Factors affecting largemouth bass recruitment in a trophy bass reservoir of Virginia, 
Briery Creek Lake

By

Bradley A. Ray

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

DOCTOR OF PHILOSOPHY

in

Fisheries and Wildlife Sciences

Approvals:

B.R. Murphy, Chairman J.J. Ney

J.M. Berkson E. McLean

E.P. Smith V.J. Dicenzo

July 28, 2008

Blacksburg, VA 24061-0321

Keywords: Largemouth bass, Recruitment, Growth, Food Availability, Predation, Competition
Factors affecting largemouth bass recruitment in a trophy bass reservoir of Virginia, Briery Creek Lake

Bradley A. Ray

ABSTRACT

Briery Creek Lake (BCL) has low abundance of young largemouth bass (LMB) compared to Sandy River Reservoir (SRR), which could jeopardize the trophy-LMB management goal in BCL. I assessed factors that may limit recruitment of LMB in BCL: angling, predation, competition, growth, and food availability. Age-0 LMB were monitored from nesting through their first summer with nest surveys, light traps, and electrofishing. Nesting success was higher in BCL (53%) than SRR (31%). Initial light trap catch-per-unit-effort (CPUE) was higher in BCL than SRR but, by July, light trap and electrofishing CPUE was higher in SRR than BCL. LMB nest success, growth, and CPUE did not differ between areas in BCL that were experimentally closed and areas left open to angling. Predation on age-0 LMB did occur in BCL, but was not higher than predation in SRR. Diet overlap between age-0 LMB and bluegill in BCL was >60% during June, indicating potential for competition. Zooplankton samples indicated that density of copepods was similar between reservoirs (2.3/liter); however, the average size of copepods was smaller in BCL (0.42 mm) than SRR (0.71 mm). I examined the activity of trypsin, which digests and converts protein. Trypsin activity was lower in BCL than SRR on 23 and 27 June, indicating that a nutritional deficiency exists for age-0 LMB in BCL. This deficiency was likely caused by the reduced zooplankton size in BCL and led to slower growth of age-0 LMB during June in BCL (0.8 mm/day) than SRR (1.2 mm/day). The fact that age-0 LMB CPUE in BCL dropped lower than SRR by July, despite BCL having a greater nesting success and higher CPUE in early June, indicates that a recruitment bottleneck for LMB
occurred in June. Maintaining the trophy LMB fishery in BCL requires management options that consider the factors in June that affect recruitment. I recommend decreasing the presently overabundant aquatic macrophytes in BCL, thus allowing for increased nutrient availability for phytoplankton, the primary food source of zooplankton. This could increase the density and size structure of zooplankton, and thereby increase food availability for age-0 LMB.
ACKNOWLEDGEMENTS

I would like to start by thanking my advisor, Dr. Brian Murphy. Dr. Murphy has done more than I could expect from a mentor. He has always pushed me to excel and been extremely helpful in my advancement, not only towards my degree but also towards my chosen career path. Without his encouragement and insight this work would not have been completed. I am truly grateful for all the time and effort he has put towards helping me reach my goals.

I also thank my committee members, Drs. John Ney, Ewen McLean, Jim Berkson, Eric Smith, and Mr. Vic Dicenzo. Their guidance and encouragement made this work possible. Further, their ability to make me strive for perfection has made me a better student and person, and for that I am thankful. I am particularly grateful to Dr. Ney for bringing me to Virginia Tech and having the confidence in me to do this work. A special thanks to the biologist that worked with me so closely on this project, Mr. Dicenzo. Without his insight and expertise this project would not have even begun.

I also acknowledge the Virginia Department of Game and Inland Fisheries, the Federal Sport Fish Restoration Act (project number: F-129-R), and the Department of Fisheries and Wildlife Sciences at Virginia Tech for four years of funding for this project. Without the generous contributions I would not have been able to complete this project. Further, thanks goes to the Virginia Department of Game and Inland Fisheries for their support and the use of equipment; particularly I wish to acknowledge Dan Michaelson for his help with the project and Jim Bowman for providing housing during my field work.

Many thanks to the numerous people who contributed time and effort to collecting data. I am grateful for the diligent work of my technicians: Mike Duncan, John Harris, Maggie Peirce,
and Jason Herrala. I greatly appreciate the laboratory assistance provided by Guillaume Salze. I would also like to acknowledge the volunteer field assistance of Dan Catlin.

Sincere thanks goes to the graduate students who provided insight and suggestions throughout this project. Special thanks to Michelle Davis, Amy Villamagna, Larissa Graham, Mike Duncan, Robert Leaf, Than Hitt, Dan Catlin, Jonathan Cohen and Joanne Davis.

In addition to the people already mentioned I thank my friends for their added support during my time at Virginia Tech. Specifically, Dan Nuckols, Josh Monk, Ron Arrivillaga, Karen Kowal, Eliza Heery, Eric Black, Rob Simmons, Sarah Lupis-Kozlowski, Mike Callahan, Greg Sass, Damon Krueger, Darren Bade.
# TABLE OF CONTENTS

**ABSTRACT**................................................................................................................................... ii

**AKNOWLEDGEMENTS**.................................................................................................................. iv

**TABLE OF CONTENTS**.................................................................................................................. vi

**LIST OF TABLES**........................................................................................................................... viii

**LIST OF FIGURES**........................................................................................................................ x

**FOREWORD**....................................................................................................................................... xii

**INTRODUCTION**................................................................................................................................ 1

Study Sites .......................................................................................................................................... 5

**CHAPTER 1. Sanctuaries do not increase largemouth bass reproductive success in a Virginia lake.**................................................................................................................................................. 7

Abstract............................................................................................................................................... 7

Introduction........................................................................................................................................... 8

Methods ............................................................................................................................................... 11

Results ............................................................................................................................................... 14

Discussion .......................................................................................................................................... 17

**CHAPTER 2. Factors affecting largemouth bass recruitment in a trophy bass reservoir of Virginia, Briery Creek Lake**.................................................................................................................. 21

Abstract............................................................................................................................................... 21

Introduction.......................................................................................................................................... 22

*Habitat* .............................................................................................................................................. 24

*Angling Effects* ................................................................................................................................ 25

*Predation and Competition* ................................................................................................................ 25

*Abiotic factors and disease* .................................................................................................................. 26

*Study Sites* ......................................................................................................................................... 26
LIST OF TABLES

Table 1. Number of age-0 largemouth bass collected in light traps and the location of each night’s set. 13

Table 2. Number of largemouth bass nests, success rate, and mean depth of the nests found in open coves, open non-coves, and closed coves. Different letters indicate significant differences among areas from a test of equality of proportions for success rate and a t-test for nest depth. ................................................................. 15

Table 3. Light trap catch rate of largemouth bass in open areas and closed coves in Briery Creek Lake. 15

Table 4. Electrofishing age-0 largemouth bass CPUE in open areas and closed coves in Briery Creek Lake during 2006-2007. ...................................................................................................................................................... 16

Table 5. Mean length of age-0 largemouth bass collected in open areas and closed coves of Briery Creek Lake during 2006-2007. Bold lines indicate significant difference in mean length between open areas and closed coves. ........................................................................................................................................ 17

Table 6. Electrofishing catch per unit effort (fish/hour) for largemouth bass between 200 mm and 299 mm, for Briery Creek Lake (BCL) and Sandy River Reservoir (SRR). ................................................................. 28

Table 7. Number of age-0 largemouth bass captured per light trap (CPUE) and standard deviation in 20 light traps during June and July 2007 in BCL and SRR. ......................................................................................... 41

Table 8. Number of diets examined from each predator, number of diets that age-0 largemouth bass were found, and mean percent by weight of age-0 largemouth bass in the diets of potential predators in BCL during 2005-2007. ........................................................................................................................................ 44

Table 9. Number of diets examined from each predator, number of diets that age-0 largemouth bass were found, and mean percent by weight of age-0 largemouth bass in the diets of potential predators in SRR during 2005-2007. ........................................................................................................................................ 45

Table 10. Monthly percent by weight of age-0 largemouth bass in largemouth bass diets examined in BCL and SRR during 2005-2007. The p-value <0.05 represents a significant difference between lakes in the percent by weight of age-0 largemouth bass in largemouth bass diets. An asterisk (*) indicates a significant difference between reservoirs. ......................................................................................... 46

Table 11. Mean percent weight of diet items found in largemouth bass diets examined in each month in BCL during 2005-2006. Bolded items were the largest contribution to the diet. Italicized items were the second largest contribution to the diet of largemouth bass. Number in parentheses represents the number of diets that contained the prey item. Other fish includes unidentifiable fish remains, catfishes (Ictalurids), mosquitofish (Gambusia spp.), and minnows (Cyprinids). Other represents vegetation and other vertebrates such as frogs and turtles. ......................................................................................... 47

Table 12. Mean percent weight of diet items found in largemouth bass diets examined in each month in BCL during 2005-2006. Bolded items were the largest contribution to the diet. Italicized items were the second largest contribution to the diet of largemouth bass. Number in parentheses represents the number of diets that contained the prey item. Other fish includes unidentifiable fish remains, catfishes (Ictalurids),
mosquitofish (*Gambusia* spp.), and minnows (Cyprinids). Other represents vegetation and other vertebrates such as frogs and turtles.

Table 13. Percent of largemouth bass in BCL and SRR within each size class that contained at least one age-0 largemouth bass during 2005-2007.

Table 14. Percent by weight of age-0 largemouth bass diets from BCL and SRR during May-September 2007. Plankton includes copepods and daphnia. PDUF is partially digested unidentifiable fish and PDUI is partially digested unidentifiable invertebrates. Other is any prey item that did not make up more than 10% of the diet during any month and includes amphipods, caddisflies, crayfish, damselflies, dragonflies, mite, mysis, phantom midge, planorbid, vegetation, water boatman and water striders.

Table 15. Number of non-empty age-0 largemouth bass diets and mean percent by weight of diet containing fish for BCL and SRR by week. Bolded weeks indicate a significant difference between lakes (*t*-test).

Table 16. Mean water quality measurements (secchi depth, temperature, and pH) in BCL and SRR during June-July 2007. Bolded lines indicate a significant difference between lakes.

Table 17. Mean copepod size (mm) in BCL and SRR during June-July 2007. Bolded rows indicate a significant difference between lakes.

Table 18. Mean length (mm) of age-0 largemouth bass by date in Briery Creek Lake and recommended mean length for stocking based on length of age-0 largemouth bass collected in Sandy River Reservoir one week later.

Table 19. Mean trypsin activity (adjusted for length) in BCL and SRR, and *p*-value of a two-sample *t*-test with a Bonferroni correction. Bolded rows indicate dates that had significant differences in trypsin activity between lakes.

Table 20. Mean condition (K) of age-0 largemouth bass in BCL and SRR during 2007 and corresponding *p*-value of two-sample *t*-test with a Bonferroni correction. Bolded rows indicate dates that had significant differences in condition between lakes.
LIST OF FIGURES
Figure 1. Map of Briery Creek Lake. Shaded coves indicate areas that were closed to fishing. Area of each cove in hectares is listed next to the coves. .............................................................. 11

Figure 2. Light trap used to collect age-0 largemouth bass in Briery Creek Lake during June and July 2007. The light source was a chemical light stick (OmniGlow, West Springfield, MA) ...................... 14

Figure 3. Map of BCL with approximate locations of electrofishing sites, monitored nests, and light trap sites marked. Electrofishing delineations indicate areas were the entire shoreline was sampled. Light trapping generally occurred within nesting areas. Where monitored nest and light traps overlapped light trap are delineations slightly shifted to avoid obscuring nest locations ...................................................... 32

Figure 4. Map of SRR with approximate locations of electrofishing sites, found nests, and light trap sites marked. Electrofishing delineations indicate areas were the entire shoreline was sampled. Light trapping generally occurred within nesting areas. Where monitored nest and light traps overlapped light trap are delineations slightly shifted to avoid obscuring nest locations ........................................ 33

Figure 5. Total number of largemouth bass nests and number observed to swim-up during spring 2007 on BCL and SRR. ............................................................................................................. 39

Figure 6. Mean age-0 largemouth bass catch-per-unit-effort (CPUE) (number / hour) for each electrofishing sampling period in BCL (Δ) and SRR (■) during 2005-2007. Error bars represent two standard errors ...................................................................................................................... 40

Figure 7. Largemouth bass PSD in BCL and SRR during 1998-2007. PSD of largemouth bass in BCL significantly increases (p = 0.002; regression equation: PSD=2.618*Year + constant). The regression for largemouth bass PSD in SRR is not significant (p = 0.336). .................................................. 42

Figure 8. Mean percent by weight of age-0 largemouth bass contained in largemouth bass diets from BCL (Δ) and SRR (■) for each sampling period during 2005-2007. Error bars represent two standard errors of the mean. An asterisk (*) represents a significant difference between lakes .............................................................. 43

Figure 9. Mean percent by weight of age-0 largemouth bass contained in black crappie diets from BCL for May (Δ) and June (■) during 2005-2007. Error bars represent two standard errors of the mean ........... 50

Figure 10. Dietary overlap during May-July of age-0 largemouth bass and bluegill and age-0 largemouth bass and redear sunfish from a) SRR and b) BCL during 2005-2007. Solid line indicates ecologically significant overlap (0.6) .......................................................................................................................... 53

Figure 11. Dietary overlap of age-0 largemouth bass collected during May-July and blueback herring collected during September in BCL during 2005-2007. Solid line indicates ecologically significant overlap (0.6) .......................................................................................................................... 54

Figure 12. Logistic regression curves for percent weight of diet of age-0 largemouth bass containing fish by collection time in BCL and SRR during 2005-2007 .......................................................... 55
Figure 13. Mean percent weight of fish in the diet of age-0 largemouth bass for each sampling period on BCL (Δ) and SRR (■) during 2005-2007. Error bars represent two standard errors of the mean. ..........56

Figure 14. Logistic regression curves for percent weight of diet of age-0 largemouth bass containing fish by length in BCL and SRR during 2005-2007 .................................................................................................................57

Figure 15. Mean length of age-0 largemouth bass from each sampling period during each year 2005-2007 in BCL (Δ) and SRR (■). ........................................................................................................................58

Figure 16. Age-0 largemouth bass hatch date distributions calculated from otolith daily growth rings from BCL and SRR during 2006 and 2007. ........................................................................................................60

Figure 17. Age-0 largemouth bass mean growth rates (mm/day) calculated from otolith daily growth rings from BCL and SRR during 2006 and 2007. ........................................................................................................61

Figure 18. Age-0 largemouth bass length (mm) at age from BCL and SRR during 2006 and 2007. BCL 2006 regression line: length = 0.69*Age + 6.36. BCL 2007 regression line: length = 0.59*Age+10.22. SRR 2006 regression line: length = 0.67*Age + 21.135. SRR 2007 regression line: length = 0.58*Age + 25.106. .......................................................................................................................... 62

Figure 19. Logarithmically-transformed length-weight relationships for age-0 largemouth bass from BCL (Δ) and SRR (■) during 2006-2007. BCL regression equation: log (weight) = 2.55 * log (length) – 4.12. SRR regression equation: log (weight) = 2.99 * log (length) - 4.92 ........................................................................................................... 63

Figure 20. Catch curve of age-0 largemouth bass in light traps in BCL (Δ) and SRR (■) during 2007. BCL catch-curve regression equation: ln(catch) = -0.65*day +14.48. SRR catch-curve regression equation: ln(catch) = -0.22*day +7.19) represent instantaneous daily mortality rates. .................................................................................................................65

Figure 21. Catch curves from age-0 largemouth bass in BCL (top) and SRR (bottom) during 2005-2007. Significant slopes of the natural logarithm of CPUE after 29 July are indicated. .................................................. 66

Figure 22. Natural logarithm of trypsin activity by length for age-0 largemouth bass in Briery Creek Lake (BCL) (Δ) and Sandy River Reservoir (SRR) (■). Each regression line is significant (p < 0.001). BCL regression line: ln(trypsin activity) = 0.24*Length - 0.01. SRR regression line: ln (trypsin activity) = 0.20*Length +0.35 ..................................................................................................................87
FOREWORD

This dissertation is formatted as three publishable manuscripts; therefore, there is some redundancy in each of the sections. The dissertation begins with an introduction to the overall project and objectives. The three chapters represent three stand-alone papers that will be submitted to the North American Journal of Fisheries Management (Chapters 1 and 2) and Transactions of the American Fisheries Society (Chapter 3). The summary and conclusions section summarizes important results and conclusions from the overall project.
INTRODUCTION

Largemouth bass *Micropterus salmoides* are a popular target of recreational fishing throughout the United States and thus have considerable economic importance. Largemouth bass populations are typically self-sustaining through natural reproduction, which consists of building nests in shallow water that contain rocks, stumps, or slopes (Miller and Kramer 1971). Hatching success in these protected habitats can exceed 80% (Miller and Kramer 1971); however, mortality of eggs and larval fish occurs due to biotic and abiotic factors, such as competition, predation, and weather. These sources of mortality can be significant and may cause variable recruitment (Garvey et al. 2002). This variable recruitment can diminish future angler satisfaction, effort, and the economic benefits associated with sport fishing. Therefore, stable recruitment is crucial for the continued success of largemouth bass fisheries, particularly those that produce trophy fish.

The Virginia Department of Game and Inland Fisheries (VDGIF) manages Briery Creek Lake, a reservoir that consistently produces trophy (> 3.6 kg) largemouth bass. Briery Creek Lake (BCL), an 845-acre impoundment in Prince Edward County, has received national exposure since opening to fishing in 1989 (Wilson and Dicenzo 2002). Managers employ a protective-slot length limit (356-610 mm) to promote trophy largemouth bass potential. This management action was recommended in 1997 due to high recruitment and abundance of fish < 300 mm (Wilson 1998). Population estimates conducted by VDGIF since 2001 have demonstrated low age-1 largemouth bass abundances in BCL in comparison with other local impoundments, specifically Sandy River Reservoir. In August 2003 and 2004, electrofishing that targeted age-0 largemouth bass indicated recruitment differences among reservoirs. Populations could be maintained by supplemental stocking in the absence of strong year classes,
but this strategy is expensive and has had variable success (Hoxmeier and Wahl 2002). Therefore, examination of the limiting factors in the recruitment of largemouth bass is needed in order to protect this trophy fishery.

The viability of largemouth bass populations may be influenced by angling pressure (Gustaveson et al. 1991; Philipp et al. 1997; Cooke et al. 2000; Lewin et al. 2006). Physiological impacts of angling may reduce reproductive fitness by reducing the ability of largemouth bass to defend nests (Cooke et al. 2000; Cooke et al. 2002; Suski et al. 2003; Suski and Philipp 2004), increasing nest abandonment by nest-guarding male largemouth bass (Philipp et al. 1997; Suski and Philipp 2004), and producing smaller offspring with a later swim-up date (Ostrand et al. 2004). Additionally, stress during gonadal development may lower fecundity (Clearwater and Pankhurst 1997) and offspring survival (Weiner et al. 1986). Angling in BCL could affect recruitment of largemouth bass by increasing stress that leads to decreased ability to defend nests, increased nest abandonment and smaller offspring with a later swim-up date. In the spring of 2003, Briery had 51,256 angler hours directed towards largemouth bass (VDGIF unpublished data). This angling pressure is concurrent with spawning when males may be most vulnerable to angling. Although 99% of all bass caught were released, there may still be negative effects on the eggs and fry, especially to those that are abandoned due to harvest (Suski et al. 2002). Reducing the stress on largemouth bass caused by catch-and-release angling could increase year class strength and reduce variable recruitment.

Suitable habitat for nesting and first-year survival exists in BCL. Standing timber is found in most (>80%) of the lake, which provides the physical structure that largemouth bass utilize. This physical structure and the abundant aquatic vegetation should allow age-0 largemouth bass refuge from predation. However, nearly 100% of the shoreline has complete
aquatic vegetation coverage, primarily water shield *Brasenia schreberi* but also eelgrass *Vallisneria americana*, Brazilian elodea *Elodea densa*, common elodea *Elodea canadensis*, and Illinois pondweed *Potamogoton illinoensis*. This dense vegetation could lead to slower growth and size-dependent mortality of age-0 largemouth bass through providing their prey refuge (Wrenn et al. 1996).

Predation and competition could be limiting largemouth bass recruitment in BCL. The nonnative blueback herring *Alosa aestivalis* is present in BCL, and as predators of age-0 largemouth bass could be a source of mortality (Davis and Foltz 1991). Further, blueback herring feed on large-bodied zooplankton and could compete with age-0 largemouth bass during their zooplanktivorous stage (Burbridge 1974). Additionally, bluegill *Lepomis macrochirus* can negatively affect largemouth bass recruitment through predation on eggs and fry (Heidinger 1975) and through competition for food resources (Brenden and Murphy 2004). This may cause changes in survival and growth. Conversely, bluegill availability is important to ontogenetic niche shift to piscivory (Garvey et al. 2002; Olson 1996). However, recent surveys by VDGIF on BCL have shown that bluegill abundance may be depressed. The depressed bluegill populations could create more variable growth rates for age-0 largemouth bass (Garvey and Stein 1998).

Diet quality may be reducing the nutritional status of age-0 largemouth bass. Trypsin is the enzyme responsible for the digestion and conversion of protein into energy that can be used for growth. Trypsin is important not only for carnivorous animals, but also for omnivorous animals that need high trypsin activity in order utilize the small amount of protein found in their diets (Hofer 1979). Low trypsin activity in the digestive tract suggests reduced food intake, low food availability, or low food quality (Pedersen et al. 1987; Einarrsson et al. 1997); thus, trypsin
can be used to reveal nutritional deficiencies (Applebaum and Holt 2003; Einarrsson et al. 1997; Cara et al. 2007). Higher trypsin activity has been linked to greater growth rates (Baragi and Lovell 1986; Lemieux et al. 1999); therefore, I investigated differences in trypsin activity in age-0 largemouth bass. Low trypsin activity in age-0 largemouth bass from BCL may indicate that food availability is a limiting factor for recruitment of age-0 largemouth bass in BCL.

The goal of this project was to determine the influence of potential limiting factors on recruitment in Virginia’s trophy largemouth bass reservoirs, specifically Briery Creek Lake. Age-0 largemouth bass relative abundance was followed through the first year of life to identify potential mechanisms that explain the observed lower relative abundance of age-0 largemouth bass in BCL. Sandy River Reservoir (SRR), a 740-acre impoundment in Prince Edward County, was used as a reference site for BCL. These reservoirs are similar in size and depth and have similar fish assemblages, with the exception of blueback herring in BCL. These reservoirs are in the same geographic region, and experience similar weather conditions throughout the year, thereby allowing for the elimination of any broad-scale abiotic factors from analysis. Specific objectives for this comparative study of Briery Creek Lake and Sandy River Reservoir were to:

1) Determine if reduced angling pressure on Briery Creek Lake may alleviate the reduced recruitment of largemouth bass (Chapter 1);

2) Determine the relative abundance of: a) largemouth bass > age 1; b) largemouth bass spawning nests; and c) age-0 largemouth bass through the first year of life (Chapter 2);

3) Quantify predation on age-0 largemouth bass (Chapter 2);

4) Quantify interspecific trophic competition for age-0 largemouth bass (Chapter 2);
5) Describe patterns of first-year growth, mortality, and the switch to piscivory of largemouth bass (Chapter 2);

6) Determine differences in trypsin activity of age-0 largemouth bass (Chapter 3);

7) Make management recommendations for the Briery Creek Lake fishery that will enhance largemouth bass year-class strength and continuation of the trophy fishery (Chapter 2 and Conclusion).

Study Sites

BCL, a 342-ha impoundment, was originally impounded in 1986 for water storage and opened to fishing in 1989. The majority of the watershed around Briery Creek is forested land. The construction left much of the existing forested land intact; therefore, the majority of the lake has abundant woody structure with standing timber throughout. The fish species present include: largemouth bass, bluegill, reed sunfish *Lepomis microlophus*, warmouth *Lepomis gulosus*, green sunfish *Lepomis cyanellus*, black crappie *Pomoxis nigromaculatus*, blueback herring, channel catfish *Ictalurus punctatus*, and chain pickerel *Esox niger*. Aquatic vegetation has recently increased and currently covers nearly 100% of the shoreline, which has subsequently led to greater water clarity (averaging over two meters) than pre-vegetation levels (Vic Dicenzo, personal communication). The aquatic vegetation is primarily water shield *Brasenia schreberi* but eelgrass *Vallisneria americana*, Brazilian elodea *Elodea densa*, common elodea *Elodea canadensis*, and Illinois pondweed *Potamogotenu illinoensis* are also present. The management regulations include a 355- to 610-mm protective-slot length limit designed to create a trophy largemouth bass fishery. There is also a 10-hp motor restriction. In 2003, fishing effort during the spring (March-May) totaled 58,559 hours; 88% (51,256 hours) was directed at largemouth
bass. Anglers released 99% of the largemouth bass caught were released (Vic Dicenzo, VDGIF, personal communication).

SRR, a 300-ha impoundment, was originally impounded in 1994 for water storage and opened to fishing in 1996. The majority of the watershed around Sandy River is a mixture of forested land and open fields. The construction left two large areas of standing timber for fish habitat and the addition of Christmas trees and hinged shoreline trees has created plenty of angling opportunities. The fish species present include: largemouth bass, bluegill, reedear sunfish *Lepomis microlophus*, warmouth *Lepomis gulosus*, green sunfish *Lepomis cyanellus*, black crappie *Pomoxis nigromaculatus*, gizzard shad *Dorosoma cepedianum*, channel catfish *Ictalurus punctatus*, and chain pickerel *Esox niger*. The aquatic vegetation is sparse and includes water shield *Brasenia schreberi* but eelgrass *Vallisneria americana*, Brazilian elodea *Elodea densa*, common elodea *Elodea canadensis*, and Illinois pondweed *Potamogeton illinoensis*, in SRR and the water clarity averages just over one meter. The management regulations include a 355- to 508-mm protective-slot length limit designed to create a trophy largemouth bass fishery. There is also a 10-hp motor restriction.
CHAPTER 1. Sanctuaries do not increase largemouth bass reproductive success in a Virginia lake.

Abstract

Creation of spawning sanctuaries has been used to increase reproductive success of largemouth bass, but success of this management strategy in the southern portion of the United States remains unknown. Since 2001, abundance of age-0 largemouth bass has been relatively low at Briery Creek Lake, Virginia, in comparison to a neighboring lake, Sandy River Reservoir. The reduced age-0 largemouth bass abundance at Briery Creek Lake has raised concern that the lake’s trophy management goal may be unattainable without the implementation of management actions. Therefore, in 2006, two coves within Briery Creek Lake were closed to fishing to provide protection to nest-guarding male largemouth bass. The nest success rate was not different in open and closed areas (30-40 % successful nests). Catch per unit effort of age-0 largemouth bass did not differ between open (1.6 per light trap, and 17.2 per hour of electrofishing) and closed areas (1.6 per light trap, and 17.9 per hour of electrofishing). Closing spawning areas to fishing may not be an effective management option to increase largemouth bass reproductive success in Briery Creek Lake.
Introduction

Largemouth bass *Micropterus salmoides* are a popular target of recreational fishing throughout the United States and thus have considerable economic importance. However, the viability of largemouth bass populations may be influenced by angling pressure (Gustaveson et al. 1991; Philipp et al. 1997; Cooke et al. 2000; Lewin et al. 2006). Stress during gonadal development may lower fecundity (Clearwater and Pankhurst 1997) and offspring survival (Weiner et al. 1986). Physiological impacts of angling may reduce reproductive fitness by reducing the ability of largemouth bass to defend nests (Cooke et al. 2000; Cooke et al. 2002; Suski et al. 2003; Suski and Philipp 2004), increasing nest abandonment by nest-guarding male largemouth bass (Philipp et al. 1997; Suski et al. 2002; Suski and Philipp 2004), and producing smaller offspring with a later swim-up date (Ostrand et al. 2004). Many of these researchers have recommended reducing fishing pressure during the spawning season to increase largemouth bass reproductive success.

One management approach to reducing fishing pressure has been the use of closed seasons during spawning (Quinn 2002). But, due to annual variation in spring warming rates, the protection provided by closed seasons to nesting largemouth bass varies significantly (Kubacki et al. 2002). Further, anglers commonly do not comply with a closed-season regulation (Philipp et al. 1997; Kubacki et al. 2002). Therefore, the use of sanctuaries (year-round-closed areas) may be more effective than closed seasons at reducing the negative impacts on largemouth bass from angling (Kubacki et al. 2002).

The use of sanctuaries has been successful in rehabilitating and protecting populations of fish that have been overfished. In the Great Lakes, the creation of sanctuaries on the spawning grounds of lake trout *Salvelinus namaycush* has aided in the rehabilitation of lake trout in Lake
Superior and is being used as a management strategy in the other Great Lakes for the restoration of lake trout (Krueger and Ebener 2004). In marine systems, sanctuaries have been shown to increase population resilience to overfishing (Apostolaki et al. 2002; Gerber et al. 2003). Marine protected areas have the potential to increase fish abundance, size distribution, and yield-per-recruit (Halpern and Warner 2002). Sanctuaries have also been linked to increased catch rates in adjacent areas (Roberts et al. 2001).

Sanctuaries have been shown to increase reproductive success of largemouth bass (Suski et al. 2002) but may not always be effective without proper compliance and enforcement. Providing sanctuary to largemouth bass in Illinois prior to spawning led to a reduction in the physiological stress produced from angling, which led to larger largemouth bass offspring (Ostrand et al. 2004). Larger age-0 largemouth bass may be less vulnerable to predation and starvation (Goodgame and Miranda 1993). Enforced sanctuaries eliminate catch-and-release angling, which would decrease stress on nest-guarding males. Reduced stress may also increase vigorous nest defense, thereby increasing the abundance of largemouth bass offspring by reducing predation on eggs and fry (Cooke et al. 2000; Cooke et al. 2002). Without parental care, offspring are greatly impacted by brood predators such as bluegill *Lepomis macrochirus* (Heidinger 1975). However, the effectiveness of sanctuaries needs to be further assessed before their blanket application (Agardy et al. 2003).

Reducing the stress on largemouth bass caused by catch-and-release angling could increase year class strength and reduce variable recruitment. Weak year classes may jeopardize sustainable fisheries (Crawford et al. 2002). Variable recruitment can diminish future angler satisfaction, effort, and the economic benefits associated with sport fishing. Therefore, stable recruitment is crucial for the continued success of largemouth bass fisheries.
The Virginia Department of Game and Inland Fisheries (VDGIF) manages a reservoir that consistently produces trophy (> 3.6 kg) largemouth bass and thus receives a high amount of fishing pressure. Briery Creek Lake (BCL), an 845-acre impoundment in Prince Edward County, has received national exposure since opening to fishing in 1989 (Wilson and Dicenzo 2002). Managers employ a protective-slot length limit (355-610 mm) to promote trophy bass potential. Population estimates conducted by VDGIF since 2001 have demonstrated low age-1 largemouth bass abundances in BCL in comparison with other local impoundments. The objective of this study was to quantify nest success of largemouth bass and age-0 largemouth bass relative abundance and average growth in areas where anglers were prohibited and to compare the nest success, relative abundance, and average growth with areas where angling was allowed.
**Figure 1.** Map of Briery Creek Lake. Shaded coves indicate areas that were closed to fishing. Area of each cove in hectares is listed next to the coves.

**Methods**

Areas of BCL were classified as either coves or non-cove areas. Coves were inlets with an opening that had a distance between shorelines < 300 m. All other areas were classified as non-cove areas.

Two coves were closed to anglers starting in April 2006 (Figure 1). The cove at the north end of the lake was 1.0 ha and the more-southern cove was 2.2 ha. These coves were chosen due to logistics of enforcement and their topography that facilitated easy exclusion of anglers. Entry
to the two coves was blocked with prominent fencing strung between trees on each side of the coves. Signs prohibiting fishing in the closed areas were placed on the fence, the surrounding trees, and at each boat ramp alerting anglers of the closures. The closures were enforced by the law enforcement division of VDGIF. The rest of the lake was left open to angling.

The lake was sampled with pulsed DC electrofishing (120 pulses / second; 4-6 amps) on nine separate occasions during August-October 2006 and June-September 2007. The abundance of age-0 largemouth bass was recorded and catch per unit effort (CPUE) was determined. All age-0 largemouth bass captured were measured to the nearest 1 mm. I used a two-sample Kolmogorov-Smirnov Test (Systat Inc., San Jose, CA) to determine if open areas (cove versus non-cove areas) differed in CPUE. Open areas did not differ; therefore, I used a two-sample Kolmogorov-Smirnov Test to identify differences in mean CPUE and mean length between closed and open areas of BCL on each of the nine sampling dates.

Nest surveys were conducted during April and May 2007, the spawning season of largemouth bass in BCL. Nests were located from a boat and marked with GPS and triangulation. I recorded the depth of each nest and used two-sample \( t \)-tests to test for a difference in mean depth of nests in open areas and closed coves. I monitored the nests every three days by snorkel survey until hatching was observed (success) or the nest had been abandoned by the male and no eggs remained (failure). I used an equality-of-two-proportions test (Systat Inc., San Jose, CA) to determine if open areas (cove versus non-cove areas) differed in nest success. Open areas did differ; therefore, I used an equality-of-two-proportions test (Systat Inc., San Jose, CA) to test for a difference in the mean number of successful nests between open coves and closed coves and open non-cove areas and closed coves.
I measured age-0 largemouth bass CPUE (fish per trap) in open areas and closed coves using light traps during June and July of 2007. Twenty light traps were constructed (Figure 2; designed by B. Halloren, Louisiana State University, personal communication) and set ten nights (Table 1). Each light trap was anchored to the bottom, and suspended in the water column by a float such that the trap was just below the surface. All 20 traps were set at dusk at each site within the littoral zone (0.5-2 m) of the lake, spaced approximately 10 meters apart. The traps were retrieved the following morning and all trapped age-0 largemouth bass were counted and measured to the nearest 1 mm. I used a two-sample Kolmogorov-Smirnov Test to determine if open areas (cove versus non-cove areas) differed in CPUE. Open areas did not differ; therefore, I used a two-sample Kolmogorov-Smirnov Test to test for differences between open areas and closed coves in mean CPUE and mean length of age-0 largemouth bass caught by each trap (open areas: $n = 140$; closed coves: $n = 40$).

Table 1. Number of age-0 largemouth bass collected in light traps and the location of each night’s set.

<table>
<thead>
<tr>
<th>Date</th>
<th>Area</th>
<th>Cove</th>
<th>Number of traps</th>
<th>Number of age-0 LMB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Jun</td>
<td>Open</td>
<td>Non-cove</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>10-Jun</td>
<td>Open</td>
<td>Cove</td>
<td>10</td>
<td>118</td>
</tr>
<tr>
<td>15-Jun</td>
<td>Open</td>
<td>Cove</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>17-Jun</td>
<td>Closed</td>
<td>Cove</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>21-Jun</td>
<td>Closed</td>
<td>Cove</td>
<td>20</td>
<td>34</td>
</tr>
<tr>
<td>23-Jun</td>
<td>Open</td>
<td>Cove</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>29-Jun</td>
<td>Open</td>
<td>Cove</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>6-Jul</td>
<td>Open</td>
<td>Non-cove</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>14-Jul</td>
<td>Open</td>
<td>Cove</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>27-Jul</td>
<td>Open</td>
<td>Non-cove</td>
<td>20</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 2. Light trap used to collect age-0 largemouth bass in Briery Creek Lake during June and July 2007. The light source was a chemical light stick (OmniGlow, West Springfield, MA).

Results

A total of 63 nests were located in the lake. Ten nests were found in closed coves, 28 nests were found in open coves, and 25 were found in open non-cove areas (Table 1). The success rate in closed (30%; number of successful nests = 3) and open (40%; number of successful nests = 11) coves of the lake did not differ ($p = 0.826$; Table 1). The highest success rate of nests was found in open non-cove areas (82%; number of successful nest = 20; Table 2) and was significantly higher than both closed coves ($p < 0.001$) and open coves ($p = 0.001$). The depth of the nests did differ among areas. Closed coves had deeper nests than open areas; however, the depth of successful nests and nests that failed did not differ ($p = 0.472$).
Table 2. Number of largemouth bass nests, success rate, and mean depth of the nests found in open coves, open non-coves, and closed coves. Different letters indicate significant differences among areas from a test of equality of proportions for success rate and a t-test for nest depth.

<table>
<thead>
<tr>
<th></th>
<th>number</th>
<th>success rate</th>
<th>depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open coves</td>
<td>28</td>
<td>0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65.75&lt;sup&gt;z&lt;/sup&gt;</td>
</tr>
<tr>
<td>Open noncoves</td>
<td>25</td>
<td>0.82&lt;sup&gt;a&lt;/sup&gt;</td>
<td>65.71&lt;sup&gt;z&lt;/sup&gt;</td>
</tr>
<tr>
<td>Closed coves</td>
<td>10</td>
<td>0.30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>78.20&lt;sup&gt;x&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Catch rates for age-0 largemouth bass did not differ between areas that excluded angling and the open areas in the lake. Light trap and electrofishing CPUE did not differ between open cove and open non-cove areas (<i>p</i> > 0.366); therefore all open areas were combined. There was no difference in mean number of age-0 largemouth bass caught per light trap within open areas and closed coves (<i>p</i> = 0.167; Table 3). The mean light trap catch rate was 1.61 fish/trap in open areas (<i>n</i> = 140) and 1.55 fish/trap in closed coves (<i>n</i> = 40) (Table 3). Age-0 largemouth bass electrofishing CPUE in closed and open areas did not differ on any sample date (<i>p</i> > 0.121; Table 4).

Table 3. Light trap catch rate of largemouth bass in open areas and closed coves in Briery Creek Lake.

<table>
<thead>
<tr>
<th></th>
<th>Closed</th>
<th></th>
<th>Open</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Mean</td>
<td>Standard Error</td>
<td>Number</td>
</tr>
<tr>
<td>2007</td>
<td>40</td>
<td>1.55</td>
<td>0.316</td>
<td>140</td>
</tr>
</tbody>
</table>
### Table 4. Electrofishing age-0 largemouth bass CPUE in open areas and closed coves in Briery Creek Lake during 2006-2007.

<table>
<thead>
<tr>
<th>Year</th>
<th>Week</th>
<th>Number</th>
<th>CPUE</th>
<th>Standard Error</th>
<th>Number</th>
<th>CPUE</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>5-Aug</td>
<td>2</td>
<td>20.484</td>
<td>9.624</td>
<td>6</td>
<td>25.333</td>
<td>12.635</td>
</tr>
<tr>
<td>2006</td>
<td>19-Aug</td>
<td>2</td>
<td>11.434</td>
<td>11.434</td>
<td>6</td>
<td>20.000</td>
<td>6.532</td>
</tr>
<tr>
<td>2006</td>
<td>2-Sep</td>
<td>2</td>
<td>11.163</td>
<td>11.163</td>
<td>6</td>
<td>16.667</td>
<td>5.103</td>
</tr>
<tr>
<td>2006</td>
<td>16-Sep</td>
<td>2</td>
<td>11.726</td>
<td>11.726</td>
<td>6</td>
<td>45.263</td>
<td>14.080</td>
</tr>
<tr>
<td>2006</td>
<td>28-Oct</td>
<td>2</td>
<td>18.000</td>
<td>18.000</td>
<td>6</td>
<td>34.667</td>
<td>10.865</td>
</tr>
<tr>
<td>2007</td>
<td>22-Jul</td>
<td>2</td>
<td>14.157</td>
<td>6.415</td>
<td>6</td>
<td>46.000</td>
<td>15.345</td>
</tr>
<tr>
<td>2007</td>
<td>16-Sep</td>
<td>2</td>
<td>42.438</td>
<td>20.261</td>
<td>6</td>
<td>36.303</td>
<td>11.071</td>
</tr>
</tbody>
</table>

Age-0 largemouth bass length was not different in closed coves compared to open areas. Length of age-0 largemouth bass did not differ between open coves and open non-cove areas (p >0.081); therefore, all open areas were combined. The only difference in the length of largemouth bass between closed coves and open areas occurred on 19 August 2006 (Table 5). On this date, age-0 largemouth bass were longer in open areas than closed coves. On all other sample dates age-0 largemouth bass length did not differ (Table 5).
**Table 5.** Mean length of age-0 largemouth bass collected in open areas and closed coves of Briery Creek Lake during 2006-2007. Bold lines indicate significant difference in mean length between open areas and closed coves.

<table>
<thead>
<tr>
<th>Year</th>
<th>Week</th>
<th>Closed</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>Mean length</td>
</tr>
<tr>
<td>2006</td>
<td>5-Aug</td>
<td>9</td>
<td>61.000</td>
</tr>
<tr>
<td>2006</td>
<td>19-Aug</td>
<td>7</td>
<td><strong>61.857</strong></td>
</tr>
<tr>
<td>2006</td>
<td>2-Sep</td>
<td>4</td>
<td>66.250</td>
</tr>
<tr>
<td>2006</td>
<td>16-Sep</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>27-May</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>10-Jun</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>17-Jun</td>
<td>64</td>
<td>30.094</td>
</tr>
<tr>
<td>2007</td>
<td>24-Jun</td>
<td>2</td>
<td>31.000</td>
</tr>
<tr>
<td>2007</td>
<td>1-Jul</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>8-Jul</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>22-Jul</td>
<td>6</td>
<td>50.833</td>
</tr>
<tr>
<td>2007</td>
<td>5-Aug</td>
<td>23</td>
<td>66.826</td>
</tr>
<tr>
<td>2007</td>
<td>16-Sep</td>
<td>12</td>
<td>80.167</td>
</tr>
</tbody>
</table>

**Discussion**

Angling does not appear to be a factor limiting largemouth bass nest success or recruitment in the lake. Although angling has been shown to negatively impact both nest success and year class strength in other systems (Cooke et al. 2002; Suski and Philipp 2004), I found no differences in nest success or age-0 largemouth bass CPUE between closed coves and open areas of Briery Creek Lake. My findings are similar to a study in Lake George, Florida, that found no increase in the abundance of age-0 largemouth bass spawned in protected spawning refuges for largemouth bass (Schramm 1986). Additionally, in a study of five
Michigan lakes, Wagner et al. (2006) found that the chance of producing swim-up fry did not decrease with increasing fishing pressure. Catch-and-release angling did not change movement or behavior of pike in a slightly eutrophic lake in Germany (Klefoth et al. 2008). The catch-and-release angling that is occurring on Briery Creek Lake does not have a negative impact on recruitment.

The observed nest success rates of 30-82 % (53 % lake-wide) were similar to other published nest success rates (38-63 %: Suski et al. 2002; 44-84 %: Philipp et al. 1997). Those studies reported higher success rates in closed areas as compared to angler-accessible areas, which is contrary to my findings. I found the greatest largemouth bass nest success rate in open non-cove areas. This may be due to the greater water movement in these less protected areas caused by wind and boat movements. Significant wave action may decrease largemouth bass nesting success (Cooke et al. 2002) and activity (Suski et al. 2005). However, the likely small increase in wave action in open areas of BCL caused by boat movements may have actually increased largemouth bass nest success. Largemouth bass have been shown to be active in low-intensity disturbances caused by wave action (Suski et al. 2005). Briery Creek Lake has a motor restriction (< 9.9 hp) and abundant woody structure which may buffer wave action caused by boat activity. These non-cove areas are more accessible to boat traffic and the slow movement by boats may disperse brood predators and allow for mixing of water that keeps eggs well oxygenated. During the first few days of development largemouth bass are extremely susceptible to decreases in oxygen (Spoor 1977).

I did not observe any differences in the length of age-0 largemouth bass between open areas and closed coves. Movement of largemouth bass into the closed coves could have provided refuge from angling at key points during gonad maturation. However, only two small
coves were closed to angling (total of 3.2 ha; 1% of total lake area), which may not be a large
enough area to identify significant differences in nest success, CPUE, or length. An increase in
the area that was closed to anglers may provide better insight by providing a greater area for
largemouth bass to spawn without stress caused by catch-and-release angling. Stress from
angling can decrease largemouth bass ability to defend their nests from predators (Cooke et al.
2000; Cooke et al. 2002). And stress from angling events during the final stage of gonad
maturation may cause smaller age-0 largemouth bass (Ostrand et al. 2004). However the
popularity of fishing on Briery Creek Lake precluded the experimental closure of more coves.

Previous studies (Kubacki et al. 2002; Suski et al. 2002) on the beneficial effects of
closed areas on reproductive success have been done on northern lakes that typically have greater
water clarity than southern systems. In those systems, the ability of anglers to “sight-fish”
(visibly targeting a specific nesting fish) may have compounded negative effects of catch-and-
release angling on largemouth bass reproductive success. The relatively low water clarity
(average spring secchi = 2 m) of BCL may limit the amount of sight fishing that can occur,
thereby providing a natural sanctuary from angling for deeper-nesting largemouth bass.
Additionally, differences in spring warming between the north and south may create longer
nesting periods in the north, which may expose nesting largemouth bass to a longer period of
angling.

Problems with enforcement of the sanctuaries may mask the effects of angling in the
lake. If sanctuaries are not properly enforced, the designation may negatively impact largemouth
bass reproductive success (Suski et al. 2002). Anglers view sanctuaries as areas where quality
largemouth bass may be found, and without adequate enforcement, these areas may put
largemouth bass at a higher risk of being captured (Suski et al. 2002). In this study, enforcement
should not have been an issue. The areas were not just marked as closed. The fencing strung
across the coves made it more difficult for anglers to access the areas and law enforcement
officials routinely monitored the areas. Therefore, the lack of significant results is most likely
not from problems with enforcement.

There were only ten nests found within the closed coves of Briery Creek Lake and only
three of those were successful. This small number of nests may not have been sufficient to
identify any significant differences in hatching success between open and closed areas of the
lake. The largemouth bass nesting success rate I found was similar to other reported nesting
success rates (Philipp et al. 1997; Suski et al. 2002). The largemouth bass nesting success in
closed coves was lower than the open areas which further supports that angling may not be
impacting largemouth bass recruitment.

Largemouth bass in Briery Creek Lake have been displaying low recruitment and the
establishment of sanctuaries did not improve the recruitment of largemouth bass. Other limiting
factors to recruitment of largemouth bass, such as early-life prey resources for age-0 largemouth
bass, predation on age-0 largemouth bass, and potential competition between age-0 largemouth
bass and bluegill (Chapter 2), may be overriding any positive impacts on recruitment the
sanctuaries provided, and require further investigation.
CHAPTER 2. Factors affecting largemouth bass recruitment in a trophy bass reservoir of Virginia, Briery Creek Lake

Abstract

Largemouth bass are a popular target of recreational fishing and are typically self-sustaining through natural reproduction. However, biotic and abiotic factors can negatively impact largemouth bass recruitment, which may lead to decreases in angler effort and satisfaction. The Virginia Department of Game and Inland Fisheries manages Briery Creek Lake, which consistently produces trophy (> 3.6 kg) largemouth bass, creating an extremely popular fishery. However, catch per unit effort (CPUE) of age-0 largemouth bass has been lower in Briery Creek Lake than in Sandy River Reservoir (another nearby trophy lake) since 2003. This lower CPUE in Briery Creek Lake has raised concern that without management actions the trophy management goal may be unattainable. I examined the relative abundance, diet, and growth of age-0 largemouth bass through the first summer of life and compared these metrics of age-0 largemouth bass from Briery Creek Lake to the nearby Sandy River Reservoir in order to identify limiting factors to the recruitment of largemouth bass in Briery Creek Lake. I also compared the amount of predation on and the potential for competition with age-0 largemouth bass in these reservoirs. I identified June as a potential bottleneck for the recruitment of largemouth bass. Delineation of this recruitment bottleneck is supported by diet overlap between age-0 largemouth bass and bluegill, which occurs during June. Additionally, the mean size of copepods is smaller in Briery Creek Lake than Sandy River Reservoir during June, which may be impacting growth of age-0 largemouth bass. The slower growth of age-0 largemouth bass in Briery Creek Lake compared to Sandy River Reservoir leads to a later switch to piscivory,
causing age-0 largemouth bass to rely longer on the smaller-sized zooplankton as a prey resource. Management actions designed to maintain the trophy largemouth bass fishery in Briery Creek Lake should focus on increasing growth of age-0 largemouth during the first two months of life by increasing production of zooplankton, the limiting prey resource.

**Introduction**

Largemouth bass *Micropterus salmoides* are a popular target of recreational fishing throughout the United States and thus have considerable economic importance. Largemouth bass populations are typically self-sustaining through natural reproduction, which consists of building nests in shallow water that contain rocks, stumps, or slopes (Miller and Kramer 1971). Hatching success in these protected habitats can exceed 80% (Miller and Kramer 1971); however, mortality of eggs and larval fish occurs due to biotic and abiotic factors, such as competition, predation, and weather. These sources of mortality can be significant and may cause variable recruitment (Garvey et al. 2002). This variable recruitment can diminish future angler satisfaction, effort, and the economic benefits associated with sport fishing. Therefore, stable recruitment is crucial for the continued success of largemouth bass fisheries, particularly those that produce trophy fish.

Variation in recruitment of largemouth bass has been extensively studied. However, there have been many different documented causes for variable recruitment. In Oklahoma, variation in year-class strength was determined in the first few weeks of life by environmental influences such as temperature and wind action (Summerfelt 1975). Variation in largemouth bass recruitment has been linked to differences in abundance at 50 mm in Lake Jordan, NC, suggesting that recruitment is largely set by early-life abundances (Jackson and Noble 2000).
Conversely, other researchers have indicated that variable recruitment was linked to density dependence of age-0 largemouth bass, primarily through slow growth that led to over-winter mortality (e.g. Miranda and Hubbard 1994; Wrenn et al. 1996; Ludsin and Devries 1997; Parkos and Wahl 2002). Additionally, some researchers have identified temperature and hydrology as driving factors (e.g. Buynak et al. 1999; Sammons et al. 1999; Garvey et al. 2000; Jackson and Noble 2000). In Lake Jordan, the pre-spawning temperature largely controlled year-class strength (Jackson and Noble 2000). In Ohio, largemouth bass year-class strength in small impoundments (190-1,145 ha) was regulated by density dependence causing slower growth during years of high rainfall amounts (Garvey et al. 2000). In years with low rainfall, discharge was low and largemouth bass year-class strength was higher (Garvey et al. 2000). In Kentucky and Barkley Lakes, Kentucky, increased reservoir discharge decreased year-class strength of largemouth bass (Buynak et al. 1999). In Guntersville Lake, Alabama, catch rates of age-0 largemouth bass were correlated to year-class strength, and strong year classes occurred when water was retained in the reservoirs > 16 days during spring and early summer (Wrenn et al. 1996). In Lake Normandy, TN, greater age-0 largemouth bass survival occurred during periods of water-level stability than during wet years (Sammons et al. 1999; Sammons and Bettoli 2000). Conversely, in Illinois, water level fluctuations appeared not to impact recruitment and recruitment was highest in high-water years (Kohler et al. 1993).

Growth and hatch date have also been identified as factors that reduce recruitment. Growth in Lake Normandy was affected by hatch date: earlier-hatched largemouth bass grew faster than later-hatched fish and thus had greater first-winter survival (Sammons et al. 1999). The slower growth of adult largemouth bass also can affect recruitment. Larger adult largemouth bass spawn earlier than small largemouth bass resulting in an earlier hatch date for age-0
largemouth bass, which has been linked to higher recruitment than that of later-hatched fish (Miranda and Muncy 1987; Ludsín and DeVries 1997; Sammons et al. 1999).

Other factors such as lake productivity and habitat have also led to recruitment variability of largemouth bass. In Alabama, age-0 largemouth bass density was positively correlated with chlorophyll a across impoundments (Allen et al. 1999). In Georgia, West Point Reservoir had decreased growth and recruitment of largemouth bass with a decrease in phosphorus concentrations (Maceina and Bayne 2001). Heavily vegetated lakes produce greater densities of age-0 largemouth bass than unvegetated lakes, but these fish often experience slower growth rates, leading to size-dependent mortality and reduced recruitment to age 1 (Wrenn et al. 1996). Age-1 largemouth bass in Lake Kissimmee, Florida, had greater growth rates and a higher density after the removal of vegetation (Allen et al. 2003). Structural habitat in Lake Jordan, NC, was found to be limiting density of age-0 largemouth bass, especially during low water periods (Irwin et al. 1997).

The breadth of potential causes of variable recruitment indicates that recruitment is probably impacted by the interdependency of different stages of largemouth bass development (Olson 1995). Therefore, it is important to examine the first year of life when identifying potential limiting factors that impact largemouth bass recruitment.

Habitat

In some cases, inadequate habitat may cause poor recruitment of largemouth bass. Water level and temperature can affect embryo mortality (Parkos III and Wahl 2002). Intermediate levels of macrophyte coverage may be best for strong recruitment (Allen and Tugend 2002). Availability of habitat is important for all life stages of largemouth bass. Specifically, age-0
largemouth bass prefer habitat with complex physical structure, particularly areas with a combination of vegetation and woody debris (Annett et al. 1996). The presence of adequate habitat is critical for nest success (Irwin et al. 2002). Therefore, habitat is important to the stable recruitment of largemouth bass, particularly for providing refuge for age-0 largemouth bass from predation.

**Angling Effects**

Nest development and protection by male largemouth bass can be affected by predators, including anglers. Angling before spawning can result in smaller age-0 largemouth bass with a later swim-up date (Ostrand et al. 2004). Even catch-and-release angling can have a negative impact (Suski et al. 2002). Catch-and-release angling of males can result in physiological stress that reduces their ability to successfully mate with females (Garvey et al. 2002). Male bass stressed by catch-and-release are often incapable of vigorous nest defense (Cooke et al. 2002), which could allow nest predators access to the eggs and fry. Sunfish (Centrarchidae) surround the nest and take eggs and fry while the male chases other sunfish away from the nest. This predation can result in the elimination of a year class (Heidinger 1975). Similarly, the removal of nest-guarding males through recreational harvest results in high mortality to the progeny. Stress from catch-and-release angling can also decrease disease resistance in largemouth bass (Cooke et al. 2000).

**Predation and Competition**

Largemouth bass fry leave the nest 10 to 14 days after hatching (Laurence 1969) and become vulnerable to both predation and competition. As the young mature they go through periods of zooplantivory and benthivory before becoming piscivorous. These three ontogenetic
stages could result in competition with fish of different trophic guilds if food is limiting. Competition decreases the growth rate of age-0 largemouth bass. The resulting smaller sizes leads to a delay in the ontogenetic shift to piscivory, thus decreasing survival and recruitment rates (Olson 1996). Smaller sizes also prolong age-0 largemouth bass vulnerability to predation. Slower growth rates can lead to a competitive bottleneck for juvenile largemouth bass through competition with bluegill *Lepomis macrochirus* (Brenden and Murphy 2004).

*Abiotic factors and disease*

Abiotic factors can affect recruitment of largemouth. Water level fluctuations and temperature can affect embryo mortality (Parkos and Wahl 2002). Lowering the water level during spring can increase water temperature and decrease the available habitat for spawning largemouth bass. In Oklahoma, largemouth bass produced the largest year classes when water levels were high and did not change (Summerfelt and Shirley 1978). Further, year-class strength increased with increased turbidity and decreased with increases in pH and water hardness (Summerfelt and Shirley 1978).

Other factors such as disease could negatively impact recruitment. Largemouth bass virus (LMBV) is prevalent in the southeastern United States and has been linked to fish kills (Grizzle and Brunner 2003). LMBV is the only lethal virus in wild populations of largemouth bass (Plumb et al. 1999). The virus primarily affects adult fish and could decrease the number of potential spawners, thus reducing recruitment.

*Study Sites*

The Virginia Department of Game and Inland Fisheries (VDGIF) manages Briery Creek Lake, a reservoir that consistently produces trophy (> 3.6 kg) largemouth bass. Briery Creek
Lake (hereafter, BCL), an 845-acre impoundment in Prince Edward County, Virginia, has received national exposure since opening to fishing in 1989 (Wilson and Dicenzo 2002). Managers employ a protective-slot length limit (356-610 mm) to promote trophy largemouth bass potential. This management action was recommended in 1997 due to high recruitment and abundance of fish < 300 mm (Wilson 1998). Population estimates conducted by VDGIF since 2001 have demonstrated low age-1 largemouth bass abundances in BCL in comparison with other local impoundments, specifically Sandy River Reservoir (SRR) (Table 6). In August 2004, electrofishing that targeted age-0 largemouth bass indicated recruitment differences among reservoirs (BCL = 17 per hour; SRR = 364 per hour). Weak year classes could jeopardize sustainable fisheries (Crawford et al. 2002). Populations could be maintained by supplemental stocking in the absence of strong year classes, but this strategy is expensive and has had variable success (Hoxmeier and Wahl 2002). Therefore, examination of the limiting factors in the recruitment of largemouth bass is needed in order to protect this trophy fishery.

**Potential limiting factors on recruitment in Briery Creek Lake**

Suitable habitat for nesting and first-year survival exists in BCL. Standing timber is found in most (> 80 %) of the reservoir, which provides the physical structure that largemouth bass use for nesting and first-year survival. This physical structure and abundant aquatic vegetation should provide age-0 largemouth bass refuge from predation. However, nearly all of the shoreline has complete aquatic vegetation coverage, primarily water shield *Brasenia schreberi* but also eelgrass *Vallisneria americana*, Brazilian elodea *Elodea densa*, common elodea *Elodea canadensis*, and Illinois pondweed *Potamogoten illinoensis*. In Lake Guntersville, AL, largemouth bass in areas of dense vegetation had slower growth and size-dependent
mortality (Wrenn et al. 1996). The vegetation in BCL has increased over the last ten years and subsequently there has been an increase in water clarity (Vic Dicenzo, VDGIF, personal communication). This increase in water clarity could be caused by a decrease in primary production of phytoplankton, which may led to a corresponding decrease in zooplankton, the primary prey resource for age-0 largemouth bass before the switch to piscivory.

---

**Table 6.** Electrofishing catch per unit effort (fish/hour) for largemouth bass between 200 mm and 299 mm, for Briery Creek Lake (BCL) and Sandy River Reservoir (SRR).

<table>
<thead>
<tr>
<th>Year</th>
<th>BCL</th>
<th>SRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>56.4</td>
<td>--</td>
</tr>
<tr>
<td>1998</td>
<td>66.4</td>
<td>108</td>
</tr>
<tr>
<td>1999</td>
<td>66.6</td>
<td>102</td>
</tr>
<tr>
<td>2000</td>
<td>41.5</td>
<td>39</td>
</tr>
<tr>
<td>2001</td>
<td>64.1</td>
<td>73.3</td>
</tr>
<tr>
<td>2002</td>
<td>29.6</td>
<td>20.7</td>
</tr>
<tr>
<td>2003</td>
<td>48.1</td>
<td>105.2</td>
</tr>
</tbody>
</table>

---

Predation and competition could be limiting largemouth bass recruitment in BCL. The nonnative blueback herring *Alosa aestivalis* is present in BCL. This species has been found to prey on age-0 largemouth bass (Davis and Foltz 1991). Further, blueback herring feed on large-bodied zooplankton and could compete with age-0 largemouth bass during their zooplanktivorous stage (Burbridge 1974). Additionally, bluegill can negatively affect
largemouth bass recruitment through predation on eggs and fry (Heidinger 1975) and through
competition for food resources (Brenden and Murphy 2004). This predation and competition
may cause changes in survival and growth. Conversely, bluegill availability is important to
ontogenetic niche shift to piscivory (Garvey et al. 2002; Olson 1996). Recent surveys by VDGIF
in BCL have shown that bluegill abundance has been declining in recent years (Vic Dicenzo,
VDGIF, personal communication). Low abundance of bluegill can contribute to variability in
growth rates for age-0 largemouth bass (Garvey and Stein 1998).

The present study is a comparative one between two reservoirs that are 8 km apart and
experience similar weather patterns; therefore, abiotic factors should not be causing the
difference in recruitment. Thus, factors such as temperature, pH, and water hardness were not
pursued in this study. Further, both of these reservoirs are used for water storage and do not
experience water level fluctuations associated with some reservoirs.

Disease was also not pursued in this study. The adult largemouth bass population from
both reservoirs had been tested for the presence of LMBV and no occurrence of LMBV was
found (Vic Dicenzo, VDGIF, personal communication).

The goal of this project was to determine the influence of potential limiting factors on
recruitment in Virginia’s trophy largemouth bass reservoirs, specifically Briery Creek Lake.
Age-0 largemouth bass relative abundance was followed through the first year of life to identify
potential mechanisms that explain the observed lower relative abundance of age-0 largemouth
bass in BCL. Sandy River Reservoir, a 740-acre impoundment in Prince Edward County, was
used as a reference site for BCL. These reservoirs are similar in size and depth and have similar
fish assemblages, with the exception of blueback herring in BCL. These reservoirs are in the
same geographic region, and experience similar weather conditions throughout the year, thereby
allowing for the elimination of any broad-scale abiotic factors from analysis. Specific objectives for this comparative study of Briery Creek Lake and Sandy River Reservoir were to:

1) Determine the relative abundance of: a) largemouth bass > age 1; b) largemouth bass spawning nests; and c) age-0 largemouth bass through the first year of life;

2) Quantify predation on age-0 largemouth bass;

3) Quantify the potential for interspecific trophic competition for age-0 largemouth bass;

4) Describe patterns of first-year growth, mortality, and the switch to piscivory of largemouth bass;

5) Make management recommendations for the Briery Creek Lake fishery that will enhance largemouth bass year-class strength and continue the trophy fishery.

Methods

Field Collections

I conducted nest surveys in BCL and SRR during April and May 2007 (Figures 3 and 4). Nests were located from a boat and marked with GPS and triangulation. Once nests were found, snorkeling was used to monitor the nests every three days until hatching was observed (success) or the nest had been abandoned by the male and no eggs remained (failure).

I used light traps in 2007 to collect age-0 largemouth bass before they were susceptible to electrofishing gear. Twenty light traps were constructed (B. Halloren, Louisiana State University, personal communication) and set ten nights during June-July in different areas where
nests had been found in each reservoir (Figures 3 and 4). Each light trap was anchored to the bottom, and suspended in the water column by a float such that the trap was just below the surface. All 20 traps were set at dusk at each site within the littoral zone (0.5-2.0 m) of the reservoir, spaced approximately 10 meters apart. The traps were retrieved the following morning and all trapped age-0 largemouth bass were counted, preserved on ice, and later frozen for laboratory analyses.

I collected plankton samples and water quality data while light traps were set. Plankton samples were collected with a Wisconsin net. The net was lowered to the bottom and pulled up, sampling the entire water column near where the light traps were set. Two net pulls were done at night and another two were taken the following morning. Samples were preserved in 10% formalin for later laboratory analysis. Water quality measurements, including secchi depth, surface temperature, and pH, were taken before sunset on nights when light traps were set.

I used pulsed DC electrofishing (120 pulses / second; 4-6 amps) for attempted eight 15-minute transects (4 in 2004 7-8 in 2006-2007) in each reservoir (Figures 3 and 4) twice a month in 2005-2006 and once a month in 2007 to collect age-0 largemouth bass and their potential predators and competitors. Transects were initially haphazardly picked and sampled each sampling date. Total catch was recorded in order to estimate catch per unit effort (CPUE). The first 50 age-0 largemouth bass collected during each sampling period were stored on ice and later frozen for food habits analysis and otolith aging. During each of the sampling periods the first 50 fish of seven species (largemouth bass, bluegill, redear sunfish \textit{Lepomis microlophus}, warmouth \textit{Lepomis gulosus}, green sunfish \textit{Lepomis cyanellus}, black crappie \textit{Pomoxis nigromaculatus}, and blueback herring) were measured to the nearest 1 mm and a total of 30 fish of each species were weighed to the nearest 1 g. Each month a target of 40 non-empty stomachs
of each species were removed and preserved in a 10% solution of formalin pending diet analysis in the laboratory, except stomach contents of largemouth bass > 150 mm which were removed using stomach tubes (Van Den Avyle and Roussel 1980).

**Figure 3.** Map of BCL with approximate locations of electrofishing sites, monitored nests, and light trap sites marked. Electrofishing delineations indicate areas were the entire shoreline was sampled. Light trapping generally occurred within nesting areas. Where monitored nest and light traps overlapped light trap are delineations slightly shifted to avoid obscuring nest locations.
Figure 4. Map of SRR with approximate locations of electrofishing sites, found nests, and light trap sites marked. Electrofishing delineations indicate areas were the entire shoreline was sampled. Light trapping generally occurred within nesting areas. Where monitored nest and light traps overlapped light trap are delineations slightly shifted to avoid obscuring nest locations.
Laboratory Analyses

Age-0 largemouth bass collected with light traps and electrofishing were measured to the nearest 1 mm and weighed to the nearest 0.01 g. Otoliths were removed from up to 20 fish for each sampling date in 2006 and 2007. Otoliths were immediately fixed to a glass slide with thermo-plastic cement, and cataloged for future daily growth-ring analysis to fix swim-up date and calculate average daily growth. Stomachs were removed from up to 30 fish for each sample date and preserved in 10% formalin for later food-habits analysis.

Preserved stomach contents were analyzed to determine predation on and diet overlap with age-0 largemouth bass. Stomach items were identified to the lowest possible taxonomic level using a dissecting microscope, separated, and counted. Separated prey items were placed in a drying oven for at least 16 hours before being weighed to the nearest 0.001 g.

Daily growth rings were counted on otoliths from age-0 largemouth bass collected in 2006 and 2007. A total of 107 age-0 largemouth bass otoliths were aged from BCL (66 in 2006 and 41 in 2007) and 113 were aged from SRR (71 in 2006 and 41 in 2007). The otoliths that were aged were from age-0 largemouth bass collected in June-September. Otoliths were gently sanded with 600-grit sand paper before a drop of immersion oil was added to make growth rings more visible. A digital picture was taken of each otolith and image analysis software (Image Pro Plus 6.1, MediaCybernetics, Bethesda, MD) was used to aid in counting daily rings. Each ring was marked on the image to avoid double counting. The total number of rings was considered to be the age of the fish in days (Miller and Storck 1982).

Plankton samples were subsampled for quantification and measurement. Volume of each sample was standardized to 200 ml and a stempel pipette was used to sample a 10-ml aliquot (5% of the sample). Initial analysis indicated that there were no differences in plankton density
estimates between 5% and 10% subsamples. All organisms were classified and counted using a stereo-zoom microscope, and up to 10 individuals were measured to the nearest 0.01 mm using a digital picture and image analysis software (Image Pro Plus 6.1, MediaCybernetics Bethesda, MD).

Data Analyses

Relative abundance and size structure. I used analysis of covariance (ANCOVA) to determine if age-0 largemouth bass CPUE for each reservoir varied among years using sampling period (week) as the covariate. Age-0 largemouth bass CPUE varied among years, therefore, each year was analyzed independently with an ANCOVA, with reservoir as the treatment and sampling period as the covariate. A two-sample t-test with a Bonferroni correction for testing multiple dates was used to test for a significant difference in mean age-0 largemouth bass CPUE between reservoirs within sampling period.

Trends in adult size structure were analyzed. Proportional size distribution (PSD) was calculated for largemouth bass in each reservoir from the VDGIF April assessment that has been conducted since 1997 in BCL and 1998 in SRR. I used linear regression to determine trends in the largemouth bass PSD in BCL and SRR across time.

Predation and diet overlap. The amount of predation on age-0 largemouth bass was calculated with the percent contribution by weight of age-0 largemouth bass found in the diet of other fish. A two-sample t-test with a Bonferroni correction was used to test for a significant difference in the amount of predation occurring in each time period between reservoirs. Diet overlap was calculated based on diet similarity using a similarity index, $C_{xy}$ (Schoener 1970):

$$C_{xy} = 1 - 0.5 \sum_{i=1}^{m} |p_{xi} - p_{yi}|$$

(1)
where $p_{xi}$ is the proportional abundance of species $i$ in the diet of species $x$, and $p_{yi}$ is the proportional abundance of species $i$ in the diet of species $y$. When $C_{xy}$ equals 1.0 there is 100% diet overlap between the two species; when $C_{xy}$ equals 0.0 there is no overlap; and a value $\geq 0.6$ is considered ecologically significant (Wallace 1981).

Pair-wise diet overlap was examined between age-0 largemouth bass and bluegill and age-0 largemouth bass and redear sunfish. Diet overlap of bluegill and redear sunfish 25-mm size classes was determined to create size-class groups appropriate for testing diet overlap with age-0 largemouth bass. From this exploratory analysis, two size classes were created for bluegill and redear sunfish. Bluegill were grouped into $< 50$ mm and 50-100 mm, and redear sunfish were grouped into $< 75$ mm and 75-100 mm. Age-0 largemouth bass diets were compared to each of these species/size-class groups to examine the degree of dietary overlap during May-July. Additionally, diet overlap between blueback herring collected during September and age-0 largemouth bass collected in May-July was assessed with these methods.

**Piscivory.** A logistic regression on the percent by weight of diet that contained fish versus timing (age and length) was used to determine length at piscivory and age at piscivory of age-0 largemouth bass. Piscivory was assumed when $\geq 60\%$ of age-0 largemouth bass consumed fish (Bettoli et al. 1992). Annual differences in the timing of piscivory were tested with an ANCOVA using length and year as the predictors and sampling period a covariate. Since year was not significant, all years were combined for the logistic regression. A 95% confidence interval for length at piscivory and age at piscivory was calculated for each reservoir by a random permutation of the residuals from the logistic regression. The random permutation randomly assigned a residual to a data point and a new logistic regression was performed. This procedure was repeated 1,000 times to establish the 95% confidence intervals. The confidence
intervals for length at piscivory and age at piscivory were compared between reservoirs to determine differences in the timing of piscivory.

*Growth.* Age-0 largemouth bass lengths at various sampling dates throughout the summer were examined to identify differences between reservoirs. Differences in mean length were analyzed with an ANCOVA using sampling period as a covariate. Since year was significant, each year was analyzed independently. A general linear model was used to examine how length changed with sampling period, reservoir, and an interaction term between reservoir and sampling period (Olson 1996).

Age-0 largemouth bass otolith ages’ were used to calculate mean swim-up date and mean daily growth rate. Swim-up date was calculated by subtracting the age from the date of collection, and was only calculated from otoliths collected after age-0 largemouth bass had become fully recruited to the electrofishing gear. Mean daily growth rates were calculated as:

\[
\text{Daily Growth Rate} = \frac{(TL_c - 6)}{\text{age}}
\]

Where \(TL_c\) was the length at capture, age was the number of days from swim-up (otolith ring count), and 6 mm was subtracted to correct for length at the time of swim-up (Goodgame and Miranda 1993). A two-sample *t*-test was used to test for significant differences in mean swim-up date and mean daily growth rate between reservoirs.

*Mortality.* Mortality estimates were calculated from cohort catch curves (Miranda and Bettoli 2007). As age-0 largemouth bass grow they become susceptible to electrofishing gear. Once age-0 largemouth bass were fully recruited to electrofishing gear, the CPUE should decline over time. Therefore, the date by which age-0 largemouth bass had fully recruited to electrofishing gear was calculated based on when CPUE started to decline. The catch data were then log\(_e\) transformed and plotted against the dates after the age-0 largemouth bass had fully
recruited to electrofishing. Instantaneous weekly mortality was calculated as the slope of the regression. A general linear model was used to compare mortality rates between reservoirs. Weekly mortality rates were also calculated using these methods for age-0 largemouth bass captured in light traps.

Water Quality. A two-sample *t*-test was used to test for significant differences in water quality measurements between reservoirs.

Plankton. Copepods and cladocerans were the most abundant organisms in the samples and also were commonly found in age-0 largemouth bass diets. Therefore, these two plankton taxa were further examined. An ANOVA with reservoir and sample period as the factors was used to test whether a significant difference existed in either mean plankton density or mean size of the major zooplankton between reservoirs. Copepod size was different between reservoirs; therefore, a two-sample *t*-test with a Bonferroni correction was used to test for a significant difference in mean copepod size between reservoirs within sampling period.

Results

Relative Abundance and Size Structure

Nests were found in spring of 2007 with eggs or fry present and an adult present between 03 April and 26 May in BCL and 04 April and 26 May in SRR. More nests were found in BCL (n=63) than in SRR (n=42). Successful nests with young present were found from 01 May to 26 May in BCL and 28 April to 26 May in SRR. BCL had a greater success rate (53%, number of successful nests = 33) than SRR (31%, number of successful nests = 13) (Figure 5).

CPUE of age-0 largemouth bass in August 2005-2007 electrofishing samples was similar to previous years and continued to be lower in BCL when compared to SRR (Figure 6). Light
traps initially caught more age-0 largemouth bass in BCL than SRR, but catch rates declined sharply during the middle of June in BCL (Table 7). In SRR, light traps catches increased during June before declining as the fish outgrew the gear.

Electrofishing CPUE (fish/hour) was different among years in BCL ($F = 6.752, \ p = 0.002$) and SRR ($F = 4.759, \ p = 0.01$); therefore, electrofishing CPUE was analyzed separately for each year. In all three years SRR had a higher CPUE than BCL with sample period as a covariate (Figure 6; $F > 33.693, \ p < 0.001$) for all years.

Largemouth bass PSD in BCL, calculated from VDGIF spring surveys had significantly increased since 1997 ($p = 0.002$) while in SRR largemouth bass PSD had not changed since 1998 ($p = 0.336$) (Figure 5).

---

**Figure 5.** Total number of largemouth bass nests and number observed to swim-up during spring 2007 on BCL and SRR.
Figure 6. Mean age-0 largemouth bass catch-per-unit-effort (CPUE) (number / hour) for each electrofishing sampling period in BCL (∆) and SRR (■) during 2005-2007. Error bars represent two standard errors.
**Table 7.** Number of age-0 largemouth bass captured per light trap (CPUE) and standard deviation in 20 light traps during June and July 2007 in BCL and SRR.

<table>
<thead>
<tr>
<th>Date</th>
<th>BCL CPUE</th>
<th>Standard Deviation</th>
<th>SRR CPUE</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Jun</td>
<td>0.80</td>
<td>1.03</td>
<td>0.50</td>
<td>0.97</td>
</tr>
<tr>
<td>10-Jun</td>
<td>11.80</td>
<td>8.23</td>
<td>1.30</td>
<td>1.34</td>
</tr>
<tr>
<td>15-Jun</td>
<td>1.85</td>
<td>1.98</td>
<td>0.25</td>
<td>0.91</td>
</tr>
<tr>
<td>17-Jun</td>
<td>1.40</td>
<td>1.88</td>
<td>0.10</td>
<td>0.31</td>
</tr>
<tr>
<td>21-Jun</td>
<td>1.70</td>
<td>2.15</td>
<td>1.65</td>
<td>3.22</td>
</tr>
<tr>
<td>23-Jun</td>
<td>1.60</td>
<td>2.19</td>
<td>1.70</td>
<td>3.26</td>
</tr>
<tr>
<td>29-Jun</td>
<td>0.20</td>
<td>0.41</td>
<td>1.05</td>
<td>1.57</td>
</tr>
<tr>
<td>6-Jul</td>
<td>0.35</td>
<td>0.59</td>
<td>0.10</td>
<td>0.31</td>
</tr>
<tr>
<td>14-Jul</td>
<td>0.75</td>
<td>1.02</td>
<td>0.80</td>
<td>1.32</td>
</tr>
<tr>
<td>27-Jul</td>
<td>0.15</td>
<td>0.49</td>
<td>0.80</td>
<td>1.15</td>
</tr>
</tbody>
</table>
**Figure 7.** Largemouth bass PSD in BCL and SRR during 1998-2007. PSD of largemouth bass in BCL significantly increases ($p = 0.002$; regression equation: $PSD=2.618*Year + constant$). The regression for largemouth bass PSD in SRR is not significant ($p = 0.336$).

---

**Predation and Diet Overlap**

Age-0 largemouth bass were consumed by other fish, primarily larger largemouth bass, in both BCL (Table 8) and SRR (Table 9). The percent by weight of largemouth bass found in the diet of largemouth bass was consistently less than 20% in both BCL and SRR during 2005-2007 (Table 10). Sunfish (*Lepomis* spp.) was typically the most important prey item for largemouth...
bass in BCL (Table 11) and SRR (Table 12). Largemouth bass diets in BCL contained a numerically higher percent by weight of age-0 largemouth bass than largemouth bass diets in SRR during May-July 2005-2007; however, the only significant difference was during May 2005 (Figure 8; Table 12). In BCL, the presence of age-0 largemouth bass in the diets of largemouth bass was lower than in SRR by August (Figure 6; Table 12). Largemouth bass < 300 mm in BCL consumed age-0 largemouth bass more often than they did in SRR (Table 13). Black crappie in BCL also consumed age-0 largemouth bass (Figure 9) in May and June; however, data are inconclusive due to low sample sizes for black crappie (Table 8).

Figure 8. Mean percent by weight of age-0 largemouth bass contained in largemouth bass diets from BCL (Δ) and SRR (■) for each sampling period during 2005-2007. Error bars represent two standard errors of the mean. An asterisk (*) represents a significant difference between lakes.
Table 8. Number of diets examined from each predator, number of diets that age-0 largemouth bass were found, and mean percent by weight of age-0 largemouth bass in the diets of potential predators in BCL during 2005-2007.

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Diets examined</th>
<th>Number of diets containing age-0 largemouth bass</th>
<th>Mean percent by weight of age-0 largemouth bass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blueback herring</td>
<td>2005</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blueback herring</td>
<td>2006</td>
<td>21</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Blueback herring</td>
<td>2007</td>
<td>20</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Black crappie</td>
<td>2005</td>
<td>7</td>
<td>1</td>
<td>0.143</td>
</tr>
<tr>
<td>Black crappie</td>
<td>2006</td>
<td>46</td>
<td>3</td>
<td>0.0477</td>
</tr>
<tr>
<td>Black crappie</td>
<td>2007</td>
<td>11</td>
<td>1</td>
<td>0.09</td>
</tr>
<tr>
<td>Bluegill</td>
<td>2005</td>
<td>151</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Bluegill</td>
<td>2006</td>
<td>258</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Bluegill</td>
<td>2007</td>
<td>149</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Green sunfish</td>
<td>2005</td>
<td>14</td>
<td>1</td>
<td>0.009</td>
</tr>
<tr>
<td>Green sunfish</td>
<td>2006</td>
<td>8</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Green sunfish</td>
<td>2007</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>2005</td>
<td>197</td>
<td>26</td>
<td>0.072</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>2006</td>
<td>273</td>
<td>25</td>
<td>0.073</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>2007</td>
<td>147</td>
<td>14</td>
<td>0.059</td>
</tr>
<tr>
<td>Redear sunfish</td>
<td>2005</td>
<td>110</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Redear sunfish</td>
<td>2006</td>
<td>249</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Redear sunfish</td>
<td>2007</td>
<td>142</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Warmouth</td>
<td>2005</td>
<td>80</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Warmouth</td>
<td>2006</td>
<td>20</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Warmouth</td>
<td>2007</td>
<td>12</td>
<td>1</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Table 9. Number of diets examined from each predator, number of diets that age-0 largemouth bass were found, and mean percent by weight of age-0 largemouth bass in the diets of potential predators in SRR during 2005-2007.

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Diets examined</th>
<th>Number of diets containing age-0 largemouth bass</th>
<th>Mean percent by weight of age-0 largemouth bass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blueback herring</td>
<td>2005</td>
<td>--</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Blueback herring</td>
<td>2006</td>
<td>--</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Blueback herring</td>
<td>2007</td>
<td>--</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Black crappie</td>
<td>2005</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Black crappie</td>
<td>2006</td>
<td>154</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Black crappie</td>
<td>2007</td>
<td>84</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bluegill</td>
<td>2005</td>
<td>151</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bluegill</td>
<td>2006</td>
<td>246</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bluegill</td>
<td>2007</td>
<td>152</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Green sunfish</td>
<td>2005</td>
<td>104</td>
<td>2</td>
<td>0.016</td>
</tr>
<tr>
<td>Green sunfish</td>
<td>2006</td>
<td>48</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Green sunfish</td>
<td>2007</td>
<td>27</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>2005</td>
<td>155</td>
<td>7</td>
<td>0.036</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>2006</td>
<td>249</td>
<td>14</td>
<td>0.051</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td>2007</td>
<td>141</td>
<td>12</td>
<td>0.063</td>
</tr>
<tr>
<td>Redear sunfish</td>
<td>2005</td>
<td>141</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Redear sunfish</td>
<td>2006</td>
<td>246</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Redear sunfish</td>
<td>2007</td>
<td>144</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Warmouth</td>
<td>2005</td>
<td>82</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Warmouth</td>
<td>2006</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Warmouth</td>
<td>2007</td>
<td>85</td>
<td>3</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Table 10. Monthly percent by weight of age-0 largemouth bass in largemouth bass diets examined in BCL and SRR during 2005-2007. The p-value <0.05 represents a significant difference between lakes in the percent by weight of age-0 largemouth bass in largemouth bass diets. An asterisk (*) indicates a significant difference between reservoirs.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>n</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>n</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>May</td>
<td>64</td>
<td>0.115</td>
<td>0.288</td>
<td>44</td>
<td>0.019</td>
<td>0.126</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>45</td>
<td>0.097</td>
<td>0.29</td>
<td>30</td>
<td>0.058</td>
<td>0.187</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>29</td>
<td>0.085</td>
<td>0.237</td>
<td>28</td>
<td>0.07</td>
<td>0.257</td>
<td>0.816</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>29</td>
<td>0</td>
<td></td>
<td>30</td>
<td>0.033</td>
<td>0.183</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>31</td>
<td>0</td>
<td></td>
<td>30</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>April</td>
<td>44</td>
<td></td>
<td></td>
<td>41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>41</td>
<td>0.153</td>
<td>0.357</td>
<td>24</td>
<td>0.121</td>
<td>0.328</td>
<td>0.715</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>44</td>
<td>0.193</td>
<td>0.381</td>
<td>44</td>
<td>0.09</td>
<td>0.271</td>
<td>0.148</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>41</td>
<td>0.127</td>
<td>0.304</td>
<td>45</td>
<td>0.042</td>
<td>0.199</td>
<td>0.137</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>43</td>
<td>0</td>
<td></td>
<td>40</td>
<td>0.025</td>
<td>0.157</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>41</td>
<td>0</td>
<td></td>
<td>41</td>
<td>0.149</td>
<td>0.218</td>
<td></td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>20</td>
<td>0</td>
<td></td>
<td>21</td>
<td>0.048</td>
<td>0.218</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>May</td>
<td>30</td>
<td>0.067</td>
<td>0.254</td>
<td>29</td>
<td>0.055</td>
<td>0.206</td>
<td>0.846</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>27</td>
<td>0.137</td>
<td>0.109</td>
<td>27</td>
<td>0.109</td>
<td>0.315</td>
<td>0.735</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>31</td>
<td>0.032</td>
<td>0.18</td>
<td>30</td>
<td>0.055</td>
<td>0.196</td>
<td>0.638</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>30</td>
<td>0.067</td>
<td>0.254</td>
<td>29</td>
<td>0.089</td>
<td>0.275</td>
<td>0.743</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>29</td>
<td>0</td>
<td></td>
<td>30</td>
<td>0.033</td>
<td>0.183</td>
<td>0.326</td>
</tr>
</tbody>
</table>
Table 11. Mean percent weight of diet items found in largemouth bass diets examined in each month in BCL during 2005-2006. Bolded items were the largest contribution to the diet. Italicized items were the second largest contribution to the diet of largemouth bass. Number in parentheses represents the number of diets that contained the prey item. Other fish includes unidentifiable fish remains, catfishes (Ictalurids), mosquitofish (Gambusia spp.), and minnows (Cyprinids). Other represents vegetation and other vertebrates such as frogs and turtles.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>N</th>
<th>Blueback herring</th>
<th>Gizzard shad</th>
<th>Largemouth bass</th>
<th>Sunfish</th>
<th>Other fish</th>
<th>Invertebrates</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>May</td>
<td>64</td>
<td>0.115 (15)</td>
<td>0.418 (30)</td>
<td>0.316 (25)</td>
<td>0.145 (15)</td>
<td>0.006 (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>45</td>
<td>0.097 (6)</td>
<td>0.288 (15)</td>
<td>0.423 (23)</td>
<td>0.169 (9)</td>
<td>0.023 (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>29</td>
<td>0.085 (5)</td>
<td>0.295 (11)</td>
<td>0.509 (17)</td>
<td>0.104 (5)</td>
<td>0.006 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>29</td>
<td>0.553 (17)</td>
<td>0.398 (14)</td>
<td>0.018 (6)</td>
<td>0.031 (6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>31</td>
<td>0.649 (21)</td>
<td>0.286 (9)</td>
<td>0.033 (2)</td>
<td>0.032 (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>April</td>
<td>44</td>
<td>0.0455 (2)</td>
<td>0.494 (22)</td>
<td>0.346 (16)</td>
<td>0.114 (5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>41</td>
<td>0.153 (8)</td>
<td>0.554 (25)</td>
<td>0.156 (9)</td>
<td>0.118 (8)</td>
<td>0.018 (8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>44</td>
<td>0.193 (10)</td>
<td>0.613 (29)</td>
<td>0.182 (9)</td>
<td>0.003 (1)</td>
<td>0.009 (7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>41</td>
<td>0.127 (7)</td>
<td>0.547 (24)</td>
<td>0.310 (14)</td>
<td>0.001 (1)</td>
<td>0.016 (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>43</td>
<td>0.616 (28)</td>
<td>0.323 (16)</td>
<td>0.023 (1)</td>
<td>0.037 (7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>41</td>
<td>0.731 (31)</td>
<td>0.188 (8)</td>
<td>0.049 (2)</td>
<td>0.032 (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>20</td>
<td>0.760 (16)</td>
<td>0.240 (7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>May</td>
<td>30</td>
<td>0.067 (2)</td>
<td>0.251 (9)</td>
<td>0.365 (14)</td>
<td>0.300 (13)</td>
<td>0.017 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>27</td>
<td>0.137 (8)</td>
<td>0.211 (6)</td>
<td>0.584 (19)</td>
<td>0.047 (5)</td>
<td>0.020 (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>31</td>
<td>0.032 (1)</td>
<td>0.630 (20)</td>
<td>0.222 (8)</td>
<td>0.115 (5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>30</td>
<td>0.067 (2)</td>
<td>0.600 (18)</td>
<td>0.300 (9)</td>
<td>0.033 (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>29</td>
<td>0.000 (1)</td>
<td>0.637 (19)</td>
<td>0.345 (10)</td>
<td>0.018 (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 12. Mean percent weight of diet items found in largemouth bass diets examined in each month in BCL during 2005-2006.

Bolded items were the largest contribution to the diet. Italicized items were the second largest contribution to the diet of largemouth bass. Number in parentheses represents the number of diets that contained the prey item. Other fish includes unidentifiable fish remains, catfishes (Ictalurids), mosquitofish (*Gambusia* spp.), and minnows (Cyprinids). Other represents vegetation and other vertebrates such as frogs and turtles.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>N</th>
<th>Blueback herring</th>
<th>Gizzard shad</th>
<th>Largemouth bass</th>
<th>Sunfish</th>
<th>Other fish</th>
<th>Invertebrates</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>May</td>
<td>44</td>
<td>0.044 (2)</td>
<td>0.019 (1)</td>
<td>0.109 (6)</td>
<td>0.281 (13)</td>
<td>0.547 (27)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>30</td>
<td>0.058 (3)</td>
<td>0.173 (7)</td>
<td>0.390 (14)</td>
<td>0.338 (11)</td>
<td>0.041 (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>28</td>
<td>0.070 (2)</td>
<td>0.085 (4)</td>
<td>0.640 (19)</td>
<td>0.113 (5)</td>
<td>0.093 (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>30</td>
<td>0.033 (1)</td>
<td>0.033 (1)</td>
<td>0.600 (18)</td>
<td>0.200 (6)</td>
<td>0.100 (4)</td>
<td>0.033 (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>30</td>
<td>0.033 (1)</td>
<td></td>
<td>0.283 (9)</td>
<td></td>
<td>0.503 (17)</td>
<td>0.168 (7)</td>
<td>0.013 (3)</td>
</tr>
<tr>
<td>2006</td>
<td>April</td>
<td>41</td>
<td>0.186 (8)</td>
<td>0.270 (12)</td>
<td>0.544 (24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>24</td>
<td>0.121 (3)</td>
<td>0.250 (7)</td>
<td>0.514 (13)</td>
<td>0.102 (6)</td>
<td>0.012 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>44</td>
<td>0.061 (3)</td>
<td>0.090 (5)</td>
<td>0.296 (15)</td>
<td>0.261 (16)</td>
<td>0.231 (16)</td>
<td>0.060 (9)</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>45</td>
<td>0.089 (4)</td>
<td>0.042 (2)</td>
<td>0.270 (14)</td>
<td>0.308 (18)</td>
<td>0.194 (18)</td>
<td>0.194 (18)</td>
<td>0.009 (19)</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>40</td>
<td>0.025 (1)</td>
<td>0.674 (28)</td>
<td>0.144 (7)</td>
<td>0.138 (6)</td>
<td>0.019 (5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>41</td>
<td>0.049 (2)</td>
<td>0.828 (35)</td>
<td>0.096 (5)</td>
<td>0.025 (4)</td>
<td>0.003 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>21</td>
<td>0.095 (2)</td>
<td>0.048 (1)</td>
<td>0.742 (16)</td>
<td>0.095 (2)</td>
<td>0.012 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>May</td>
<td>29</td>
<td>0.103 (3)</td>
<td>0.055 (2)</td>
<td>0.359 (11)</td>
<td>0.350 (11)</td>
<td>0.123 (10)</td>
<td>0.009 (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>27</td>
<td>0.109 (3)</td>
<td>0.085 (3)</td>
<td>0.651 (20)</td>
<td>0.139 (8)</td>
<td>0.016 (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>30</td>
<td>0.055 (4)</td>
<td>0.152 (5)</td>
<td>0.549 (18)</td>
<td>0.212 (7)</td>
<td>0.031 (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>29</td>
<td>0.089 (3)</td>
<td>0.431 (14)</td>
<td>0.334 (11)</td>
<td>0.146 (5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>30</td>
<td>0.033 (1)</td>
<td>0.732 (22)</td>
<td>0.166 (5)</td>
<td>0.002 (3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 13. Percent of largemouth bass in BCL and SRR within each size class that contained at least one age-0 largemouth bass during 2005-2007.

<table>
<thead>
<tr>
<th>Year</th>
<th>Size Class (mm)</th>
<th>BCL</th>
<th>SRR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number of diets examined</td>
<td>Percent with largemouth bass</td>
<td>number of diets examined</td>
</tr>
<tr>
<td>2005</td>
<td>&lt;150</td>
<td>26</td>
<td>0.12</td>
</tr>
<tr>
<td>2006</td>
<td>&lt;150</td>
<td>58</td>
<td>0.19</td>
</tr>
<tr>
<td>2007</td>
<td>&lt;150</td>
<td>30</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>150-300</td>
<td>113</td>
<td>0.14</td>
</tr>
<tr>
<td>2005</td>
<td>150-300</td>
<td>143</td>
<td>0.08</td>
</tr>
<tr>
<td>2006</td>
<td>150-300</td>
<td>91</td>
<td>0.08</td>
</tr>
<tr>
<td>2007</td>
<td>&gt;300</td>
<td>59</td>
<td>0.12</td>
</tr>
<tr>
<td>2006</td>
<td>&gt;300</td>
<td>73</td>
<td>0.03</td>
</tr>
<tr>
<td>2007</td>
<td>&gt;300</td>
<td>26</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Figure 9. Mean percent by weight of age-0 largemouth bass contained in black crappie diets from BCL for May (Δ) and June (■) during 2005-2007. Error bars represent two standard errors of the mean.

Age-0 largemouth bass in BCL and SRR showed some diet overlap with small bluegill (< 100 mm). In SRR, bluegill 50-100 mm had diets similar to age-0 largemouth bass during May (Figure 10a). In BCL, the diet of age-0 largemouth bass was similar to bluegill less than 100 mm during June, but was not ecologically significant (≥ 0.60) in May or July (Figure 10b). The diet of age-0 largemouth bass in BCL was primarily comprised of small aquatic invertebrates during May and June before fish began to become an important prey item in July (Table 14). The average size of copepods found in the diet of age-0 largemouth bass was 0.80 mm (Standard
deviation = 0.14) in BCL and 0.86 mm (Standard deviation = 0.20) in SRR. In SRR, age-0 largemouth bass began consuming fish as a major prey item in June (Table 14).

Although competition may occur during the zooplanktivorous stage of age-0 largemouth bass with blueback herring, no blueback herring were captured during May-July. Therefore, diet overlap was assessed between blueback herring captured in September and age-0 largemouth bass captured in May, June, and July in BCL. The diet of blueback herring was most similar to that of age-0 largemouth bass during June; however, it was only 0.39 similar and is not ecologically significant (Figure 11).
Table 14. Percent by weight of age-0 largemouth bass diets from BCL and SRR during May-September 2007. Plankton includes copepods and daphnia. PDUF is partially digested unidentifiable fish and PDUI is partially digested unidentifiable invertebrates. Other is any prey item that did not make up more than 10% of the diet during any month and includes amphipods, caddisflies, crayfish, damselflies, dragonflies, mite, mysis, phantom midge, planorbid, vegetation, water boatman and water striders.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Month</th>
<th>Sunfish</th>
<th>Chironomid</th>
<th>Plankton</th>
<th>Diptera</th>
<th>Mayfly</th>
<th>PDUF</th>
<th>PDUI</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCL</td>
<td>May</td>
<td>0.00</td>
<td>0.14</td>
<td>0.22</td>
<td>0.24</td>
<td>0.00</td>
<td>0.00</td>
<td>0.40</td>
<td>0.00</td>
</tr>
<tr>
<td>SRR</td>
<td>May</td>
<td>0.00</td>
<td>0.13</td>
<td>0.33</td>
<td>0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.47</td>
<td>0.00</td>
</tr>
<tr>
<td>BCL</td>
<td>June</td>
<td>0.02</td>
<td>0.12</td>
<td>0.22</td>
<td>0.33</td>
<td>0.01</td>
<td>0.03</td>
<td>0.47</td>
<td>0.13</td>
</tr>
<tr>
<td>SRR</td>
<td>June</td>
<td>0.23</td>
<td>0.01</td>
<td>0.03</td>
<td>0.07</td>
<td>0.01</td>
<td>0.41</td>
<td>0.16</td>
<td>0.07</td>
</tr>
<tr>
<td>BCL</td>
<td>July</td>
<td>0.22</td>
<td>0.00</td>
<td>0.15</td>
<td>0.06</td>
<td>0.11</td>
<td>0.11</td>
<td>0.22</td>
<td>0.13</td>
</tr>
<tr>
<td>SRR</td>
<td>July</td>
<td>0.28</td>
<td>0.00</td>
<td>0.00</td>
<td>0.05</td>
<td>0.00</td>
<td>0.35</td>
<td>0.20</td>
<td>0.12</td>
</tr>
<tr>
<td>BCL</td>
<td>August</td>
<td>0.30</td>
<td>0.00</td>
<td>0.00</td>
<td>0.05</td>
<td>0.00</td>
<td>0.25</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>SRR</td>
<td>August</td>
<td>0.26</td>
<td>0.00</td>
<td>0.00</td>
<td>0.13</td>
<td>0.00</td>
<td>0.21</td>
<td>0.34</td>
<td>0.06</td>
</tr>
<tr>
<td>BCL</td>
<td>September</td>
<td>0.58</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.11</td>
<td>0.21</td>
<td>0.11</td>
</tr>
<tr>
<td>SRR</td>
<td>September</td>
<td>0.20</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.11</td>
<td>0.49</td>
<td>0.08</td>
<td>0.10</td>
</tr>
</tbody>
</table>
**Figure 10.** Dietary overlap during May-July of age-0 largemouth bass and bluegill and age-0 largemouth bass and redear sunfish from a) SRR and b) BCL during 2005-2007. Solid line indicates ecologically significant overlap (0.6).
Figure 11. Dietary overlap of age-0 largemouth bass collected during May-July and blueback herring collected during September in BCL during 2005-2007. Solid line indicates ecologically significant overlap (0.6).

Species

The age at which the switch to piscivory occurred in largemouth bass differed between the two reservoirs, but the size at which it occurred did not differ. The ontogenetic switch to piscivory was not different among years ($F = 0, p > 0.978$); therefore, all years were combined. Largemouth bass in SRR switched to piscivory 3 weeks earlier than they did in BCL (Figure 12; 95% confidence intervals: 15 August-9 September for BCL versus 17 July-24 July in SRR). Further, largemouth bass from SRR ate a greater percentage of fish in June than those from BCL.
(Figure 13; Table 15). The mean length when ≥ 60% of age-0 largemouth bass diets contained fish had a 95% confidence interval of 59.9-75.3 mm in BCL and 61.6-65.5 mm in SRR, indicating no difference in the mean length of piscivory (Figure 14); therefore, largemouth bass in SRR begin eating fish earlier than in BCL, but the switch happened at the same length.

![Logistic regression curves for percent weight of diet of age-0 largemouth bass containing fish by collection time in BCL and SRR during 2005-2007.](image)

**Figure 12.** Logistic regression curves for percent weight of diet of age-0 largemouth bass containing fish by collection time in BCL and SRR during 2005-2007.
Figure 13. Mean percent weight of fish in the diet of age-0 largemouth bass for each sampling period on BCL (Δ) and SRR (■) during 2005-2007. Error bars represent two standard errors of the mean.
Table 15. Number of non-empty age-0 largemouth bass diets and mean percent by weight of diet containing fish for BCL and SRR by week. Bolded weeks indicate a significant difference between lakes (t-test).

<table>
<thead>
<tr>
<th>Week</th>
<th>BCL</th>
<th>SRR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-May</td>
<td>0</td>
<td>0</td>
<td>0.596</td>
</tr>
<tr>
<td>10-Jun</td>
<td>0.077</td>
<td>0.112</td>
<td>0.596</td>
</tr>
<tr>
<td>17-Jun</td>
<td>0.028</td>
<td>0.927</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>24-Jun</td>
<td>0.053</td>
<td>0.594</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>8-Jul</td>
<td>0.062</td>
<td>0.294</td>
<td>0.064</td>
</tr>
<tr>
<td>22-Jul</td>
<td>0.343</td>
<td>0.521</td>
<td>0.116</td>
</tr>
<tr>
<td>5-Aug</td>
<td>0.506</td>
<td>0.701</td>
<td>0.072</td>
</tr>
<tr>
<td>19-Aug</td>
<td>0.647</td>
<td>0.831</td>
<td>0.188</td>
</tr>
<tr>
<td>2-Sep</td>
<td>0.8</td>
<td>0.85</td>
<td>0.687</td>
</tr>
<tr>
<td>16-Sep</td>
<td>0.783</td>
<td>0.795</td>
<td>0.891</td>
</tr>
<tr>
<td>28-Oct</td>
<td>0.567</td>
<td>0.81</td>
<td>0.053</td>
</tr>
</tbody>
</table>

Figure 14. Logistic regression curves for percent weight of diet of age-0 largemouth bass containing fish by length in BCL and SRR during 2005-2007.
Growth

Age-0 largemouth bass length differed among years when sampling period was a covariate in BCL ($F = 3.918, p = 0.02$) and in SRR ($F = 14.228, p < 0.001$); therefore years were analyzed separately. During 2005, BCL and SRR age-0 largemouth bass had similar lengths throughout the summer ($F = 0.033, p = 0.856$; Figure 15). However, in both 2006 and 2007 SRR age-0 largemouth bass were larger than those from BCL when sampling period was a covariate (2006: $F = 23.073, p < 0.001$; 2007: $F = 20.191, p < 0.001$; Figure 15).

---

**Figure 15.** Mean length of age-0 largemouth bass from each sampling period during each year 2005-2007 in BCL (Δ) and SRR (■).

---

Swim-up dates differed between 2006 and 2007 in BCL ($p = 0.002$) and SRR ($p = 0.001$) (Figure 16). Swim-up dates calculated from age-0 largemouth bass collected after they were recruited to electrofishing gear (8 August 2006 and 22 July 2007) did not differ between reservoirs in 2006 ($p = 0.201$) or 2007 ($p = 0.224$).
Differences in the mean length of age-0 largemouth bass between the reservoirs were due to differences in growth rates. Daily growth rates calculated from otolith daily-ring counts were higher in SRR than in BCL ($p < 0.001$) (Figure 17). Age-0 largemouth bass in SRR initially have a higher growth rate than those in BCL (Figure 17), however, the growth rate in SRR declines through the summer ($p > 0.001$) while the growth rate in BCL remains constant throughout the summer ($p > 0.082$). Therefore, although daily growth rates differed between reservoirs, summer growth rate does not differ between reservoirs (GLM: $p > 0.410$; Figure 18) but SRR age-0 largemouth bass are larger than those in BCL at the same age (Figure 18). The length-weight relationships were different between BCL and SRR (GLM: $F = 10.43; p = 0.001$) (Figure 19).
Figure 16. Age-0 largemouth bass hatch date distributions calculated from otolith daily growth rings from BCL and SRR during 2006 and 2007.
Figure 17. Age-0 largemouth bass mean growth rates (mm/day) calculated from otolith daily growth rings from BCL and SRR during 2006 and 2007.
Figure 18. Age-0 largemouth bass length (mm) at age from BCL and SRR during 2006 and 2007. BCL 2006 regression line: length = 0.69*Age + 6.36. BCL 2007 regression line: length = 0.59*Age + 10.22. SRR 2006 regression line: length = 0.67*Age + 21.135. SRR 2007 regression line: length = 0.58*Age + 25.106.
Mortality

Mortality rates calculated from catch curves of age-0 largemouth bass did not differ between reservoirs. Catch rates from light traps began declining in BCL on 10 June and in SRR on 20 June, therefore, the mortality estimates used these dates as the starting point. Based on the

Figure 19. Logarithmically-transformed length-weight relationships for age-0 largemouth bass from BCL (Δ) and SRR (■) during 2006-2007. BCL regression equation: log (weight) = 2.55 * log (length) – 4.12. SRR regression equation: log (weight) = 2.99 * log (length) - 4.92.
light trap data, BCL had a daily instantaneous mortality rate of -0.065 \( (p = 0.006) \) and SRR had a rate of -0.022 \( (p = 0.039) \) (Figure 20), thus, weekly mortality rates were 37\% for BCL and 14\% for SRR. These rates were not significantly different (GLM: \( F = 3.008, p = 0.114 \)).

An estimate of a mortality rate in BCL from electrofishing data was not significant due to the consistent catch rates of age-0 largemouth bass (Figure 21). Regressions of log\(_e\) CPUE and sampling date for each year and all years combined produced nonsignificant slopes \( (p > 0.167) \).

Catch curves produced an estimate of a mortality rate of age-0 largemouth bass in SRR during 2006 and 2007. The age-0 largemouth bass from SRR were recruited to the electrofishing gear by the first week of August in 2006 and 22 July 2007. These dates were used as the starting point for the catch curve which indicated a weekly instantaneous mortality rate of -0.062 in 2006 and -0.058 in 2007 which gives a weekly mortality rate of 6\% in both 2006 and 2007.

**Water quality**

Difference in water quality measurements between reservoirs were found in pH \( (p = 0.049) \) and secchi depth \( (p = 0.001) \), but there was no difference in temperature between the reservoirs \( (28^\circ C) \) during June and July \( (p=0.395) \) (Table 16). The pH in SRR \( (\text{mean} = 8.4) \) was more basic than it was in BCL \( (\text{mean} = 8.1) \). Additionally, water clarity was higher in BCL \( (\text{mean} = 2.1 \text{ m}) \) than SRR \( (\text{mean} = 1.4 \text{ m}) \).
Figure 20. Catch curve of age-0 largemouth bass in light traps in BCL (Δ) and SRR (■) during 2007. BCL catch-curve regression equation: ln(catch) = -0.65*day +14.48. SRR catch-curve regression equation: ln(catch) = -0.22*day +7.19) represent instantaneous daily mortality rates.
Figure 21. Catch curves from age-0 largemouth bass in BCL (top) and SRR (bottom) during 2005-2007. Significant slopes of the natural logarithm of CPUE after 29 July are indicated.

Table 16. Mean water quality measurements (secchi depth, temperature, and pH) in BCL and SRR during June-July 2007. Bolded lines indicate a significant difference between lakes.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>BCL</th>
<th>SRR</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>Standard deviation</td>
<td>n</td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>secchi depth</td>
<td>9</td>
<td>2.144</td>
<td>0.416</td>
<td>9</td>
<td>1.411</td>
<td>0.176</td>
</tr>
<tr>
<td>temperature</td>
<td>9</td>
<td>28.167</td>
<td>0.1299</td>
<td>9</td>
<td>27.667</td>
<td>1.118</td>
</tr>
<tr>
<td>pH</td>
<td>9</td>
<td>8.056</td>
<td>0.461</td>
<td>9</td>
<td>8.444</td>
<td>0.274</td>
</tr>
</tbody>
</table>
**Plankton**

The most abundant organisms in the plankton samples were copepods and cladocerans. These were also commonly found in the diet of age-0 largemouth bass. The density of these species groups did not differ between reservoirs or collection date (copepods: BCL: 2.28/liter, SRR: 2.36/liter, $F = 0.019$, $p = 0.892$; cladocerans: BCL: 0.36/liter, SRR: 0.32/liter, $F = 0.178$, $p = 0.674$). Further, the size of cladocerans did not differ between reservoirs (BCL: 0.42 mm, SRR: 0.42 mm, $F = 0.311$, $p = 0.579$). However, the size of copepods was larger in SRR (0.71 mm) than in BCL (0.42 mm) ($F = 60.324$, $p < 0.001$; Table 17).

---

**Table 17.** Mean copepod size (mm) in BCL and SRR during June-July 2007. Bolded rows indicate a significant difference between lakes.

<table>
<thead>
<tr>
<th>Week</th>
<th>BCL</th>
<th>SRR</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>mean</td>
<td>Standard deviation</td>
<td>n</td>
</tr>
<tr>
<td>27-May</td>
<td>30</td>
<td>0.462</td>
<td>0.193</td>
<td>30</td>
</tr>
<tr>
<td>10-Jun</td>
<td>90</td>
<td>0.49</td>
<td>0.226</td>
<td>90</td>
</tr>
<tr>
<td>17-Jun</td>
<td>110</td>
<td>0.442</td>
<td>0.201</td>
<td>110</td>
</tr>
<tr>
<td>24-Jun</td>
<td>40</td>
<td>0.456</td>
<td>0.24</td>
<td>40</td>
</tr>
<tr>
<td>1-Jul</td>
<td>40</td>
<td>0.334</td>
<td>0.186</td>
<td>40</td>
</tr>
<tr>
<td>8-Jul</td>
<td>40</td>
<td>0.351</td>
<td>0.164</td>
<td>40</td>
</tr>
<tr>
<td>22-Jul</td>
<td>40</td>
<td>0.377</td>
<td>0.216</td>
<td>30</td>
</tr>
</tbody>
</table>

---

**Discussion**

Recruitment bottlenecks are discrete periods of high mortality (Coleman and Fausch 2007). Such bottlenecks have been shown to occur for largemouth bass at the time of hatching.
(Phillip et al. 1995; Pine III et al. 2000), during the invertebrate feeding stage (Olson et al. 1995), at the time of the ontogenetic diet shift to piscivory (Shelton et al. 1979; Olson 1996), during their first winter (Miranda and Hubbard 1994; Parkos and Wahl 2002), and through the interdependency of these stages (Ludsin and DeVries 1997). My results indicate that a bottleneck may be occurring in June on BCL.

The low CPUE of age-0 largemouth bass is beginning to be displayed in the adult population in BCL, with an increasing PSD which may indicate that there is a decrease in stock-sized largemouth bass. Continued weak year classes can jeopardize sustainable largemouth bass populations (Crawford 2002). My electrofishing samples always produced higher CPUE for age-0 largemouth bass in SRR than in BCL. However, not all gears showed this trend. There was greater nest success in BCL than SRR and light traps initially had a higher CPUE in BCL than SRR. By the end of June, electrofishing and light trap CPUE was lower in BCL than SRR, indicating that a bottleneck for largemouth bass recruitment exists in BCL during this month. Therefore, management needs to focus on the recruitment bottleneck that occurs in June in order to maintain Briery Creek Lake’s status as a trophy fishery.

I observed predation on age-0 largemouth bass by other largemouth bass, which adds support for the hypothesis that a bottleneck for recruitment occurred in June and may be the reason for the lower CPUE observed. BCL largemouth bass consumed more young largemouth bass than in SRR during May 2005, which was the only month with statistically different levels of cannibalism between the reservoirs. This higher amount of predation in BCL compared to SRR could be due to the greater age-0 largemouth CPUE in BCL during this time. Higher levels of cannibalism have been found when age-0 largemouth bass are more abundant (Clady 1974). However, predation on age-0 largemouth bass continues during July when their CPUE becomes
lower in BCL than SRR. Predation of age-0 largemouth bass by largemouth bass could be reducing recruitment; however, since similar levels of cannibalism occurred in SRR throughout most of the summer, it may not be a major impact. Further, despite small sample size of black crappie, this species indeed consumed age-0 largemouth bass in BCL, and black crappie have been known to affect recruitment of largemouth bass (Keast 1985). Although electrofishing surveys indicated that black crappie are more abundant in SRR than BCL, I did not observe black crappie consumption of largemouth bass in SRR. Electrofishing may not be the best way of sampling black crappie populations (Sammons et al. 2002), which could be the reason for small sample sizes of black crappie in BCL. However, more effective sampling gears (i.e. trap nets) for black crappie are difficult to use in BCL due to the abundant woody structure in the reservoir.

Additional evidence for a bottleneck to largemouth bass recruitment was found from diet overlap between age-0 largemouth bass and bluegill. The only time diet overlap was found between age-0 largemouth bass and bluegill in BCL was during June, when small aquatic invertebrates are a large portion of the diet. This potential competition could be one cause of the observed slower growth of age-0 largemouth bass in BCL. Bluegill have been shown to decrease growth rates of age-0 largemouth bass (Brenden and Murphy 2004). Direct examination of diet overlap between blueback herring and age-0 largemouth bass was not possible because blueback herring were only captured in September electrofishing samples. However, these blueback herring were used to assess potential diet overlap with age-0 largemouth bass captured during May-July. From this comparison, there was no indication that diet overlap was occurring. However, diets of blueback herring have been shown to change throughout the year, with the largest prey being consumed in August (Davis and Foltz 1991). Therefore, although I found no
evidence of diet overlap between blueback herring collected in September and age-0 largemouth bass collected in May-July, competition may occur during the early life of age-0 largemouth bass.

Age-0 largemouth bass collected with light traps from BCL had a higher weekly instantaneous mortality than those from SRR; however, the difference was not statistically significant. Timmons et al. (1980) estimated weekly mortality at 20% for age-0 largemouth bass sampled with rotenone, which is lower than the estimated weekly mortality of 37% for age-0 largemouth bass collected with light traps in BCL. Timmons et al. (1980) mortality estimate is similar to what I found for SRR (14%). Other studies have found that mortality during this early life stage of largemouth bass may not negatively affect recruitment (Pine III et al. 2000; Parkos and Wahl 2002). However, limitations in data may have masked the importance of mortality operating at low levels during the summer (Pine III et al. 2000). The lack of significant mortality differences between reservoirs may be due to the limited timeframe that age-0 largemouth bass are vulnerable to light traps and my limited sample size. In my study, light traps may have become ineffective at capturing age-0 largemouth bass in SRR because they grew faster in SRR than BCL, artificially increasing the mortality rate in SRR. BCL age-0 largemouth bass were smaller than those from SRR and should have been vulnerable to light traps longer. The mean length of age-0 largemouth bass in BCL was 49 mm on the last day light traps were used. This size was found four weeks earlier in SRR; therefore, the age-0 largemouth bass in BCL should have still been vulnerable to capture by the light traps. Further, the largest age-0 largemouth bass collected with light traps was 70 mm and age-0 largemouth bass in BCL did not reach this size until the middle of August. Therefore, the estimated mortality rate in BCL may be accurate, while the rate in SRR may be higher than the mortality rate occurring because of the age-0
largemouth bass outgrowing the gear. Later in the first year of life, largemouth bass are susceptible to size-dependent and density-dependent mortality, although this has primarily been during winter (Pine III et al. 2000; Parkos and Wahl 2002). Although I was unable to calculate mortality of age-0 largemouth bass in BCL from electrofishing data, mortality from this time may not be important source of recruitment differences between reservoirs because the low CPUE of age-0 largemouth bass has already become apparent. The importance of early mortality to year-class strength is contrary to other published studies (Olson 1996; Ludsin and DeVries 1997; Fullerton et al 2000; Pine III et al. 2000; Parkos and Wahl 2002) that found that first winter mortality is more important.

Slower growth in BCL than SRR led to differences in the timing of the ontogenetic switch to piscivory between reservoirs. Mean length of age-0 largemouth bass was significantly greater in SRR than BCL by 15 June. The larger-sized age-0 largemouth bass in SRR were able to begin eating fish earlier, which maintained their growth advantage. The length-weight relationships of age-0 largemouth bass in BCL and SRR were different, indicating that the age-0 largemouth bass in SRR were in higher condition than those in BCL. Growth has been linked to swim-up date, with larger age-0 largemouth bass having an earlier swim-up date (Ludsin and DeVries 1997). Age-0 largemouth bass length was different between lakes by mid-June; however, this difference in length was not due to differences in swim-up date. The mean swim-up dates of age-0 largemouth bass were not significantly different. Therefore, growth after swim-up led to the observed size difference between lakes. The initial high growth rates of age-0 largemouth bass in SRR may have been due to the larger size of copepods found in SRR. Olson et al. (1995) found that growth rates during the planktivorous stage of age-0 largemouth bass lead to an earlier switch to piscivory. Larger prey have more energetic benefits to a predator and
allow for greater growth. Further, the energetic cost associated with feeding on larger copepods is reduced (Graeb et al. 2004). Although the mean sizes of copepods in the diets of age-0 largemouth bass in BCL and SRR were not different the smaller-sized copepods may have been digested faster and become unidentifiable in the diet. Partially digested unidentifiable invertebrates (PDUI) were more prevalent in the diets of age-0 largemouth bass in BCL than SRR throughout the summer. The zooplankton samples give an unbiased estimate of the zooplankton size structure; therefore, the size difference found in the zooplankton samples between lakes may be the cause of the slower growth found in BCL.

The smaller-sized copepods from the zooplankton samples in BCL may be a result of lower primary productivity. Dense vegetation and clear water have been linked to lower phytoplankton biomass which can lead to lower biomass of zooplankton (Blindow et al. 2000). Furthermore, dense vegetation in BCL may be contributing to reduced zooplankton size structure, which may be caused by the increase in vegetation and subsequent increase in water clarity over the last ten years. Chlorophyll, a measure of primary productivity, has been shown to decrease with increases in water clarity (Fee et al. 1996). Water clarity is greater in BCL (2.1 m) than SRR (1.4 m) during June, indicating that primary production may be lower in BCL than SRR. Lower phytoplankton productivity may result in less energy being transferred up the food chain, resulting in smaller copepods (Blindow et al. 2000). The reduction in the size of copepods in BCL also could be due to the blueback herring. Blueback herring selectively feed on large-bodied zooplankton (Davis and Foltz 1991). However, gizzard shad are abundant in SRR, and have been shown to have a similar effect as blueback herring on the zooplankton community (Garvey and Stein 1998). Nevertheless, the depressed food quality in BCL is likely the cause of the slower growth of age-0 largemouth bass in BCL, which is further confounded by the later
switch to piscivory. Recruitment may be limited because age-0 largemouth bass rely on less energetically favorable food for a longer time in BCL than they do in SRR.

Capturing age-0 largemouth bass may have been impeded by the dense vegetation found in BCL. Electrofishing capture efficiency decreases as vegetation increases, particularly with small fish (Dewey 1992; Bayley and Austen 2002). However, a narrow band of littoral vegetation along the shoreline, and lack of deeper submersed plant communities, may actually increase electrofishing CPUE during the spring when largemouth bass concentrate in shallow areas of a lake (Wes Porak, Florida Fish and Wildlife Conservation Commission, personal communication). Additionally, the increase in PSD since 1997 in BCL suggests that there has been a decline in stock-sized fish which may be a result of inadequate recruitment.

Conclusions and Management Implications

Briery Creek Lake is experiencing reduced largemouth bass recruitment as compared to historical levels, which has resulted in alteration of the size structure of the adult population. In order to maintain the trophy status of BCL, recruitment of younger individuals needs to occur to replace older individuals that experience mortality. Largemouth bass populations can be maintained through natural reproduction, but the current population in BCL may not be self-sustaining. Therefore, alternatives need to be considered in order to continue the current trophy management goal for Briery Creek Lake.

In some cases, variable recruitment has been linked to factors that cannot be controlled (i.e. temperature, rainfall). However, management decisions have improved recruitment of largemouth bass by manipulating vegetation, water level fluctuations, and size structure. When vegetation was found to be impacting recruitment of largemouth bass, removal of the vegetation
led to greater growth rates of largemouth bass in Wisconsin and Florida (Olson et al. 1998; Allen and Tugend 2002). In Guntersville Lake, Alabama, years that had higher amounts of rain had lower recruitment (Wrenn et al. 1996). Management of reservoirs to mimic hydrology of natural lakes by limiting water flow through the reservoir increased year-class strength on the Tennessee River impoundments and in Oklahoma (Macieina and Bettoli 1998; Boxrucker et al. 2005). This also occurred on smaller impoundments (190-1,145 ha) in Ohio (Garvey et al. 2000). Larger largemouth bass spawn earlier, creating larger offspring that are able to switch to piscivory earlier and experience faster growth rates than largemouth bass that hatch later; therefore, protecting the larger adults has the potential to increase recruitment (Miranda and Muncy 1987). Changing harvest regulations from a 356- to 381-mm minimum length limit was used to protect older fish in Kentucky reservoirs in an attempt to increase recruitment (Buynak et al. 1999). However, in a simulation model, Allen and Pine (2000) showed that recruitment variability did not change with minor length-limit regulation changes. Eutrophic reservoirs have high chlorophyll-a values, leading to high densities of planktivorous fish which may provide higher recruitment of largemouth bass than mesotrophic reservoirs (Allen et al. 1999; Maceina and Bayne 2001).

A bottleneck to largemouth bass recruitment is likely occurring during the month of June in BCL. This conclusion is supported by the fact that catch rates for age-0 largemouth bass in BCL drop lower than SRR by August, despite the fact that BCL had a greater nesting success and higher CPUE in early June. Further support includes: the predation on age-0 largemouth bass, the potential competition with bluegill and lower trypsin activity as compared to Sandy River Reservoir. These factors lead to reduced CPUE and slower growth of age-0 largemouth bass. The amount of cannibalism occurring in BCL may be a function of the reduced bluegill
population that limits the amount of prey available for larger largemouth bass. The reduced bluegill population also may limit the growth potential of age-0 largemouth bass, by reducing the number of age-0 bluegill available as prey (Garvey and Stein 1998). The slower growth of age-0 largemouth bass appears to be a combination of potential competition with bluegill <100 mm and the availability of quality prey resources. Potential impacts of competition may be exacerbated by the fact that prey resources (primarily copepods) may be nutritionally limiting, due to a smaller size structure of these zooplankton. Therefore, management options need to particularly consider factors that affect largemouth bass recruitment.

Supplemental stocking of largemouth bass could be used to increase abundance. Since the recruitment bottleneck is occurring in June, any stocking efforts should occur after this time. If stocking occurs before this time, the stocked fish may experience the same limiting factors that currently impact the naturally reproduced largemouth bass. Therefore, if stocking does occur before July, the stocked fish should be larger than those naturally occurring. Stocking has been shown to successfully increase year class strength in some situations (Buckmeier et al. 2005; Buckmeier et al. 2003; Buynak and Mitchell 1999; Colvin et al. 2008). However, stocking is expensive and has variable success (Hoxmeier and Wahl 2002). Additionally, cannibalism (age-0 largemouth being eaten by older largemouth bass) is occurring in BCL. Such predation can be a significant source of mortality in stocked piscivorous communities (Liao et al. 2004). Hatchery-raised fish have lower predator avoidance capabilities (Olla and Davis 1989). Habituation (caging fish within target habitat before release) can lead to a reduced predation (Schlechte and Buckmeier 2006).

Prey availability was found to be the major factor in determining age-0 largemouth bass density after their first year in Alabama ponds when experimentally examining the effects of
origin of the brood stock (Slaughter et al. 2008). Prey availability was limiting in BCL. Management efforts may be better spent to increase prey availability for the largemouth bass already adapted to the host system (Slaughter et al. 2008). Furthermore, since there have been multiple years of poor recruitment, stocking would need to be done frequently in order to rebuild suitable year-class structure in the population. Therefore, the best management options should include solutions to the factors that are currently limiting natural recruitment.

A change in the size regulations of largemouth bass in BCL may allow for more small largemouth bass to reach larger sizes. The current harvest regulations in BCL allow for the harvest of largemouth bass < 355 mm. The number of age-0 largemouth that live through their first year of life is lower in BCL than SRR. Therefore, protecting the largemouth < 355 mm may decrease fishing mortality for the young fish that are less abundant in BCL compared to SRR. However, a recent review of largemouth bass fisheries indicated that angler’s were voluntarily releasing harvestable largemouth bass, subsequently reducing largemouth bass fishing mortality (Allen et al. 2008). If this is true on BCL then changing the protective-slot length limit on BCL to a minimum length limit may not increase the number of young largemouth bass that would eventually become trophy-sized largemouth bass.

Predation may be a factor limiting the recruitment of age-0 largemouth bass in BCL. Since nearly 20 % of largemouth bass diets in BCL are composed of age-0 largemouth bass, making additional forage fish available may reduce the level of cannibalism. Although the level of predation is not higher in BCL than SRR throughout most of the summer, the presence of forage fish may help to reduce predation on age-0 largemouth bass by offering more available forage choices for predators. Further, it is important to increase first-summer growth to decrease the time largemouth bass are vulnerable to predation (Garvey et al. 1998). Garvey et al. (1998)
found that abundance of largemouth bass after their first winter was strongly related to the number of predators. Gizzard shad are found in SRR, which may be keeping the predation on age-0 largemouth bass at levels that do not negatively impact abundance. However, gizzard shad can quickly grow large enough to avoid predation by stock-sized largemouth bass (Stein et al. 1995). A better alternative may be the addition of threadfin shad *Dorosoma petenense*. In other systems, threadfin shad have been used to successfully improve largemouth bass fisheries (Johnson 1970), but threadfin shad have not proven to be ideal for all systems (Kohler and Ney 1982). Since a pelagic planktivore (blueback herring) is already present in BCL, the addition of another may compound any issues with potential competition. Although potential competition presently was not indicated with blueback herring, this conclusion was based on very limited data and should be viewed with caution. Additionally, blueback herring consume larger prey items than threadfin shad (Davis and Foltz 1991) which could further reduce the availability of prey resources important for early life stages of age-0 largemouth bass. The addition of forage fish should be done with caution. The ideal forage fish should be prolific, stable, efficient at energy transfer, vulnerable to predation, non-emigrating, and innocuous (Ney 1981). However, stocked forage fish should also be easy to control if an unanticipated problem occurs, and the traits of being prolific and innocuous makes that difficult (Ney 1981). Therefore, examination of potential effects on different trophic levels should be examined before additional forage species are added. Furthermore, largemouth bass may grow slower in systems with *Dorosoma* spp. than in those where bluegill are abundant (Stein et al. 1995). Since bluegill are not very abundant in BCL, the slow growth and low survival of age-0 largemouth bass that already occur may be magnified during the planktivorous stage through competition with additional planktivores. Prey
(e.g. bluegill) that has co-evolved with the existing predator (largemouth bass) may be a better choice for stocking (Ney 1981).

The recruitment bottleneck for age-0 largemouth bass in BCL likely occurs early in their life, when zooplankton is their primary food resource; therefore, increases in primary productivity may alleviate this limiting factor. Water clarity has been linked to primary production, with lower water clarity indicating higher primary production (Maceina et al. 1996). Since water clarity is higher in BCL, primary production may be lower than it is in SRR. Additions of phosphorus, the likely limiting nutrient for phytoplankton, may increase recruitment success and decrease the time it takes largemouth bass to reach preferred size (381 mm) (Maceina et al. 1996), this could be done by the addition of fertilizer (Diana et al. 1991). However, the vascular plants that are abundant in BCL may be able to utilize the fertilizer prior to phytoplankton, thus unintentionally increasing macrophyte coverage. Therefore, a reduction in macrophytes is necessary prior to any addition of fertilizer. By reducing macrophytes, more available nutrients can be utilized by phytoplankton, thus increasing primary production (Maceina et al. 1992; Sammons et al. 2003). Dense macrophytes can provide structure for avoiding predation; however, growth of age-0 largemouth bass can be significantly reduced in heavily vegetated areas (Wrenn et al. 1996). Reduced vegetation can lead to increases in the abundance of age-0 largemouth bass, as well as increases in bluegill growth (Trebitz et al. 1997). A reduction in the vegetation could be beneficial to the recruitment of largemouth bass. Growth rates of largemouth bass have been increased after mechanical removal of 20% of shoreline vegetation; however, vegetation quickly returned (Olson et al. 1998). Thus mechanical removal may be impractical for long-term control.
Biological control of aquatic macrophytes can be a long-lasting and cost-effective method for controlling troublesome species (Malecki et al. 1993). The use of triploid grass carp *Ctenopharyngodon idella* has been an effective method for reducing and controlling vegetation in lakes and reservoirs (Mitzner 1978; Bettoli et al. 1992; Bettoli et al. 1993; Bonar et al. 2002;). Removal of vegetation has lead to increases in age-0 largemouth bass growth (Bettoli et al. 1992). Additionally, the biomass of > age-1 largemouth bass did not change in a previous study (Bettoli et al 1993) and there were no negative effects of grass carp addition to the littoral fish community (Killgore et al. 1998). Increases in planktivorous fish can also result from vegetation removal (Maceina et al. 1992; Sammons et al. 2003). A reduction in vegetation and an increase in planktivorous fish should cause largemouth bass to actively search for prey, which should increase foraging success (Sammons et al. 2003). Fishing opportunities may also improve due to changes in bass behavior and better angler access. Due to greater growth rates of largemouth bass in areas with sparse vegetation, the amount of effort to catch a memorable-sized largemouth bass may decrease (Maceina and Reeves 1996). There was no relationship between adult largemouth bass abundance and amount of vegetation in Florida lakes (Hoyer and Canfield Jr. 1996), so vegetation reduction may have positive impacts on age-0 largemouth bass without impacts on adult fish. Growth of largemouth bass has been shown to be maximized with intermediate levels of vegetation (Trebitz et al. 1997). Caution must be used in stocking grass carp, however, as effective rates are reported to be variable and overstocking can result in total eradication of aquatic vegetation (Bonar et al. 2002) and subsequent unintended consequences. Planning and evaluation should be part of any stocking program should be part of any stocking program to ensure stocking does not waste time and money or damage the existing environment (Murphy and Kelso 1986). Stocking grass carp will undoubtedly change the habitat of BCL. The
grass carp will consume aquatic vegetation preferentially and change the vegetation species composition as well as the amount of vegetation coverage. This may change predator-prey interactions by decreasing the amount of refuge from predation for prey. The goal is to increase prey availability for age-0 largemouth bass during the first two months of life; however, other unattended consequences could occur. Therefore, the ecological effects need to be monitored, which will require community monitoring that examines trends in all species abundances, survival, and growth.

Recommendations

Specific management recommendations for Briery Creek Lake include:

1. Stock grass carp to control vegetation. Stocking should be done with triploid grass carp that are large enough to avoid predation (> 10 inches). Rates of stocking should be between 10 and 20 fish per vegetated acre (Sutton and Vandiver Jr. 1986), as total vegetation removal occurred in Lake Conroe, Texas, with a stocking rate of 30 fish per acre (Bettoli et al. 1992). The control of vegetation may be adequate to reduce the effects of the recruitment bottleneck in BCL. However, other options listed below might be considered.

2. Fertilization can be initiated once aquatic macrophyte coverage in the reservoir is reduced, usually 1-2 years following grass carp stocking (Bettoli et al. 1992). Fertilization should be done between May and September with a nitrogen-to-phosphorus (N:P) ratio $\geq 25:1$, and approximately 1 mg m$^{-3}$ d$^{-1}$ of P should be added (Carpenter et al. 1996; Carpenter et al. 1998; Vadeboncoeur et al. 2001). The increase in primary production may result in a natural increase in blueback herring, which could become an
important prey resource for largemouth bass. If blueback herring do not become abundant, stocking of threadfin shad could occur. Stocking rates should be at least 125 fish per hectare (> 300 fish/acre) (Hale 1996).

3. If supplemental stocking of largemouth bass is pursued, it should take place after June to avoid the recruitment bottleneck that the naturally reproducing population is experiencing. A supplemental stocking rate of 10-41 fish / hectare should create the greatest benefit to the population (Buckmeier et al. 2003). If stocking occurs before the end of June, stocked fish should be larger than the length of age-0 largemouth bass that are currently impacted by the bottleneck (Table 18).

---

**Table 18.** Mean length (mm) of age-0 largemouth bass by date in Briery Creek Lake and recommended mean length for stocking based on length of age-0 largemouth bass collected in Sandy River Reservoir one week later.

<table>
<thead>
<tr>
<th>Date</th>
<th>Mean length currently found (mm)</th>
<th>Recommended minimum mean length for stocking (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-Jun</td>
<td>30</td>
<td>44</td>
</tr>
<tr>
<td>17-Jun</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>24-Jun</td>
<td>33</td>
<td>54</td>
</tr>
</tbody>
</table>
CHAPTER 3. Trypsin activity in largemouth bass during their first summer: implications for recruitment.

Abstract

Largemouth bass populations are typically self-sustaining through natural reproduction; however, loss of age-0 fish to biotic and abiotic factors can negatively affect recruitment. Prolonged reduced recruitment can diminish future angler effort and satisfaction, and thus, the economic benefits associated with sport fishing. In Virginia, Briery Creek Reservoir has continually produced trophy largemouth bass (> 3.6 kg), but recent electrofishing assessments of age-0 largemouth bass revealed low catch per unit effort as compared to a nearby reservoir, Sandy River Reservoir. In order to understand the factors affecting recruitment in this population, I examined the activity of the dietary enzyme trypsin, which is responsible for the digestion and conversion of protein. Trypsin activity is related to food intake and stomach fullness; therefore, starvation or reduced food intake decreases the activity of the enzyme. Trypsin activity increased with length of age-0 largemouth bass therefore; trypsin activity was standardized for age-0 largemouth bass length. Age-0 largemouth bass from Briery Creek Reservoir had reduced trypsin activity on 23 June and 27 June, as compared to those from Sandy River Reservoir. Reduced trypsin activity may be a result of a nutritionally poor diet. The nutritionally poor diet may be a result of reduced zooplankton size in Briery Creek Lake as compared to Sandy River Reservoir. This nutritional deficiency may be leading to the slow growth and low relative abundance of age-0 largemouth bass in Briery Creek Lake.
Introduction

Largemouth bass *Micropterus salmoides* are a popular target of recreational fishing throughout the United States and have considerable economic importance. Largemouth bass populations are typically self-sustaining through natural reproduction, building nests in shallow water areas that contain rocks, stumps or slopes (Miller and Kramer 1971). Hatching success in these protected habitats can exceed 80% (Miller and Kramer 1971); however, mortality of eggs and larval fish occurs due to both biotic (e.g., competition and predation) and abiotic (e.g., climate) factors. These sources of mortality can be significant and cause variable recruitment (Garvey et al. 2002), which can diminish future angler effort and satisfaction, as well as the economic benefits associated with sport fishing. Further, weak year classes may jeopardize trophy fisheries (Crawford et al. 2002). Therefore, stable recruitment is crucial for the continued success of largemouth bass fisheries.

The Virginia Department of Game and Inland Fisheries (VDGIF) manages Briery Creek Lake, a reservoir that consistently produces trophy-sized (> 3.6 kg) largemouth bass. Briery Creek Lake (BCL), an 845-acre impoundment in Prince Edward County, has received national exposure since opening to fishing in 1989 (Wilson and Dicenzo 2002). Managers employ a protective-slot length limit (14-24 inches) to promote trophy bass potential in BCL. Recent electrofishing surveys that targeted age-0 largemouth bass indicated recruitment differences between BCL and a nearby reservoir, Sandy River Reservoir. Catch rate from BCL electrofishing surveys in 2004 was 17 age-0 largemouth bass per hour, while Sandy River Reservoir had a catch rate of 364 age-0 largemouth bass per hour. Sandy River Reservoir (SRR), a 740-acre impoundment in Prince Edward County, was used as a reference site for BCL. These reservoirs are similar in size and depth and have similar fish assemblages. These reservoirs are
in the same geographic region, and experience similar weather conditions throughout the year, thereby allowing for the elimination of any broad-scale abiotic factors from analysis.

Age-0 largemouth bass were smaller and less abundant in BCL than in SRR during 2005-2007 (Chapter 2). I found predation on age-0 largemouth bass and competition between age-0 largemouth bass and bluegill *Lepomis macrochirus* to be potential factors limiting recruitment of largemouth bass in BCL (Chapter 2). Additionally, the observed lower CPUE and slower growth may be due to zooplankton-prey resources potentially limiting recruitment in BCL. In BCL, copepods averaged 40% smaller than they were in SRR (Chapter 2). I analyzed the digestive enzyme trypsin in age-0 largemouth bass throughout their first summer to further examine food resources as a potential limiting factor to the recruitment of largemouth bass in BCL.

Trypsin is the enzyme responsible for the digestion and conversion of protein into energy that can be used for growth. Trypsin is important not only for carnivorous animals, but also for omnivorous animals which need high trypsin activity in order utilize the small amount of protein found in their diets (Hofer 1979). Low trypsin activity in the digestive tract suggests reduced food intake, low food availability, or low food quality (Pedersen et al. 1987; Einarsson et al. 1997); thus, trypsin can be used to reveal nutritional deficiencies (Applebaum and Holt 2003; Cara et al. 2007). For example, starvation lowered trypsin activity in carp *Catla catla* (Kumar et al. 2000). Higher trypsin activity has been linked to greater growth rates (Baragi and Lovell 1986; Lemieux et al. 1999); therefore, I investigated differences in trypsin activity in age-0 largemouth bass. Differences in trypsin activity between BCL and SRR may help explain the slower growth rates found in BCL as compared to SRR (Chapter 2). Trypsin activity has been linked to food quality (Einarsson et al. 1997). Such reduced food quality may be a result of smaller-sized zooplankton found in BCL as compared to SRR (Chapter 2).
The goal of this study was to determine if there were differences in trypsin activity between age-0 largemouth bass in BCL and age-0 largemouth bass in SRR. Lower trypsin activity in age-0 largemouth bass from BCL may indicate that food availability is a limiting factor for recruitment of age-0 largemouth bass in BCL, and may help explain the observed recruitment bottleneck and slower growth of age-0 largemouth bass in BCL (Chapter 2).

**Methods**

I used light traps in 2007 to collect age-0 largemouth bass before they were susceptible to electrofishing gear. Twenty light traps were constructed (B. Halloren, Louisiana State University, personal communication) and set ten nights during June-July in each reservoir. Each light trap was anchored to the bottom, and suspended in the water column by a float such that the trap was just below the surface. All 20 traps were set at dusk within the littoral zone (0.5-2.0 m) of the reservoir, spaced approximately 10 meters apart. The traps were retrieved the following morning and up to 10 trapped age-0 largemouth bass were temporarily stored on ice before being stored at -20°C until trypsin analysis was completed. I collected up to 10 age-0 largemouth bass monthly from each lake with pulsed-DC electrofishing (120 pulses/second; 4-6 amps), and treated them similarly for later trypsin analysis.

Trypsin analysis methods were modified from Uys and Hecht (1987). Fish were dissected to remove their stomachs and digestive tracts. The stomach and digestive tract were emptied, ground in 1 ml of a homogenization buffer (20 mM Tris, 1 mM EDTA, and 10 mM CaCl₂, adjusting pH to 7.4 with hydrochloric acid), and centrifuged using an Eppendorf refrigerated centrifuge at 10,000 rpm for five minutes. A 100 µl sample of the supernatant was added to a 300-µl well on a 96-well UV-plate. Each plate contained 100 µl each of a blank
(distilled water), five trypsin standards ranging from 0.125-20 µg/µl, and the samples, all in duplicate. Each well then received 200 µl of a substrate solution (40 mM Tris, 10 mM CaCl₂, and 1.04 mM TAME: p-toluenesulphonyl-L-arginine methyl ester, adjusting the pH to 8.0 with hydrochloric acid) before being placed into a spectrometer where changes in absorbance at 247 nm were used to measure trypsin activity (µg/µl) at 27.5°C, the preferred temperature of largemouth bass (Venables et al. 1978). This substrate was used because it has a high sensitivity and selectivity for trypsin (Uys and Hecht 1987). The absorbance was recorded every 10 seconds for 6 minutes total. The change in absorbance of the known standards across time was used to create a standard curve, which was used to determine the trypsin activity (µg/µl) of the unknown samples.

Applebaum and Holt (2003) found that Trypsin activity increases as fish grow; I found the same relationship in preliminary analyses (Figure 22). Therefore, I standardized all measures of trypsin activity (µg/µl) by dividing the observed activity by the length (mm) of the fish and applied a logₑ transformation as in Pedersen (1987). I used this standardized value to determine the effects of lake and gear on mean trypsin activity using an ANCOVA, with date as the covariate. Any factors that were significant in determining mean standardized trypsin activity were further analyzed with two-sample t-tests with a Bonferroni correction.

Nutritional status was further examined by evaluating stomach fullness (dry-weight of stomach contents per weight of fish) and a condition factor. Stomach fullness was calculated by dividing the dry weight of the stomach contents by the weight of the age-0 largemouth bass. A two-sample z-test with a Bonferroni correction for each date was used to determine significant differences between lakes. A condition index was calculated using a Fulton-type condition factor (K):
\[ K = \frac{\text{Weight}}{\text{Length}^3} \times 100,000 \]

where weight is the weight in g of the age-0 largemouth bass and length is their length in mm. A two-sample \( t \)-test with a Bonferroni correction for testing multiple dates was used to examine differences between reservoirs.

**Figure 22.** Natural logarithm of trypsin activity by length for age-0 largemouth bass in Briery Creek Lake (BCL) (Δ) and Sandy River Reservoir (SRR) (□). Each regression line is significant \((p < 0.001)\). BCL regression line: \( \ln(\text{trypsin activity}) = 0.24 \times \text{Length} - 0.01 \). SRR regression line: \( \ln(\text{trypsin activity}) = 0.20 \times \text{Length} + 0.35 \)
Results

No significant differences in the mean trypsin activity were found between the two lakes ($p = 0.549$). However, significant differences in mean trypsin activity between gear types ($p = 0.001$) and the dates of collection ($p = 0.002$) warranted further analysis. Mean trypsin activity per mm of age-0 largemouth bass in each lake was greater when fish were caught with electrofishing gear rather than with light traps. Since trypsin activity was significantly different between gear types, each gear type was analyzed separately. There was no difference in trypsin activity between lakes when age-0 largemouth bass were collected with electrofishing gear ($p = 0.186$) or light traps ($p = 0.530$).

Mean trypsin activity of age-0 largemouth bass was significantly different among sampling dates ($p = 0.001$); therefore, each sampling date was analyzed individually for differences in mean trypsin activity between lakes (Table 19). Two dates in June had significant differences in mean trypsin activity between lakes. Mean trypsin activity was significantly higher in SRR than BCL on 23 June ($p < 0.001$) and 27 June ($p = 0.009$) (Table 18).
Table 19. Mean trypsin activity (adjusted for length) in BCL and SRR, and $p$-value of a two-sample $t$-test with a Bonferroni correction. Bolded rows indicate dates that had significant differences in trypsin activity between lakes.

<table>
<thead>
<tr>
<th>Date</th>
<th>Gear</th>
<th>BCL</th>
<th></th>
<th></th>
<th></th>
<th>SRR</th>
<th></th>
<th></th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-May</td>
<td>Light Trap</td>
<td>10</td>
<td>0.117</td>
<td>0.042</td>
<td>11</td>
<td>0.14</td>
<td>0.049</td>
<td></td>
<td>0.265</td>
</tr>
<tr>
<td>10-Jun</td>
<td>Light Trap</td>
<td>10</td>
<td>0.157</td>
<td>0.078</td>
<td>10</td>
<td>0.107</td>
<td>0.038</td>
<td></td>
<td>0.092</td>
</tr>
<tr>
<td>15-Jun</td>
<td>Light Trap</td>
<td>10</td>
<td>0.119</td>
<td>0.052</td>
<td>4</td>
<td>0.077</td>
<td>0.024</td>
<td></td>
<td>0.058</td>
</tr>
<tr>
<td>17-Jun</td>
<td>Light Trap</td>
<td>10</td>
<td>0.084</td>
<td>0.039</td>
<td>2</td>
<td>0.083</td>
<td>0.014</td>
<td></td>
<td>0.925</td>
</tr>
<tr>
<td>23-Jun</td>
<td>Light Trap</td>
<td>10</td>
<td>0.05</td>
<td>0.02</td>
<td>11</td>
<td>0.095</td>
<td>0.028</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>27-Jun</td>
<td>Electrofishing</td>
<td>10</td>
<td>0.034</td>
<td>0.015</td>
<td>10</td>
<td>0.076</td>
<td>0.039</td>
<td></td>
<td>0.009</td>
</tr>
<tr>
<td>29-Jun</td>
<td>Light Trap</td>
<td>4</td>
<td>0.05</td>
<td>0.032</td>
<td>10</td>
<td>0.054</td>
<td>0.028</td>
<td></td>
<td>0.833</td>
</tr>
<tr>
<td>6-Jul</td>
<td>Light Trap</td>
<td>7</td>
<td>0.031</td>
<td>0.009</td>
<td>2</td>
<td>0.049</td>
<td>0.02</td>
<td></td>
<td>0.411</td>
</tr>
<tr>
<td>14-Jul</td>
<td>Light Trap</td>
<td>10</td>
<td>0.067</td>
<td>0.043</td>
<td>10</td>
<td>0.089</td>
<td>0.035</td>
<td></td>
<td>0.310</td>
</tr>
<tr>
<td>23-Jul</td>
<td>Electrofishing</td>
<td>10</td>
<td>0.107</td>
<td>0.073</td>
<td>10</td>
<td>0.121</td>
<td>0.085</td>
<td></td>
<td>0.702</td>
</tr>
<tr>
<td>9-Aug</td>
<td>Electrofishing</td>
<td>10</td>
<td>0.107</td>
<td>0.066</td>
<td>5</td>
<td>0.106</td>
<td>0.044</td>
<td></td>
<td>0.974</td>
</tr>
<tr>
<td>18-Sep</td>
<td>Electrofishing</td>
<td>8</td>
<td>0.129</td>
<td>0.075</td>
<td>7</td>
<td>0.109</td>
<td>0.056</td>
<td></td>
<td>0.567</td>
</tr>
</tbody>
</table>

Stomach fullness did not differ between reservoirs on any sampling date. The amount of food by dry weight in stomachs of age-0 largemouth bass was the same per gram of fish weight (mean in both BCL and SRR = 0.01). However, the index used to assess condition did differ between reservoirs during the middle of June and July (Table 20). Age-0 largemouth bass in SRR had a condition was greater than those from BCL.
Table 20. Mean condition (K) of age-0 largemouth bass in BCL and SRR during 2007 and corresponding p-value of two-sample t-test with a Bonferroni correction. Bolded rows indicate dates that had significant differences in condition between lakes.

<table>
<thead>
<tr>
<th>Date</th>
<th>BCL N</th>
<th>Mean</th>
<th>SD</th>
<th>SRR N</th>
<th>Mean</th>
<th>SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-May</td>
<td>10</td>
<td>2.015</td>
<td>0.338</td>
<td>11</td>
<td>2.024</td>
<td>0.147</td>
<td>0.938</td>
</tr>
<tr>
<td>10-Jun</td>
<td>10</td>
<td>1.938</td>
<td>0.207</td>
<td>10</td>
<td>2.049</td>
<td>0.173</td>
<td>0.200</td>
</tr>
<tr>
<td>15-Jun</td>
<td>10</td>
<td>1.811</td>
<td>0.188</td>
<td>4</td>
<td>1.885</td>
<td>0.352</td>
<td>0.714</td>
</tr>
<tr>
<td>17-Jun</td>
<td>10</td>
<td>1.913</td>
<td>0.156</td>
<td>2</td>
<td>2.240</td>
<td>0.013</td>
<td>0.000</td>
</tr>
<tr>
<td>23-Jun</td>
<td>10</td>
<td>1.775</td>
<td>0.150</td>
<td>11</td>
<td>2.231</td>
<td>0.159</td>
<td>0.000</td>
</tr>
<tr>
<td>27-Jun</td>
<td>10</td>
<td>1.942</td>
<td>0.230</td>
<td>10</td>
<td>2.149</td>
<td>0.176</td>
<td>0.037</td>
</tr>
<tr>
<td>29-Jun</td>
<td>4</td>
<td>1.872</td>
<td>0.155</td>
<td>10</td>
<td>2.120</td>
<td>0.328</td>
<td>0.081</td>
</tr>
<tr>
<td>6-Jul</td>
<td>7</td>
<td>1.779</td>
<td>0.234</td>
<td>2</td>
<td>2.179</td>
<td>0.024</td>
<td>0.004</td>
</tr>
<tr>
<td>14-Jul</td>
<td>10</td>
<td>1.979</td>
<td>0.230</td>
<td>10</td>
<td>2.335</td>
<td>0.119</td>
<td>0.001</td>
</tr>
<tr>
<td>23-Jul</td>
<td>10</td>
<td>1.908</td>
<td>0.135</td>
<td>10</td>
<td>2.072</td>
<td>0.170</td>
<td>0.029</td>
</tr>
<tr>
<td>9-Aug</td>
<td>10</td>
<td>2.079</td>
<td>0.307</td>
<td>5</td>
<td>2.048</td>
<td>1.680</td>
<td>0.778</td>
</tr>
<tr>
<td>18-Sep</td>
<td>8</td>
<td>2.127</td>
<td>0.185</td>
<td>7</td>
<td>2.045</td>
<td>0.133</td>
<td>2.690</td>
</tr>
</tbody>
</table>

Discussion

Age-0 largemouth bass from BCL had a lower trypsin activity than those from SRR during the end of June, indicating that these fish may be consuming a diet of lower nutritional value. This lower nutritional intake may subsequently result in the slower growth, lower survival, and lower CPUE of age-0 largemouth bass in BCL, as compared to age-0 largemouth bass in SRR (Chapter 2).

Age-0 largemouth bass in BCL were smaller in length than those in SRR, particularly during the latter part of June (24 Jun 07: BCL = 33 mm SRR = 48 mm) (Chapter 2), and exhibited reduced trypsin activity in late June. This reduced trypsin activity may be caused by
reduced food intake, which could potentially limit growth rates (Lemieux et al. 1999). There were no differences in trypsin activity between the study lakes early in June, but it may take 20 days of reduced food intake before differences in trypsin activity are observed (Applebuam and Holt 2003). If this is true for age-0 largemouth bass, the nutritional deficiency apparent in late June may be due to a poor diet early in June. Further, trypsin activity has been shown to increase early in life of striped bass *Morone ssaxatilis* regardless of diet (Baragi and Lovell 1986) and juvenile yellow perch *Perca flavescens* had sufficient enzyme levels regardless of diet (Kolkovski et al. 2000). At the time of first feeding, levels of trypsin activity is generally sufficient to digest exogenous sources of protein (Baragi and Lovell 1986). The lack of early differences in trypsin activity between lakes may be due to the trypsin enzymes readily staying in the digestive tract and not being excreted with digested food (Pedersen and Hjelmeland 1988). As prolonged starvation or reduced food intake occurs, trypsin activity decreases (Baragi and Lovell 1986; Pedersen et al. 1987; Pedersen and Hjelmeland 1988; Einarsson et al. 1997; Lemieux et al. 1999; Applebuam and Holt 2003), which may explain the later differences in trypsin activity of age-0 largemouth bass between lakes. As the age-0 largemouth bass switch to piscivory, differences in trypsin activity between lakes were no longer apparent. The length of age-0 largemouth bass at piscivory (60 mm) was not different between lakes, but since the age-0 largemouth bass were consistently longer in SRR, the timing of the switch to piscivory in BCL occurred three weeks later during mid-August (Chapter 2). This later switch to piscivory in BCL further suggests that food availability for largemouth bass early in life may be the cause of the slow growth, reduced survival, and ultimately, a recruitment bottleneck in BCL.

The lower trypsin activity observed in BCL could be caused by either reduced food intake or reduced conversion efficiency of prey consumed (Lemieux et al. 1999). Lower trypsin
activity can indicate that fish are experiencing starvation (Einarsson et al. 1996). Reduced food intake can be a result of limited prey resources (Pedersen et al. 1987). In present study there were no differences in mean density of zooplankton between reservoirs, but copepods were larger in SRR than BCL (Chapter 2). Applebaum and Holt (2003) reported that larval red drum *Sciaenops ocellatus* had lower trypsin activity when fed smaller prey than when fed larger prey. Trypsin activity in larval carp in India drastically declined when the carp were withheld food, indicating that feeding on zooplankton regulated trypsin activity (Chakrabarti and Sharma 1997). Lower trypsin activity in BCL could be the result of nutritional deficiency, caused by the size difference of prey resources in the two lakes. Assimilation rates of prey should be similar with similar densities of prey (Boehlert and Yoklavich 1984). The stomach fullness that I measured was similar between reservoirs; therefore, the difference in trypsin activity and the resulting differences in condition (K), length-weight relationships (chapter 2) and growth were most likely a result of a nutritional deficiency in BCL.

The ability of fish to turn food into body growth (conversion efficiency) is directly proportional to trypsin activity (Pedersen et al. 1987; Lemieux et al. 1999). Slow growth and reduced trypsin are symptoms of low food quality. Trypsin activity is reduced in BCL and otolith aging suggests that growth is slower in BCL than SRR (Chapter 2); therefore, age-0 largemouth bass may be limited by a nutritional deficiency in BCL.

The length of age-0 largemouth bass was important in determining trypsin activity, which may be due to the ontogenetic diet shift. Trypsin activity increased as age-0 largemouth bass grew and began consuming more nutritionally valuable prey, namely fish. When trypsin activity was standardized for the length of age-0 largemouth bass, there were significant differences in trypsin activity of age-0 largemouth bass between lakes during the latter part of June, suggesting
that a difference in the diet of age-0 largemouth bass between lakes may be more important in
determining trypsin activity than the differences in length of age-0 largemouth bass.

The difference in trypsin activity between age-0 largemouth bass in BCL and SRR may
be due to a difference in their diet. Carnivores have a higher trypsin activity than omnivores or
herbivores (Hofer and Schiemer 1981). The difference in trypsin activity between lakes may be
due to the age-0 largemouth bass beginning to consume fish earlier in SRR than BCL. However,
the switch to piscivory in SRR did not occur until late July (Chapter 2) and the difference in
trypsin activity between lakes was only significant during late June, which further supports that
early diet may be nutritionally limiting in BCL.

The difference in trypsin activity of age-0 largemouth bass between lakes in late June
indicates that a nutritional deficiency occurred during June in BCL. This nutritional deficiency
may be a result of the smaller-sized copepods in BCL (Chapter 2). This may have led to the
slower growth, reduced survival, and ultimately a recruitment bottleneck in BCL. Therefore,
management actions that address early diet of age-0 largemouth bass are needed to maintain the
trophy potential in Briery Creek Lake.
SUMMARY AND CONCLUSIONS

1. The Virginia Department of Game and Inland Fisheries manages Briery Creek Lake, which consistently produces trophy (> 3.6 kg) largemouth bass, creating an extremely popular fishery. However, recent surveys indicated that there may be recruitment differences between Briery Creek Lake and other nearby reservoirs, specifically Sandy River Reservoir.

2. Catch per unit effort (CPUE) of age-0 largemouth bass has been lower in Briery Creek Lake than in Sandy River Reservoir since 2003. This lower CPUE in Briery Creek Lake has raised concern that without management actions the trophy management goal may be unattainable.

3. Potential limiting factors for largemouth bass recruitment were examined in a comparative study between Briery Creek Lake and a similar reservoir, Sandy River Reservoir. The potential limiting factors examined included angling, predation and potential competition, and food availability.

4. Angling impacts on the recruitment of largemouth bass were assessed by closing two coves in Briery Creek Lake. These closed areas were compared with open areas in Briery Creek Lake. Excluding anglers to provide sanctuaries for largemouth bass to spawn did not result in increases in nest success, CPUE, or growth.

5. Nest success of age-0 largemouth bass was higher in Briery Creek Lake than Sandy River Reservoir.
6. CPUE from light traps in Briery Creek Lake were initially higher than in Sandy River Reservoir. However, CPUE for light traps became higher in Sandy River Reservoir by the end of June.

7. Electrofishing CPUE was always higher in Sandy River Reservoir than Briery Creek Lake.

8. Predation on age-0 largemouth bass in Briery Creek Lake did occur, primarily by largemouth bass. However, the amount of predation on age-0 largemouth bass in Briery was not significantly different from Sandy River Reservoir throughout most of the summer.

9. Diet overlap between age-0 largemouth bass and bluegill did occur in Briery Creek Lake during June. This may indicate that there is potential for competition between these species.

10. The length at which age-0 largemouth bass became piscivorous was similar between the two reservoirs. However, the switch occurred three weeks earlier in Sandy River Reservoir due to faster growth rates during June.

11. Growth rates of age-0 largemouth bass were initially higher in Sandy River Reservoir than Briery Creek Lake. The summer growth rates were not different between reservoirs. However, since growth rate during June was higher in Sandy River Reservoir, age-0 largemouth bass were longer in Sandy River Reservoir than they were in Briery Creek Lake throughout the summer.

12. Mortality estimates were not different between reservoirs. However, this is based on limited data.
13. The density of zooplankton did not differ between reservoirs. However, the mean length of copepods was significantly longer in Sandy River Reservoir than Briery Creek Lake during the age-0 largemouth bass invertebrate-feeding stage.

14. The smaller-sized prey resources may be causing a nutritional deficiency in Briery Creek Lake. This nutritional deficiency is evident in the lower trypsin activity of age-0 largemouth bass in Briery Creek Lake as compared to Sandy River Reservoir during the latter part of June.

15. Conclusions from this study are:

a. A largemouth bass recruitment bottleneck is occurring during June in Briery Creek Lake. This bottleneck is causing a change in the adult population size structure and may negatively impact the trophy largemouth bass fishery in Briery Creek Lake.

b. The bottleneck is likely caused by a nutritional deficiency during the age-0 largemouth bass invertebrate-feeding stage, which may be a result of the smaller-size structure of copepods.

c. The lower diet quality for age-0 largemouth bass in Briery Creek Lake is leading to slower growth and ultimately to a lower relative abundance than Sandy River Reservoir. This slower growth may be increasing the amount of time that age-0 are vulnerable to cannibalism and competition with bluegill.

d. Reducing vegetation in Briery Creek Lake may help alleviate the limiting factors to recruitment of largemouth bass. A reduction in vegetation could increase primary production and allow zooplankton to reach larger sizes. Larger-sized
zooplankton could increase age-0 largemouth bass growth rates and allow for an earlier switch to piscivory.

16. Recommendations for the continued trophy largemouth bass fishery in Briery Creek Lake:
   a. Stock grass carp to control vegetation in order to increase zooplankton production by increasing nutrients available for phytoplankton production. Stocking should be done with triploid grass carp that are large enough to avoid predation (> 250 mm). Rates of stocking should be between 10 and 20 fish per vegetated acre (Sutton and Vandiver Jr. 1986), as total vegetation removal occurred in Lake Conroe, Texas, with a stocking rate of 30 fish per acre (Bettoli et al. 1992). The control of vegetation may be adequate to reduce the effects of the recruitment bottleneck in BCL. However, other options listed below might be considered.
   b. Fertilization can be initiated once aquatic macrophyte coverage in the reservoir is reduced, usually 1-2 years following grass carp stocking (Bettoli et al. 1992). Fertilization could increase the available nutrients for phytoplankton, the primary food source for zooplankton. Fertilization should be done between May and September with a nitrogen-to-phosphorus (N:P) ratio \( \geq 25:1 \), and approximately 1 mg m\(^{-3}\) d\(^{-1}\) of P should be added (Carpenter et al. 1996; Carpenter et al. 1998; Vadeboncoeur et al. 2001). The increase in primary production may result in a natural increase in blueback herring, which could become an important prey resource for largemouth bass. If blueback herring do not become abundant, stocking of threadfin shad could occur. Stocking rates should be at least 125 fish per hectare (> 300 fish/acre) (Hale 1996).
c. If supplemental stocking of largemouth bass is pursued, it should take place after June to avoid the recruitment bottleneck that the naturally reproducing population is experiencing. A supplemental stocking rate of 10-41 fish/hectare should create the greatest benefit to the population (Buckmeier et al. 2003). If stocking occurs before the end of June, stocked fish should be at least 50 mm (Table 17) to insure stocked fish do not experience the same bottleneck that the naturally reproducing age-0 largemouth bass experience.
REFERENCES
Annett, C., J. Hunt, and E. D. Dibble. 1996. The complete bass: habitat use patterns of all stages of the life cycle of largemouth bass. Pages 306-314 in L. E. Miranda, and D. R. DeVries,


conservation, and management. American Fisheries Society Symposium 31, Bethesda, Maryland.


Lemieux, H., P. Blier, and J. D. Dutil. 1999. Do digestive enzymes set a physiological limit on growth rate and food conversion efficiency in the Atlantic cod (Gadus morhua)? Fish Physiology and Biochemistry 20:293-303.


20:791-800.


