); 1x ProMega PCR buffer; 3.0mM MgCl₂; 0.25mM dNTPs; 1.25 units *Taq* polymerase; 20mM combined forward

and reverse primers; and sterile ddH₂O to a final volume of 25µl. The cycling conditions for PCR consisted of denaturation at 94°C for 1 min, followed by 40 amplification cycles (30 sec at 94°C, 1 min at 45°C, and 2 min at 72°C), with a final holding temperature of 4°C. The PCR products were loaded onto 7% polyacrylamide gels with 1xTBE buffer and subjected to electrophoresis at 175V for 4-hr in a Hoefer SE 600 (Amersham Pharmacia Biotech Inc., San Francisco, CA) midi-gel unit. A 10-bp ladder (Life Technologies, Baltimore, MD) was added every 12 lanes on all gels as a molecular weight standard for allele scoring. Amplification products in gels were visualized by silver staining (Bassam et al. 1991), and photographed for permanent record.

Data Analysis

Statistical analyses of microsatellite DNA data were performed using four software programs. Two datasets were created for analysis, one comprising genotypes for all individuals and the other comprising genotypes for each of the populations of Lake Norman, Santee-Cooper, and Arkansas. The degree of conformity to Hardy-Weinberg equilibrium was assessed by the exact test using a Markov chain technique (Guo and Thompson 1992), as implemented by the program Arlequin (version 2.0, Raymond and Rousset 1995). The program Microsat (version 1.5, Minch et al. 1995) was used to estimate pairwise genetic distances using the kinship coefficient (Dkf) and the proportion-of-shared-alleles (Dps) metrics (Bowcock et al. 1994). Data from all individuals were used to perform the phylogenetic analysis. Phylogenetic tree diagrams were constructed from Dkf and Dps distance matrices using the *neighbor* function of the program Phylip (version 3.5c, Felsenstein 1993). The program Treeview (version 1.5, Page 1998) was utilized to create trees from the Phylip output. A global test of

differentiation among samples was performed as an indicator of population subdivision by the program Arlequin.

Results

Of ten primer pairs amplifying microsatellite loci in channel catfish, three primer pairs (*Ip393*, *Ip555*, *Ip557*) failed to amplify blue catfish DNA and were eliminated from further study. An additional two primer pairs (*Ip397*, *Ip466*) were eliminated after successful amplification due to homozygosity for all samples, and one (*Ip385*) because of production of unscorable results due to excessively heavy banding during silver staining. Four primer pairs (*Ip383*, *Ip394*, *Ip396*, *Ip554*) yielded consistently scorable results for analysis. Numbers of Santee-Cooper individuals scored varied among loci due to the apparent occurrence of null alleles. Among several explanations for null alleles, the most likely in this context is that because of variation at the DNA sequence to which one or both PCR primers were targeted, the primer did not anneal and amplification did not occur. A total of 20 different alleles were identified at the four microsatellite loci (Table 3.1), with four to six alleles observed per locus.

Levels of genetic variability within the three populations studied differed. The Lake Norman population exhibited the lowest level of genetic diversity (Table 3.2), measured as: average number of alleles (2.00 vs. 3.25-3.75); total number of alleles (8 vs. 13-15); average heterozygosity (0.258 vs. 0.532-0.561); and variance in number of repeats (0.615 vs. 2.706-3.116). Significant departures from Hardy-Weinberg equilibrium were observed at locus *Ip396* in the Lake Norman population and loci *Ip396* and *Ip554* in the Santee-Cooper population.

Table 3.1. Allele frequencies at four microsatellite loci among blue catfish from Lake Norman, the Santee-Cooper system, and Arkansas.

Locus		Lake Norman	Santee-Cooper	Arkansas
<i>Ip383</i>	Number of alleles observed	40	28	16
Alleles (bp)	Frequency			
71		0.00	0.11	0.44
81		1.00	0.04	0.38
83		0.00	0.25	0.00
85		0.00	0.07	0.19
87		0.00	0.04	0.00
89		0.00	0.50	0.00
<i>Ip394</i>	Number of alleles observed	40	40	16
Alleles (bp)	Frequency			
104		0.75	0.83	0.63
106		0.25	0.18	0.13
108		0.00	0.00	0.13
110		0.00	0.00	0.13
<i>Ip396</i>	Number of alleles observed	40	36	16
Alleles (bp)	Frequency			
130		0.00	0.25	0.00
132		0.20	0.33	0.56
134		0.00	0.00	0.06
136		0.03	0.33	0.06
138		0.35	0.08	0.31
140		0.43	0.00	0.00
<i>Ip554</i>	Number of alleles observed	40	32	16
Alleles (bp)	Frequency			
226		0.00	0.00	0.63
228		0.00	0.25	0.38
230		0.00	0.06	0.00
232		1.00	0.69	0.00

Table 3.2. Genetic variability metrics for four microsatellite loci among populations of blue catfish from Lake Norman, Santee-Cooper, and Arkansas.

Population	No. individuals	Total no. alleles	Mean no. alleles	Mean heterozygosity.	Average variance in no. repeats
Lake-Norman	20	8	2	0.258	0.615
Santee-Cooper	21	15	3.75	0.532	2.706
Arkansas	8	13	3.25	0.561	3.116

Phylogenetic trees constructed from Dkf (Figure 3.1) and Dps (Figure 3.2) genetic distance estimates among individuals show the majority of Santee-Cooper and Arkansas blue catfish grouped together, while Lake Norman blue catfish are separated into several groups distinct from the other populations. The few exceptions are Santee-Cooper blue catfish 3005, 3015, 3016, and 3019, which are grouped with Lake Norman blue catfish (Figure 3.1 and Figure 3.2). Genetic distances among Lake Norman individuals tended to be smaller than those among Santee-Cooper or Arkansas individuals (range of Dk f values: Lake Norman = 0.000-0.312, Santee-Cooper = 0.000-0.812, and Arkansas = 0.062-0.812; range of Dps values: Lake Norman = 0.000-0.625, Santee-Cooper = 0.000-0.875, and Arkansas = 0.125-1.000), indicating less genetic variation in that population. The grouping of Santee-Cooper and Arkansas individuals is an indication of little genetic differentiation among the populations that they represented.

At the population level, Dkf distance values ranged from 0.219 to 0.316. The Santee-Cooper and Arkansas populations were most similar (0.219), and to this group was joined the Lake Norman population. The Lake Norman and Arkansas populations were the least similar (0.316). Similar results were seen using the Dps metric (range 0.511-0.584), where Lake Norman and Arkansas populations were the least similar (0.584). However, Dps values indicated that Lake Norman and Santee-Cooper populations were most similar (0.511). Results of a global test of differentiation among samples indicated significant differentiation ($p = 0.05$) between the Lake Norman and the Santee-Cooper and Arkansas populations. No significant differentiation was observed between the Santee-Cooper and Arkansas populations.

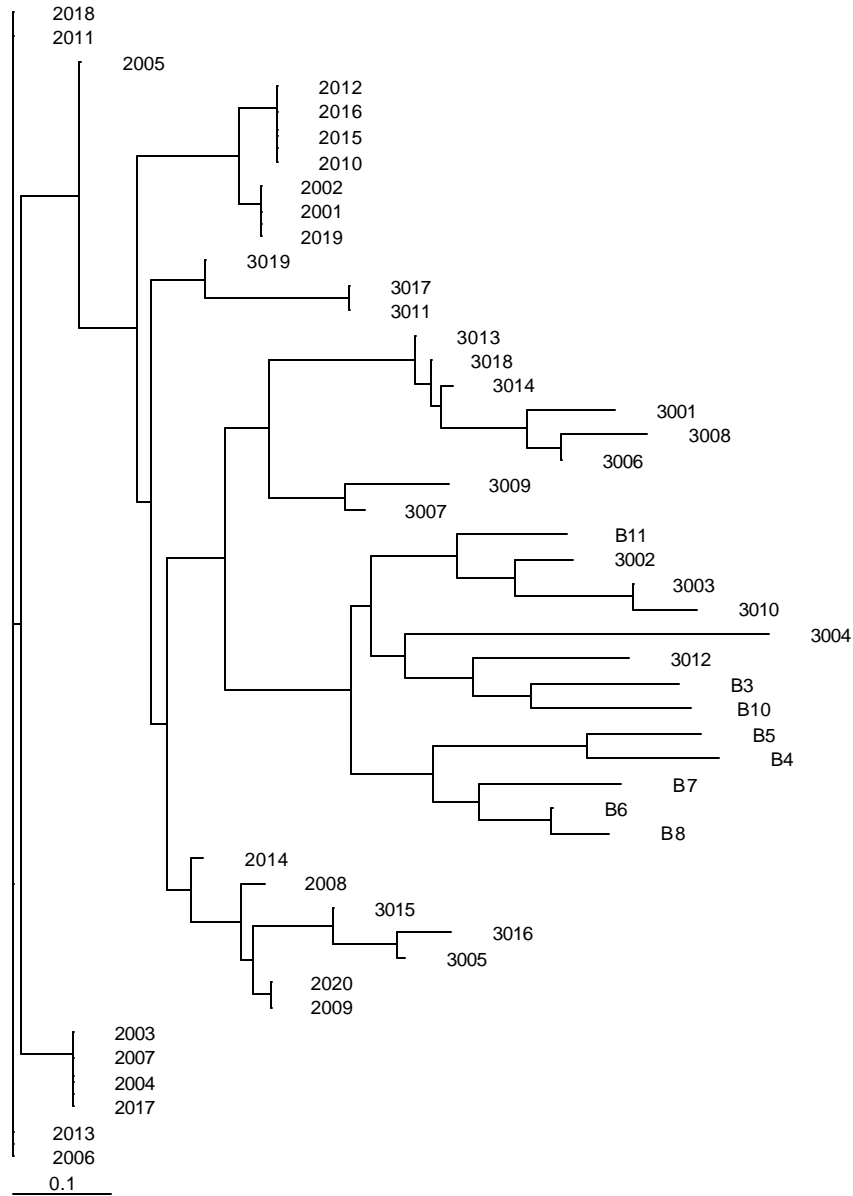


Figure 3.1. Genetic distances among individual blue catfish from Lake Norman (2000 series), Santee-Cooper (3000 series), and Arkansas (B series), estimated using data from four microsatellite loci using the kinship coefficient (Dkf) metric.

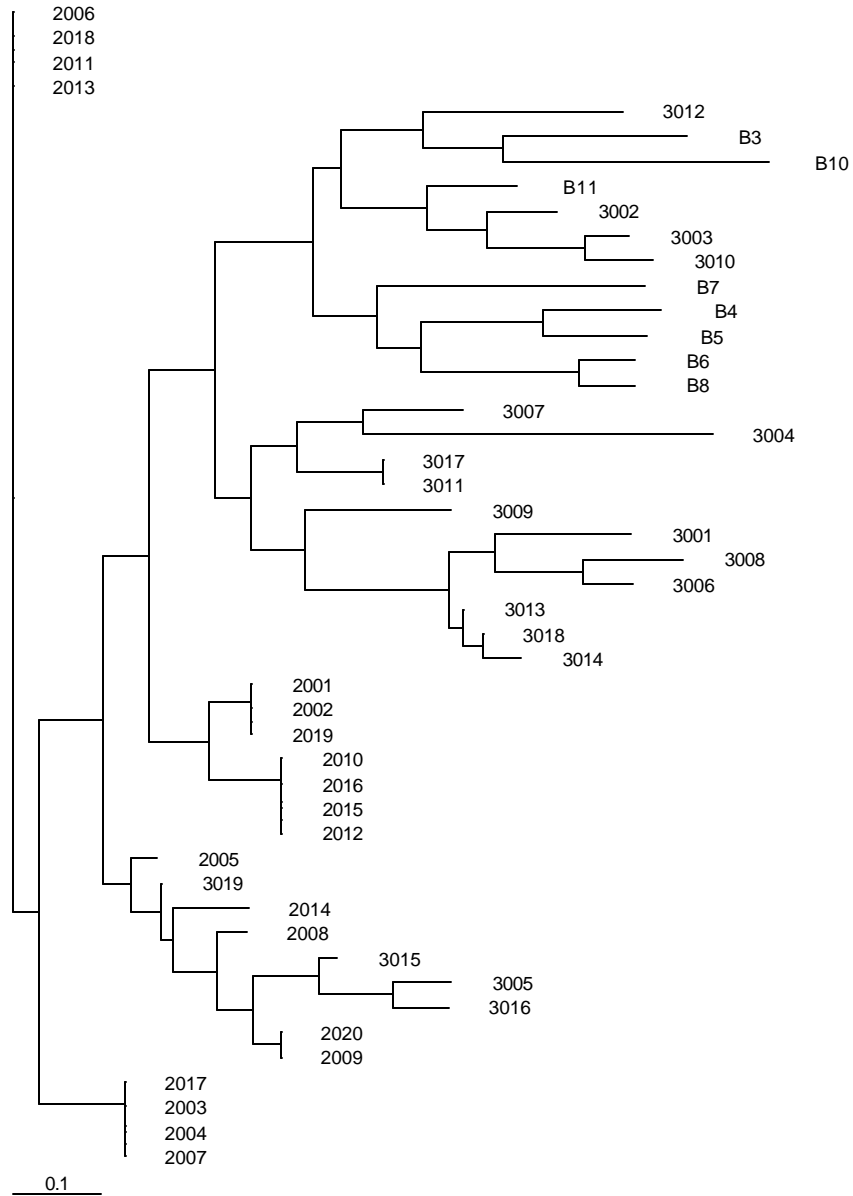


Figure 3.2. Genetic distances among individual blue catfish from Lake Norman (2000 series), Santee-Cooper (3000 series), and Arkansas (B Series), estimated using data from four microsatellite loci using the proportion of shared alleles (Dps) metric.

Discussion

Screening of allele frequencies at four microsatellite DNA loci in introduced populations of blue catfish from the Southeast showed the utility of genetic markers developed for channel catfish *I. punctatus* in its congener, blue catfish *I. furcatus*.

Tests of allele frequencies within populations showed departures from Hardy-Weinberg equilibrium in two of the populations surveyed (Lake Norman and Santee-Cooper). Significant departures from Hardy-Weinberg equilibrium indicated that one or more of the assumptions underlying the model was violated. Key assumptions include unlimited numbers of breeders, non-overlapping generations, and a panmictic population, i.e., no population subdivision or inbreeding. The Santee-Cooper population exhibited apparent segregation of null alleles at the *Ip383*, *Ip396*, and *Ip554* loci. We could not test definitively for segregation of null alleles because we did not have access to known family groups to check for Mendelian inheritance. The presence of null alleles might explain some or all of the departure from Hardy-Weinberg equilibrium in the Santee-Cooper population at the *Ip383* and *Ip554* loci. A subdivided blue catfish population may have arisen in the two-reservoir Santee-Cooper system or in Lake Norman (see below). Inbreeding or small sample size might have been at issue in the genetically closed Arkansas-derived population. A targeted study of larger scope would be needed to infer which assumptions were violated.

Lake Norman's blue catfish population contains fish in good condition as determined by relative weight analysis, but with a tendency to grow more slowly than populations within other similar reservoirs (Chapter 1, this document). The Lake Norman population exhibited relatively little genetic variability and was genetically differentiated from the

Santee-Cooper and Arkansas populations. There are several possible explanations for these findings. Lake Norman was stocked once with 4,000 blue catfish in 1966. Genetic diversity could have been limited by a population bottleneck at the founding of the population or in subsequent generations. Additionally, stocking of a group of related individuals could have led to subsequent mating of related individuals. Further examination of the blue catfish population in Lake Norman would be useful to infer why Lake Norman blue catfish have become significantly differentiated from their genetic source. Movement studies (Chapter Two, this document) suggested that spatial separation of blue catfish subpopulations in Lake Norman may be present during the late fall and winter seasons, which should be sampled to collect material for testing for possible sub-population structure. Such substructure could have implications for effective management of the respective blue catfish populations.

Personal communications have indicated that anglers recently have moved blue catfish from Lake Norman and the Santee-Cooper system to found other populations in the respective drainages; such movements of small numbers of prospective spawners could (further) bottleneck the genetic variability in the population so founded.

Population genetics of blue catfish are not well characterized. Our results represent the first population genetics survey of introduced blue catfish populations in the southeast, and suggest that some populations may carry only a portion of the genetic variability of native, source populations. Small sample sizes in this study rendered the results useful as a preliminary examination of the genetic composition of Lake Norman, the Santee-Cooper system, and Arkansas blue catfish populations. Screening of the southeastern populations and of multiple populations from the native range in the

Mississippi River drainage would provide more conclusive determination of whether and to what degree introduced blue catfish populations have retained ancestral variation or diverged from their source populations.

Chapter IV

Management of blue catfish

Catfish fisheries are unregulated throughout most of North Carolina, except on the small ponds and lakes maintained for the state's Community Fishing Program or where local (city or county) regulations limit gear use. In Lake Norman, catfish are both unregulated and considered a non-game fish species, meaning all catfish harvested can be sold for profit. A 1995 creel survey (Duke Power Company 1997) estimated blue catfish *Ictalurus furcatus* were only 1.0% of the total annual catch for all fish species in Lake Norman, but represented 12.4% of the annual biomass harvested from the reservoir (Table 4.1).

Lake Norman blue catfish grow at a slower rate than other reservoir populations, with fair to poor body condition ($W_r < 85$) early in life, but improving as length increases ($W_r > 95$) (Chapter 1). The diets of blue catfish vary by season, with greater amounts of fish (primarily clupeids) and *Chara* present in the diets during the winter while Asiatic clams are the predominant food item during the spring, summer, and fall (Chapter 1).

Striped Bass vs. Blue Catfish

Lake Norman supports a popular put-grow-take striped bass *Morone saxatilis* fishery maintained by the North Carolina Wildlife Resources Commission. Though my study does not provide evidence that blue catfish and striped bass compete directly for forage within Lake Norman, the consumption of clupeids by blue catfish (primarily during the winter) may have a detrimental effect upon striped bass body condition and production in Lake Norman. Length and weight data from 1994-1997 indicate that as

Table 4.1: 1995 creel survey data for Lake Norman, NC (Duke Power Company 1997).

Taxa	sublegal released	% sublegal released	legal released	% legal released	total released	% total released	total harvested	% total harvested	biomass harvested (kg)	% biomass harvested	total catch	% total catch
Carp			457	40.6%	457	40.6%	668	59.4%	898	1.0%	1,125	0.1%
Blue Catfish			389	5.0%	389	5.0%	7,362	95.0%	11,223	12.4%	7,751	1.0%
Channel Catfish			3,151	26.0%	3,151	26.0%	8,991	74.0%	2,684	3.0%	12,142	1.6%
Flathead Catfish			131	33.5%	131	33.5%	260	66.5%	621	0.7%	391	0.1%
Other Catfish			3,034	57.1%	3,034	57.1%	2,280	42.9%	724	0.8%	5,314	0.7%
White Bass			16,899	41.7%	1,6899	41.7%	23,636	58.3%	4,718	5.2%	40,535	5.4%
Striped Bass	35,715	77.5%	1,420	3.1%	37,136	80.6%	8,931	19.4%	11,761	12.9%	46,067	6.1%
Sunfish			34,233	59.3%	34,465	59.7%	23,290	40.3%	1,127	1.2%	57,755	7.7%
Largemouth Bass	160,357	70.7%	42,501	18.7%	202,858	89.4%	24,090	10.6%	12,197	13.4%	226,948	30.2%
Crappie			101,000	28.7%	100,717	28.6%	251,590	71.4%	44,913	49.4%	352,308	46.9%
Yellow Perch			1,487	100.0%	1,487	100.0%					1,487	0.2%
TOTALS					400,724		351,098		90,866		751,823	

Lake Norman striped bass length increases their body condition decreases (Figure 4.1), opposite of that observed for blue catfish in my study (Scott Van Horn, North Carolina Wildlife Resources Commission, personal communication).

Although the overall and seasonal diets of Lake Norman striped bass have not been specifically identified to date, their diet composition can be inferred by a literature review of similar regional reservoir striped bass populations. Cyterski (1999) reported that clupeids composed the bulk of striped bass diets for all age-classes (except young-of-the-year) year-round in Smith Mountain Lake (SML), Virginia. Clupeids also dominated the diet composition of striped bass in Claytor Lake, Virginia, comprising over 70% of stomach contents observed throughout a two-year study (Bonds 2000), as well as in the Santee-Cooper system (Stevens 1959; White 1980). Matthews et al. (1988) stated that striped bass have evolved to most effectively feed on schooling clupeids and will progress to the point of near starvation when clupeid populations decline. By comparison, clupeids were primarily observed in the diets of large (>400 mm) Lake Norman blue catfish during the winter months of my study.

Specific information on the standing stock of blue catfish in Lake Norman, or a direct estimate of how many clupeids blue catfish consume per year, is currently non-existent. However, information from my study on blue catfish diets, as well as studies examining catfish standing stock and clupeid consumption in other reservoirs in comparison to striped bass, can be used to develop a consumptive model for clupeid harvest by Lake Norman blue catfish.

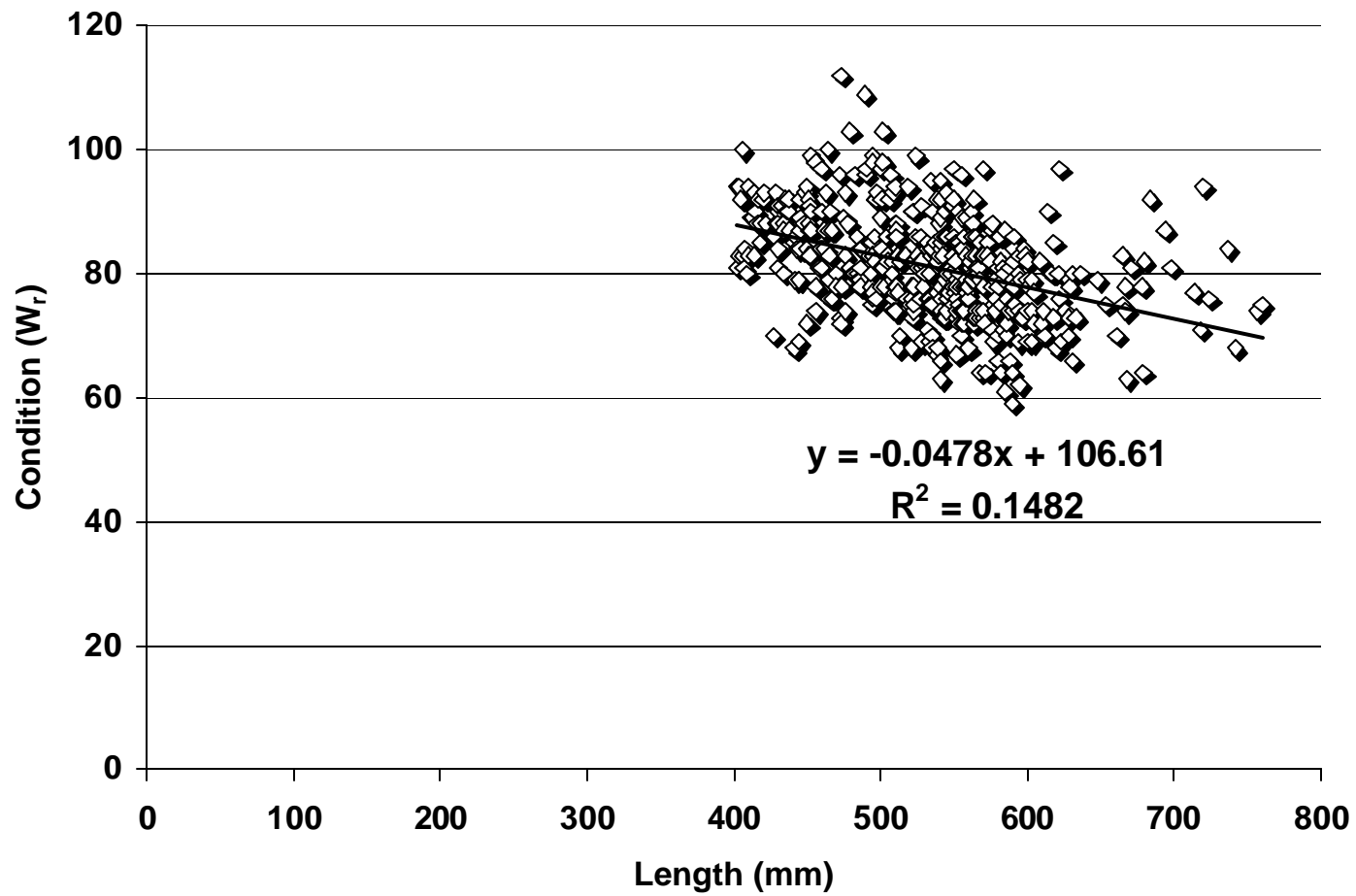


Figure 4.1: Condition at length for striped bass ($n=472$) collected by the North Carolina Wildlife Resources Commission from 1994-1997.

Cyterski (1999) estimated the standing stock for all catfish species at 30 kg/ha in SML. In Lake Norman, blue catfish made up approximately 70% of the total catch of all catfish during my study, and 77% of the total biomass (kg/ha) harvested in 1995 for all catfish within the lake. If I were to conservatively assume that 70% of the biomass of all catfish in Lake Norman are blue catfish, and then extrapolate the SML estimates as representative of Lake Norman, the standing stock of blue catfish in Lake Norman would be 21.21 kg/ha. By examining the distribution of blue catfish within the diet study's size classes (36% <400mm, 27% 400-599mm, and 38% >600mm), I could then surmise that the standing stock of blue catfish <400mm in Lake Norman is 7.56 kg/ha, 5.67 kg/ha for blue catfish 400-599mm and 7.98 kg/ha for blue catfish >600mm (Table 4.2). By multiplying these values by the percentage of clupeids (by weight) consumed by blue catfish in my study and the amount of food needed for minimum annual maintenance {the annual maintenance ratio would need 3 kg/shad to maintain 1 kg/catfish, (Cyterski 1999)}, a total annual harvest of 8.4 kg/ha of shad could be consumed by blue catfish in Lake Norman.

However, this model is based on multiple assumptions, including that SML and Lake Norman are similar. I have already reported that the total phosphorus concentration for Lake Norman is 15-ug/L (Chapter 1), and that total phosphorus concentrations are correlated to standing stock (Ney et al. 1990). By using the conversion formula provided by Ney et. al (1990), 15 ug/L total phosphorus in Lake Norman can be translated into a total fish standing stock of 275 kg/ha. The total phosphorus concentration for SML is 25 ug/L, which translates into a total fish standing stock of 463 kg/ha. The total fish

Table 4.2: Model of the annual consumption of clupeid standing stock by blue catfish in Lake Norman using standing stock and annual maintenance estimates for catfish in Smith Mountain Lake, VA.

Size Class	Standing Stock (21.0 kg/ha)	Percent Diet Clupeids	Annual Maintenance (3 kg clupeids:1 kg catfish)	Totals (kg/ha)
<400 mm	7.6	5%	3	1.1
400-599 mm	5.7	16%	3	2.7
>600 mm	8.0	19%	3	4.5
			TOTAL:	8.4

standing stock of Lake Norman is 59% of the total for SML and, by assuming all proportions equal, this would reduce the assumed standing stock of blue catfish in Lake Norman from 21.21kg/ha to 12.40 kg/ha. By reducing this new standing stock estimate by the same size class distributions, and recalculating, this would result in a total annual harvest of 5.0 kg/ha of clupeids by blue catfish in Lake Norman (Table 4.3 A). However, the annual maintenance value utilized by Cyterski (1999) for catfish was not based on an exact calculation but a best estimate available through literature review at the time of his study. Blue catfish annual maintenance costs could be higher, so I have included calculations of total annual harvest of clupeids using annual maintenance ratios of 4:1 and 5:1 (Table 4.3 B and C). These ratios provide a possible range of total annual harvest from 5.0 kg/ha to 8.3 kg/ha by blue catfish in Lake Norman.

A direct estimate of standing stock for clupeids in Lake Norman is not available, but by using frequency estimates by hydroacoustic surveys (1900/ha) and weight estimates from purse-seine collections (10 g/clupeid) provided by Duke Power Company (Gene Vaughan, Duke Power Company, personal communication), a standing stock of 95 kg/ha can be assumed for Lake Norman clupeids. If blue catfish are harvesting 5.0 kg/ha of the clupeids in Lake Norman, this would represent a loss of 5.2% of clupeids to blue catfish foraging annually. The overall range of loss would be 5.3% to 8.7% of clupeids to blue catfish annually (based on the range of annual maintenance calculated in Table 4.3).

Table 4.3: Model of the annual consumption of clupeid standing stock by blue catfish in Lake Norman assuming blue catfish standing stock of 12.4 kg/ha (see text) using variable annual maintenance costs.

A

Size Class	Standing Stock (12.4 kg/ha)	Percent Diet Clupeids	Annual Maintenance (3 kg clupeids:1 kg catfish)	Totals (kg/ha)
<400 mm	4.3	5%	3	0.7
400-599 mm	3.4	16%	3	1.6
>600 mm	4.7	19%	3	2.7
			TOTAL:	5.0

B

Size Class	Standing Stock (12.4 kg/ha)	Percent Diet Clupeids	Annual Maintenance (4 kg clupeids:1 kg catfish)	Totals (kg/ha)
<400 mm	4.3	5%	4	0.9
400-599 mm	3.4	16%	4	2.2
>600 mm	4.7	19%	4	3.6
			TOTAL:	6.7

C

Size Class	Standing Stock (12.4 kg/ha)	Percent Diet Clupeids	Annual Maintenance (5 kg clupeids:1 kg catfish)	Totals (kg/ha)
<400 mm	4.3	5%	5	1.1
400-599 mm	3.4	16%	5	2.7
>600 mm	4.7	19%	5	4.5
			TOTAL:	8.3

But the real question that one must ask when examining standing stocks of predators and forage is not what is the total mean weight of food items used, but rather what percent caloric value each food item contributes to the overall diet of fish in question. Alewives *Alosa pseudoharengus* in SML have a mean caloric value of 1546 cal/g, while Cummins and Wuycheck (1971) reported lower caloric values for clams (550 cal/g) and *Chara* (415 cal/g). Using these values, and multiplying by the mean weight in grams for each of the three predominant food items found in the diets of Lake Norman blue catfish (clupeids, Asiatic clams *Corbicula fluminea*, and *Chara*), it can be shown that clupeids provide a higher percentage (>46%) of calories to the diets of blue catfish in all three size classes observed (Table 4.4). By using the percent caloric contribution of clupeids to the diet of blue catfish in place of the percent diet of clupeids by weight, a total harvest of 24.7 kg/ha annually (Table 4.5 A, annual maintenance ratio of 3:1), or 26% of the estimated standing stock of clupeids in Lake Norman, might be needed to meet blue catfish demand. The range of possible harvest based on percent caloric contribution and varying blue catfish annual maintenance costs would be 26% to 43% (Table 4.5 A, B, and C).

What I have just presented is a very assumptive model of the possible blue catfish demand on clupeid production within Lake Norman. However, if one considers that: 1) the largest blue catfish are eating the most fish are in the best condition; 2) the largest striped bass that are in the worst condition; and 3) the possibility that blue catfish are limiting the amount of forage available to the put-grow-take striped bass fishery in Lake Norman, an argument for further study could easily be made. A direct estimate of the standing stock of striped bass, blue catfish, and other predators (i.e. largemouth bass *Micropterus salmoides*, spotted bass *M.*

Table 4.4: Percent caloric contribution by the three predominant food items in blue catfish identified by stomach contents by weight in Chapter 1.

Size Class	Item	Mean Content (g) /catfish	cal/g	Calories	Percent caloric contribution to diet
<400 mm	Clupeids	1.4	1546*	2173	49%
	Clams	3.2	550‡	1735	39%
	Chara	1.3	415‡	519	12%
400-599 mm	Clupeids	8.3	1546*	12798	66%
	Clams	10.7	550‡	5866	30%
	Chara	1.6	415‡	654	3%
>600 mm	Clupeids	31.8	1546*	49116	82%
	Clams	18.4	550‡	10137	17%
	Chara	1.3	415‡	528	1%

* Moore (1988)

‡ Cummins and Wuycheck (1971)

Table 4.5: Model of the annual consumption of clupeid standing stock by blue catfish in Lake Norman using percent caloric contribution instead of percent clupeid mean weights from stomach content data and variable annual maintenance costs.

A

Size Class	Standing Stock (12.4 kg/ha)	Annual Maintenance (3 kg clupeids:1 kg catfish)	Percent caloric contribution	Totals (kg/ha)
<400 mm	4.3	3	49%	6.4
400-599 mm	3.4	3	66%	6.7
>600 mm	4.7	3	82%	11.6
TOTAL:				24.7

B

Size Class	Standing Stock (12.4 kg/ha)	Annual Maintenance (4 kg clupeids:1 kg catfish)	Percent caloric contribution	Totals (kg/ha)
<400 mm	4.3	4	49%	8.4
400-599 mm	3.4	4	66%	9.0
>600 mm	4.7	4	82%	15.4
TOTAL:				32.8

C

Size Class	Standing Stock (12.4 kg/ha)	Annual Maintenance (5 kg clupeids:1 kg catfish)	Percent caloric contribution	Totals (kg/ha)
<400 mm	4.3	5	49%	10.5
400-599 mm	3.4	5	66%	11.2
>600 mm	4.7	5	82%	19.3
TOTAL:				41.0

punctalatus, crappie *Pomoxis spp.*, flathead catfish *Pylodictis olivaris*, channel catfish *Ictalurus punctatus*), as well as all forage (primarily clupeids) within Lake Norman is needed. A direct study of the bioenergetic demand of blue catfish on the Lake Norman fishery will better help fishery managers address issues from forage availability to the effects upon other key predator species for future management needs.

Population Genetics

Blue catfish movements vary throughout Lake Norman, with a probable spring spawning site located in the upper lake region, and the possibility that up to three separate sub-populations exist (Chapter 2). The Lake Norman blue catfish population exhibited relatively little intra-lake genetic variability and was genetically differentiated from populations from Santee-Cooper, SC, and Arkansas (Chapter 3).

Further examination of the blue catfish population would be useful to infer why Lake Norman blue catfish have become both significantly differentiated from their genetic source, and whether a sub-population structure for blue catfish does exist within the reservoir. A population substructure could have implications for effective management of the respective blue catfish populations. Such sampling should be conducted in May during the spring spawning season throughout Lake Norman.

Management Recommendations

Since 1995, a multi-reservoir catch-and-release tournament series for catfish anglers has developed in North Carolina, including multiple visits to Lake Norman annually. Additionally since 1995 a new regional catfish angler's club (The Carolina's Catfish Club) has been created by local anglers. During 2002, the Carolina's Catfish Club began to lobby the North Carolina Wildlife Resources Commission (NCWRC) for

catfish regulations with a desire for management strategies that would produce a trophy catfish reservoir fishery.

It is not uncommon for fishery managers to develop management plans based on limited amounts of data when trying to satisfy the angling public's desires. Stocking rates, size limits, and bag limits often are affected by public opinion and pressure in light of what fisheries science suggests. However, in the case of Lake Norman's blue catfish, there are still too many unknowns to directly support any specific changes to the current management strategy. Though my results have provided information that was previously unknown about Lake Norman's blue catfish population, these results are based on a single year's dataset rather than a range of multi-year values.

I recommend that the NCWRC begin the annual collection of length, weight, and age data from blue catfish in Lake Norman. This data collection would at the least verify the accuracy of my one-year snapshot of the blue catfish population, as well as provide subsequent datasets from upcoming years that could be used to depict year-class differences and changes in growth characteristics.

Current Regulations

Currently, North Carolina Wildlife Resources Commission manages blue catfish in Lake Norman as a nongame species, allowing unlimited harvest commercially and recreationally. This approach assumes that the fishery is not overexploited. Blue catfish in Lake Norman are in poor condition during the early stages of life, and are slow to reach quality sizes {8 years or more to reach sizes greater than 510 mm (Anderson and Neumann 1996)}. Unlimited harvest would be the normal strategy to thin slow-growing fish, in order to reduce intraspecific competition and promote faster growth to larger sizes.

There is no evidence of overexploitation of blue catfish in Lake Norman, so continuing to allow unlimited harvest is the best current management plan for this population.

Possible Future Regulations

The exact form of any management regulations should be driven by a combination of understanding the ecology of blue catfish and the desires of the angling public. The presence of bigger (>600 mm), and older (>10 years) blue catfish does suggest that management for preferred (>760 mm), memorable (>890), or even trophy size blue catfish (>1140 mm) is viable as long as it assures continued harvest of small fish (Gabelhouse 1984). Two possible approaches could be considered if the angling public desires greater quantities of larger blue catfish. One would be the implementation of a maximum size limit for harvest, which is used where large numbers of smaller fish exist and the manager intends to increase growth rates (Noble and Jones 1999). I'll use the proportional stock densities sizes for preferred blue catfish (760 mm) as the maximum size limit for this example (blue catfish >760 mm are sexually mature and their body condition is >90 and increasing with length). All blue catfish <760 mm could continue to be harvested by all entities (including commercial and special device users), while fish greater than 760 mm would be released alive. This should promote a fishery over time with greater quantities of larger fish. However, some anglers will still want to take home a trophy-sized blue catfish, so the implementation of a harvest regulation allowing one or more fish to be culled over the maximum harvest size could also be incorporated.

Another approach would be to set a slot limit, which is set at the lower and upper limits of the size of fish that must be released. This would sustain angling yields while maintaining recruitment into and through the slot as a means of sustaining the availability

of large fish above the slot (Power and Power 1996; Noble and Jones 1999). For this example, I'll use the proportional stock densities sizes for preferred (760 mm) and quality (890 mm) blue catfish (Gabelhouse 1984). Blue catfish between 760 mm and 890 mm would be protected from harvest, allowing them the chance to spawn and grow to at least a quality length. Fish below and above the slot would be harvested, thinning the smaller blue catfish to reduce intra-specific competition and ideally promoting higher body condition, while providing larger quantities of quality blue catfish for harvest.

Summary

My research on blue catfish ecology in Lake Norman has provided a baseline of data for a snapshot examination of a reservoir blue catfish population. However, as I have presented in this chapter, more and continuing research is needed to better understand the impacts and interactions of blue catfish with other species before promoting any changes in the current management strategies for blue catfish.

Literature Cited

- Anderson, R. O. and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* Murphy, B. R. and D. W. Willis, editors. 1996. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Arterburn, J. E., D. J. Kirby, and C. R. Berry, Jr. 2002. A survey of angler attitudes and biologist opinions regarding trophy catfish and their management. *Fisheries* 27(5):10-21.
- Bassam, B. J., G. Caetano-anolles, and P. M. Gresshoff. 1991. Fast and sensitive silver staining of DNA in polyacrylamide gels. *Annals of Biochemistry* 196:80-83.
- Blouin M. A. and G. R. Hall. 1990. Improved method for sectioning pectoral spines of catfish for age determination. *Journal of Freshwater Ecology* 5(4):489-490.
- Booke, H. E., Hollender, B., and G. Lutterbie. 1978. Sodium bicarbonate, an inexpensive fish anesthetic for field use. *The Progressive Fish-Culturist* 40(1):11-13.
- Bonds, C. C. 2000. Assessment of the response of piscivorous sportfishes to the establishment of gizzard shad in Claytor Lake, Virginia. Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg.
- Bowcock, A.M., A. Ruiz-Linares, J. Tomfohrde, E. Minch, J.R. Kidd, and L.L. Cavalli-Sforza. 1994. High resolution of human evolutionary trees with polymorphic microsatellites. *Nature* 368:455-457.
- Bowen, S. H. 1996. Quantitative description of diet. Pages 513-532 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Brown, B. E., and J. S. Dendy. 1961. Observations on the food habits of the flathead and blue catfish in Alabama. *Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners* 15:219-222.
- Burr, B. M. and M. L. Warren, Jr. 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Commission Scientific and Technical Series 4.
- Carlander, K. D. 1969. Handbook of freshwater biology, volume I. Iowa State University Press, Ames.

- Conder, J. R., and R. Hoffarth. 1965. Growth of channel catfish, *Ictalurus punctatus*, and blue catfish, *Ictalurus furcatus*, in the Kentucky Lake portion of the Tennessee River in Tennessee. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 16(1962):348-354.
- Cross, F. B. 1967. Handbook of fishes of Kansas. University of Kansas Museum of Natural History Miscellaneous Publication 45.
- Cummins, K. W. and J. C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. Mitteilung Internationale Vereinigung Limnologie 18.
- Cyterski, M. J. 1999. Analysis of the trophic support capacity of Smith Mountain Lake, Virginia, for piscivorous fish. Doctoral dissertation. Virginia Polytechnic Institute and State University, Blacksburg.
- Davis, W. L. 1979. A comparative food habits analysis of channel and blue catfishes in Kentucky and Barkley lakes, Kentucky. Master's thesis. Murray State University, Murray, Kentucky.
- Diana, J. S. 1995. Biology and ecology of fishes. Biological Sciences Press, Carmel, Indiana.
- Duke Power Company. 1997. Lake Norman Creel Survey. 23 pp.
- Duncan, T. O., and M. R. Myers, Jr. 1978. Movements of channel catfish and flathead catfish in Beaver Reservoir, Northwest Arkansas. Proceedings of the Arkansas Academy of Science 32:43-45.
- Dunham, R. A., R. O. Smitherman, and C. Webber. 1983. Relative tolerance of channel x blue hybrid and channel catfish to low oxygen concentrations. Progressive Fish-Culturist 45:55-57.
- Elrod, J. H. 1974. Abundance, growth, survival, and maturation of channel catfish in Lake Sharpe, South Dakota. Transactions of the American Fisheries Society 103:53-58.
- Environmental Systems Research Institute, Inc. 1996. ArcView GIS. Redlands, California.
- Felsenstein, J. 1993. Phylip-phylogeny inference package, version 3.5c. University of Washington, Seattle, WA. <http://evolution.genetics.washington.edu/phylip.html>

- Fisher, S. A., S. Eder, and E. D. Aragon. 1999. Movements and habitat use of channel catfish and blue catfish in a small impoundment in Missouri. Pages 239-255 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Freeze, T. M. 1977. Age and growth, condition, and length-weight relationships of *Ictalurus furcatus* and *Ictalurus punctatus* from Barkley and Kentucky lakes, Kentucky. Master's thesis, Murray State University, Murray, Kentucky.
- Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. *North American Journal of Fisheries Management* 4:273-285.
- Graham, K. 1999. The review of the biology and management of blue catfish. Pages 37-49 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Guo, S. and E. Thompson. 1992. Performing the exact test of Hardy-Weinberg proportion for multiple alleles. *Biometrics* 48:361-372.
- Hale, R. S. 1987. Commercial catch analysis, spawning season, and length at maturity of blue catfish in Kentucky Lake, Kentucky-Tennessee. Master's thesis. Murray State University, Murray Kentucky.
- Hale, R. S. and T. J. Timmons. 1989. Comparative age and growth of blue catfish in the Kentucky portion of Kentucky Lake between 1967 and 1985. *Transactions of the Kentucky Academy of Science* 50(1-2):22-26.
- Harlan, J. R. and E. B. Speaker, editors. 1956. *Iowa fish and fishing*, 3rd edition. Iowa State Conservation Commission, Des Moines.
- Harrell, D. 1984. Comparison of creel and physical/chemical parameters for Lake Norman, North Carolina and Lake Wylie, North Carolina and South Carolina. *Proceedings of the Annual Conference of Fisheries and Wildlife Agencies* 38:532-548.
- Harrison, H. M. 1957. Growth of the channel catfish, *Ictalurus punctatus* (Rafinesque), in some Iowa waters. *Proceedings of the Iowa Academy of Science* 64:657-666.
- Hanson, J. M. and W. C. Leggett. 1982. Empirical prediction of fish biomass and yield. *Canadian Journal of Fisheries and Aquatic Sciences* 39(2):257-263.
- Hart, L. G. 1974. A telemetric study of homing and home range of flathead catfish, *Pylodictis olivaris* (Rafinesque), in an 850 hectare Oklahoma reservoir. Master's thesis. Oklahoma State University.

- Henderson, G. G. 1972. Rio Grande blue catfish study. Federal Aid in Fisheries Restoration Project F-18-R-7, Job No. 11, Job Progress Report. Texas Parks and Wildlife Department, Austin.
- Herke, S. W., and J. R. Moring. 1999. "Soft" harness for external attachment of large radio transmitters to northern pike (*Esox lucius*). *Fisheries Research* 39:305-312.
- Hesse, L. W., and four coauthors. 1982. The Missouri River channel catfish. Nebraska Game and Parks Technical Series 11, Lincoln.
- Hooge, P. N. and B. Eichenlaub. 1997. Animal movement extension to ArcView. Version 1.1. Alaska Biological Science Center. U. S. Geological Survey. Anchorage, Alaska.
- Houser, A. 1960. The effect of homing on channel catfish population estimates in large reservoirs. *Proceedings of the Oklahoma Academy of Science* 40:121-133.
- Hubert, W. A. 1999. Biology and management of channel catfish. Pages 3-22 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Hubert, W. A. and D. T. O'Shea. 1991. Reproduction by fishes in a headwater stream flowing into Graycocks reservoir, Wyoming. *Prarie Naturalist* 23:61-68.
- Irwin, E. R., W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. 1999. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Jackson, D. C. 1999. Flathead catfish: biology, fisheries, and management. Pages 23-36 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Jenkins, R. E., and N. M. Burkhead. 1993. *Freshwater fishes of Virginia*. American Fisheries Society, Bethesda, Maryland.
- Jenkins, R. M. 1956. Growth of blue catfish (*Ictalurus furcatus*) in Lake Texoma. *Southwestern Naturalist* 1(4):166-173.
- Jones, R. A. 1965. Blue catfish, *Ictalurus furcatus*. Page 121 in A. J. McClane, editor. *McClane's standard fishing encyclopedia*. Holt, Rinehart and Winston, New York.

- Jordan, D. S. and B. W. Evermann. 1920. American food and game fishes. Doubleday, Page and Company, Garden City, New York.
- Klaassen, H. E., and G. R. Marzolf. 1971. Relationships between distributions of benthic insects and bottomfeeding fishes in Tuttle Creek Reservoir. Pages 385-395 in G. E. Hall, editor. Reservoir fisheries and limnology, American Fisheries Society, Special Publication 8, Bethesda, Maryland.
- Lagler, K. F. 1961. Freshwater fishery biology. William C. Brown Company, Dubuque, Iowa.
- Layher, W. G. and O. E. Maughan. 1985. Relations between habitat variables and channel catfish populations in prairie streams. Transactions of the American Fisheries Society 114:771-781.
- Lee, D. C. 1983. Growth of blue, channel, and flathead catfish in selected habitats of the lower Mississippi River. Master's thesis. The University of Tennessee, Knoxville.
- Liu, Z. J., G. Tan, H. Kucuktas, P. Li, A. Karsi, D.R. Yant, and R.A. Dunham. 1999. High levels of conservation at microsatellite loci among ictalurid catfishes. Journal of Heredity 90:307-312.
- Macdonald, D. 1990. The channel catfish sport fishery of the lower Red River. Master's thesis. University of Manitoba, Winnipeg.
- Marty, G. D. and R. C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from channel catfish. Transactions of the American Fisheries Society 115:577-589.
- Marty, G. D. and R. C. Summerfelt. 1988. Inflammatory response of channel catfish to abdominal implants: a histological and ultrastructural study. Transactions of the American Fisheries Society 117:401-416.
- Matthews, W. J., L. G. Hill, D. R. Edds, J. J. Hoover and T. G. Heger. 1988. Trophic ecology of striped bass in a freshwater reservoir. Journal of Fish Biology 33:273-288.
- Mellas, E. J., and J. M. Haynes. 1985. Swimming performance and behavior of rainbow trout and white perch: effects of attaching telemetry transmitters. Canadian Journal of Fisheries and Aquatic Sciences 42:488-493.
- Michaletz, P. H. and J. G. Dillard. 1999. A survey of catfish management in the United States and Canada. Fisheries 24(8):6-11.

- Millspaugh J. J. and J. M. Marzluff, editors. 2001. Radio tracking and animal populations. Academic Press, New York.
- Minch, E., A. Ruiz-Linares, D. Goldstein, M. Feldman, and L. L. Cavalli-Sforza. 1995. MICROSAT, version 1.5. <http://lotka.stanford.edu/microsat.html>
- Minckley W. L. and J. E. Deacon. 1959. Biology of the flathead catfish in Kansas. Transactions of the American Fisheries Society 88:344-355.
- Minckley, W. L. 1962. Spring foods of juvenile blue catfish from the Ohio River. Transactions of the American Fisheries Society 91:95.
- Moore, C. M. 1988. Food habits, population dynamics, and bioenergetics of four predatory fish species in Smith Mountain Lake, Virginia. Doctoral dissertation. Virginia Polytechnic Institute and State University, Blacksburg.
- Moss, D. D. and D. C. Scott. 1961. Dissolved-oxygen requirements of three species of fish. Transactions of the American Fisheries Society 90:377-393.
- Muoneke, M. I. and K. L. Pope. 1999. Development and evaluation of a standard weight (W_s) equation for blue catfish. North American Journal of Fisheries Management 19:878-879.
- Nash, M. K. and E. R. Irwin. 1999. Use of otoliths versus pectoral spines for aging adult flathead catfish. Pages 309-316 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Ney, J. J. 1990. Trophic economics in fisheries: assessment of demand-supply relationships between predators and prey. Aquatic Sciences 2(1):55-81.
- Ney, J. J., C. M. Moore, M. S. Tisa, J. J. Yurk, and R. J. Neves. 1990. Factors affecting the sport fishery in a multiple-use Virginia reservoir. Lake and Reservoir Management 6(1):21-32.
- Ney, J. J. 1996. Oligotrophication and its discontents: effects of reduced nutrient loading on reservoir fisheries. American Fisheries Society Symposium 16:285-295.
- Noble, R. L., and T. W. Jones. 1999. Managing fisheries with regulations. Pages 455-477 in C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

- Page, R.D.M. 1998. Treeview, version 1.5. Division of Environmental and Evolutionary Biology, Institute of Biomedical and Life Sciences, University of Glasgow, Glasgow, Scotland.
<http://taxonomy.zoology.glas.ac.uk/rod/treeview/treeview.html>
- Peake, S. 1998. Sodium bicarbonate and clove oil as potential anesthetics for nonsalmonid fishes. *North American Journal of Fisheries Management* 18:919-924.
- Pellett, T. D., G. J. van Dyck, and J. V. Adams. 1998. Season migration and homing of channel catfish in the lower Wisconsin River, Wisconsin. *North American Journal of Fisheries Management* 18:85-95.
- Pelzman, R. J. 1971. The blue catfish. California Department of Fish and Game, Inland Fisheries Administrative Report 71-11, Sacramento.
- Perry, W. G., Jr. 1969. Food habits of blue and channel catfish collected from a brackish-water habitat. *The Progressive Fish-Culturist* 31:47-50.
- Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation, Columbia.
- Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservations, Jefferson City.
- Porter, M. E. 1969. Comparative age, growth, and condition studies on the blue catfish, *Ictalurus furcatus*, and the channel catfish, *Ictalurus punctatus*, within the Kentucky waters of Kentucky Lake. Master's thesis. Murray State University, Murray, Kentucky.
- Post, G. 1979. Carbonic acid anesthesia for aquatic organisms. *The Progressive Fish-Culturist* 41(3):142-144.
- Power M. and G. Power. 1996. Comparing minimum-size and slot limits for brook trout management. *North American Journal of Fisheries Management* 16:49-62.
- Prince, A. M. J., S. E. Low, T. J. Lissimore, R. E. Diewert, and S. G. Hinch. 1995. Sodium bicarbonate and acetic acid: an effective anesthetic for field use. *North American Journal of Fisheries Management* 15:170-172.
- Pugh, L. L. and H. L. Schramm, Jr. 1999. Movement of tagged catfishes in the lower Mississippi River. Pages 193-198 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.

- Ramsey, D. and K. Graham. 1991. A review of literature on blue catfish and channel catfish in streams. Missouri Department of Conservation. Final Report, Dingell-Johnson Project F-1-R-40, Study S-38, Job 1, Columbia.
- Raymond, M. and F. Rousset. 1995. An exact test for population differentiation. *Evolution* 49:1280-1283.
- Richardson, W. M., J. A. St. Amant, L. J. Bottroff, and W. L. Parker. 1970. Introduction of blue catfish in California. *California Game and Fish* 56(4):311-312.
- Rodriguez, M. S. 1982. Relationships between phytoplankton growth rates and nutrient dynamics in Lake Norman, North Carolina. Duke Power Company, DUKE PWR/82-01, Charlotte, North Carolina.
- Ross, M. J., and J. H. McCormick. 1981. Effects of external radio transmitters on fish. *Progressive Fish-Culturist* 43(2):67-72.
- SAS Institute Inc. 1999. Version 8.02. Cary, North Carolina.
- Schoffman, R. J. 1954. Age and growth of the channel catfish in Reelfoot Lake, Tennessee. *Journal of the Tennessee Academy of Science* 39:2-8.
- Siegwarth G. L. and J. M Pitlo, Jr. 1999. A modified procedure for surgically implanting radio transmitters in channel catfish. Pages 287-292 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Siler, J. R., W. J. Foris, and M. C. McInerney. 1986. Spatial heterogeneity in fish parameters within a reservoir. Pages 122-136 *in* G. E. Hall and M. J. Van Den Avyle, editors. *Reservoir fisheries management: strategies for the 80's*. Reservoir Committee, Southern Division American Fisheries Society, Bethesda, Maryland.
- Silverman, B. W. 1986. *Density estimation for statistics and data analysis*. Chapman and Hall, London, UK.
- Sneed, K. E. 1951. A method for calculating the growth of channel catfish, *Ictalurus lacustris punctatus*. *Transactions of the American Fisheries Society* 80:174-183.
- Stefan, G. E. 1992. FDA regulation of animal drugs used in aquaculture. *Aquaculture Magazine* 18(5):62-67.
- Stevens, R. E. 1959. The striped bass of the Santee-Cooper reservoir. *Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissions* 11:253-264.

- Stevens, R. E. 1960. The white and channel catfishes of the Santee-Cooper reservoir and tailrace sanctuary. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissions 13:203-219.
- Summerfelt, R. C. and D. Mosier. 1984. Transintestinal expulsion of surgically implanted dummy transmitters by channel catfish. Transactions of the American Fisheries Society 113:760-766.
- Timmons, T. J. 1999. Movement and exploitation of blue and channel catfish in Kentucky Lake. Pages 187-191 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- Turner, P. R. 1977. Age determination and growth of flathead catfish. Doctoral dissertation. Oklahoma State University, Stillwater.
- Van Eeckhout, G. 1974. Movement, reproduction and ecological relationships of channel catfish in the Little Missouri River, North Dakota, 1972-1973. Master's thesis. University of North Dakota, Grand Forks.
- Wahtola, C. H., Jr. 1969. The age, rate of growth and ecological distribution of channel catfish, *Ictalurus punctatus* (Rafinesque), in the Little Missouri Arm of Lake Sakakawea, North Dakota. Master's thesis. University of North Dakota, Grand Forks.
- Weiss, C. M. and E. J. Kuenzler. 1976. The trophic state of North Carolina lakes. Water Resources Research Institute. University of North Carolina, Raleigh.
- Wendel, J. L. and S. W. Kelsch. 1999. Summer range and movement of channel catfish in the Red River of the North. Pages 203-214 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.
- White, M. G. 1980. Fisheries studies in District V. South Carolina Wildlife and Marine Resources Department, Division of Wildlife and Freshwater Fisheries. Job Completion Report, F-16-10, Columbia
- White, M. G and S. D. Lamprecht. 1992. Fisheries investigations in lakes and streams district V. South Carolina Wildlife and Marine Resources Department, Division of Wildlife and Freshwater Fisheries. Job Completion Report, F-16-23, Columbia.

Winter, J. D. 1996. Advances in Underwater Biotelemetry. Pages 555-590 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70:164-168.

Yurk, J. J. and J. J. Ney. 1989. Phosphorus-fish community biomass relationships in southern Appalachian reservoirs: can lakes be too clean for fish? *Lake and Reservoir Management* 5(2):83-90.

Vita

Joseph Daniel Grist was born December 7, 1968, in Newport News, Virginia. At a very young age he developed an insatiable interest in fishing, and spent many memorable moments fishing with his family throughout the lower Chesapeake Bay and all along the Outer Banks of North Carolina. He attended Peninsula Catholic High School and graduated in June of 1988. After several years of working for the family business he returned to school, earning a Bachelors of Science in Biology from Christopher Newport University in December 1996. While at Christopher Newport University, he was able to utilize his personal knowledge of the Chesapeake Bay and Outer Banks to assist in studies of bottlenose dolphin populations and barrier island ecology. In 1998 he headed west to the Virginia Polytechnic Institute and State University in the ridge and valley region of the Blue Ridge Mountains to begin working as a fisheries technician and take courses in fisheries science to continuing his education. During the summer of 2000, while working on a co-operative project with Duke Power Company, he was offered a graduate research assistantship to study blue catfish ecology in Lake Norman, North Carolina. While at Virginia Tech he has served as president of the Fisheries and Wildlife Graduate Student Association and served as a teaching assistant in Fisheries Management and Fisheries Technique courses for undergraduates. In September 2002, he successfully completed his Master's of Science requirements in Fisheries Sciences, and when last seen was actively seeking a research position at a location with a sandy beach, salty air, and an ocean breeze.