The Impacts of Stocking Stress and Largemouth Bass Predation on the Survivorship of Juvenile Striped Bass Stocked in Smith Mountain Lake, Virginia

by

Daniel P. Michaelson

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

Master of Science
in
Fisheries and Wildlife Sciences

APPROVED:

John J. Ney
J.J. Ney, Chair

S.L. McMullin

Donald J. Orth
D.J. Orth

July 1996

Blacksburg, VA

Keywords: Striped bass, Survivorship, Stress, Predation

The Impacts of Stocking Stress and Largemouth Bass Predation on the Survivorship of Juvenile Striped Bass Stocked in Smith Mountain Lake, Virginia

by

Daniel P. Michaelson

John J. Ney, Chair

ABSTRACT

Smith Mountain Lake, Virginia supports a successful put-grow-take striped bass fishery. Empiric analysis of striped bass stocking has shown an inverse relationship between number of fingerling striped bass stocked and survival to age 1. Potential causes for this inverse relationship include largemouth bass predation on fingerling striped bass and mortality resulting from stocking stress.

Cage studies performed in 1994 and 1995 quantified percentage of fingerlings lost due to hauling/handling stress. Mean mortalities ranged from 1.78% for Phase I fingerlings in 1994 to 99.5% for Phase II fingerlings (reared in a recirculating aquaculture system for increased size at stocking) in 1994. Mortality rates varied greatly and were probably directly related to length of transport and inadequate thermal tempering prior to stocking. Highest mortality occurred at transport times in excess of six hours and when receiving water was 5° C warmer than transport water. A trial in which Phase I fingerlings were caged without transport or temperature change resulted in no mortality.

Predation mortality by largemouth bass was also considered as a source of poor first year survival of striped bass in Penhook and Waterwheel stocking coves at Smith Mountain Lake. It was necessary to estimate largemouth bass population size, diet composition, and daily consumption (bioenergetic modelling) to determine the total number of striped bass lost to predation. Diet analysis revealed that age-0 striped bass made up a maximum of 2.5% of largemouth bass diets in the month following stocking; adult alewives constituted more than 60% by weight. The estimated number of striped bass lost was only 360 (0.1%) in 1994 and 3062 (1.2%) in 1995. Bioenergetic simulations demonstrated that predation could become significant in the unlikely event that the contribution of striped bass to largemouth diets increased to 10% or more. Based on results from diet analysis and a prey preference laboratory study, alewives appear to buffer predation of age-0 striped bass during the month after stocking. In 1994 and 1995, neither stocking stress associated with the typical Phase I fingerling stocking procedure nor largemouth bass predation resulted in substantial mortality of stocked fingerling striped bass.

ACKNOWLEDGEMENTS

I thank the members of my graduate committee for help in the completion of this thesis: Dr. Steve McMullin, Dr. Donald Orth, and especially my chairman, Dr. John Ney. Dr. Ney's guidance and humor made this learning process a mostly enjoyable one.

I would also like to thank the faculty and staff for the additional help and instruction in the completion of this process. In addition, all of the graduate students at Virginia Tech made my stay here an enjoyable and informative one. Of these students, I would especially like to thank Trent Sutton for his help in, and out of the field for the past 2+ years. Also, thanks to the Byrd family for permission to set up cages on their boat docks and Mike Duval (VDGIF) for equipment donation and wisdom. Last, but certainly not least, I must thank Laurie for being sympathetic during a stressful week prior to my defense (I am trying to appreciate country music) and to my parents, Stan and Nancy, for their life-long encouragement and support (emotionally as well as financially).

This project was funded by American Electric Power/ Appalachian Power Company.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Supplemental stocking of sportfishes is a standard fisheries management tool, used to maintain fishable populations of non-reproducing species in reservoirs (Pritchard et al. 1978; Wydoski and Bennett 1981). Hatchery-reared fish are usually stocked as fingerlings, then managed on a put-grow-take basis (National Task Force 1974). Historically, salmonids have been the species which receive the majority of the stocking attention and effort. However, in the past two decades the striped bass *Morone saxatilis* has become a very popular species to stock in large, warmwater U.S. reservoirs. Striped bass are increasingly favored because they are large, aggressive predators which can take advantage of the reservoir's pelagic prey supply (National Task Force 1974). As of 1981, 30 state fisheries agencies had stocked striped bass or striped bass hybrids. Striped bass were introduced into 122 lakes and 15 rivers in 1981 alone (Axon and Whitehurst 1985).

With this increase in the fishery, some research has been performed to determine the best stocking strategies to maximize success of striped bass. Bailey (1975) found that stocking of fingerling striped bass instead of fry led to increased survival; fingerling stocking became the norm in most states by the early 1970's. In the late 1970's, Pritchard et al. (1978) reported that fingerling striped bass stocking densities in several U.S. reservoirs ranged from 0.2 fish/acre (0.5 fish/ha) to 42.1 fish/acre (104 fish/ha). The mean stocking density was 5.96 fish/acre (14.7 fish/ha). Pritchard et al. (1978) give good historic values of stocking densities but do not address first- year survival of fingerlings stocked at these various densities. Despite the rapid increase in number of put-grow-take striped bass fisheries in the United States, factors affecting their poststocking survival have received little attention. Van Den Avyle and Higginbotham (1979) found that survival and average size attained by age-1 and age-2 striped bass stocked in Watts Bar Reservoir, Tennessee, were inversely related to stocking density and directly related to stocking size.

Smith Mountain Lake, Virginia, maintains a successful put-grow-take striped bass fishery. Due to a lack of natural reproduction in this 8,337 ha hydroelectric impoundment, it is necessary to maintain the population through annual stockings. Smith Mountain Lake stocking densities lie within the range reported by Pritchard et al. (1978) and are now approximately 15 fish/acre (37 fish/ha). The highest total survival of fingerling striped bass stocked into reservoirs may occur at a density lower than the maximum hatchery production potential. Empiric analysis of striped bass stocking records for Smith Mountain Lake has shown an inverse relationship between number of fingerling striped bass stocked and survival to age-1, a trend seen in other U.S. reservoirs (Moore 1988; Ney et al. 1990). Over a 20-year period, first-year survival of stocked striped bass in Smith Mountain Lake ranged from 3.9% to 54.3%, averaging 20.8% (Moore et al. 1991). Van Den Avyle and Higginbotham (1979) observed a similar inverse relationship for striped bass in Watts Barr Reservoir, Tennessee but were unable to explain it. Based on these discoveries and marginal yield analysis, it has been estimated that 250,000-300,000 (30 to 36 fish/ha) stocked fingerlings is optimal in Smith Mountain Lake. Apparently because of density-dependent forces, stocking more than 300,000 would be counterproductive as fewer adult striped bass would be produced (Moore et al. 1991). Possible causes for this inverse relationship in Smith Mountain Lake include competition for limited resources, predation on fingerling striped bass, and mortality resulting directly from the stocking event. This study is an investigation of predation impacts and stocking mortality as potential sources of the inverse relationship.

Predation on fingerlings may prove to be severe immediately after stocking, when fingerling striped bass are congregated and naive. In addition, predators may be attracted to the newly introduced source of available prey. In Smith Mountain Lake, striped bass fingerlings are stocked in approximately equal numbers (125,000-150,000) at only two sites. Stocking mortality may also be a partial cause for the inverse relationship. High densities of fingerlings are transported in tanker trucks and then transferred into the lake. Stress from loading into the truck, traveling to the stocking site, and the actual release could cause considerable mortality. Wallin et al. (1995) discovered that travel in tanker trucks and handling of young-of-the-year striped bass to be stocked into the Savannah River, Georgia increased stress and resulted in low survival (6-48%) in the first 48 hours poststocking. Additionally, 48-hour survival of stocked striped bass was consistently higher for fish stocked in brackish water than for those stocked in fresh water. This was probably due to factors affecting ion balance in this anadromous species.

Piscivorous predators can also inflict high mortality on stocked species. Keith and Barkley (1971) discovered that 15-25 cm stocked rainbow trout *Oncorhynchus mykiss* in Lake Ouchita, Arkansas, were preyed upon extensively by largemouth bass *Micropterus salmoides* and chain pickerel *Esox niger*. All 48 cm and larger chain pickerel sampled had consumed trout, and 91% of 46 cm or larger bass had preyed upon trout.

Carline et al. (1986) found that 168-216 mm stocked tiger muskellunge *Esox masquinongy x E. lucius* stocked in an experimental pond in Ohio were also highly susceptible to predation, especially by largemouth bass. One possible reason for the high predation rate was the aggregation of bass and esocids near shore because of an anoxic hypolimnion that limited habitat and increased esocid-bass contacts. Also, alternative prey were either unavailable or not as vulnerable as the recently stocked esocids. In Smith Mountain Lake, striped bass may school or aggregate near shore before dispersal and thus be more susceptible to predation by littoral piscivores, such as largemouth bass. Van Den Avyle and Higginbotham (1979) found that striped bass in Watts Bar Reservoir tended to disperse from the stocking site rapidly but did remain in the same general area into which they were stocked. Also, newly stocked striped bass may be "naive" and lack the necessary predator avoidance behaviors that wild fish exhibit (Stein et al. 1981; Santucci and Wahl 1993).

One of the major tools that fisheries managers have to combat predation on stocked fish is size at stocking. Largemouth bass have been shown to only ingest prey with body depths less than their external mouth width (Hambright 1991). Santucci and Wahl (1993) found that mean survival rate between three size classes of walleye *Stizostedion vitreum* in Ridge Lake, Illinois (a centrarchid-dominated lake) was highest for the largest class (186-216 mm). By stocking walleye at 200 mm, most of the largemouth bass predators were unable to utilize stocked walleye for prey. Shireman et al. (1978) determined that grass carp

Ctenopharyngodon idella would have to be greater than 450 mm total length to be completely excluded from predation by largemouth bass. Though stocking larger-sized fish is an effective method to prevent predation, the added cost to raise hatchery fish to larger sizes is often a limiting factor.

Stocking success may also depend on the numerical and functional responses of predators to prey number, as well as on the rate at which stocked striped bass disperse. A numerical response is an increase in number of predators due to an attraction to prey (Readshaw 1973). It is also possible that a functional response is operating in this system. A functional predator response is a function (N=f(D)) that relates the number of prey eaten per predator per unit time (N) to the density of the prey (D) (Murdoch 1973). Two types of functional response, Type II and Type III, are common in natural systems. In the Type II response, the rate of increase in consumption by a predator (e.g. number eaten per day) declines with increasing prey density due to limits of handling time and satiation (Holling 1965). A Type III response differs in that rate of consumption first increases with prey density before decelerating. A predator that displays a Type III functional response differs from a Type II predator because Type III predators undergo a learning period when prey densities are low (Peterman and Gatto 1978).

In Smith Mountain Lake, if striped bass predators display a Type III (learning curve) response, then stocking at a higher density may not be beneficial if it only serves to accelerate learning without satiation. Conversely, stocking at high densities might be beneficial to striped bass survival if predators exhibit a Type II response and if the fingerlings disperse rapidly. High striped bass densities will then satiate resident predators without attracting new predators, whereas lower densities might simply be consumed by the local predator population. The functional and numerical response modes of predators can be examined indirectly through analysis of the patterns of striped bass consumption (number eaten/predator, number of predators) versus striped bass density (CPUE, based on sampling catch) over time or space. Lowered stocking densities at a site should reduce predation on fingerling striped bass if the system shows an aggregation of predators or they display a Type III functional response. If predators are not attracted to stocking sites (i.e. not aggregating) and display a Type II functional response, then lowering stocking densities may be detrimental. The major factor that will influence the severity of predation mortality on juvenile striped bass is dispersion rate. If stocked fingerlings disperse rapidly from the stocking areas, then predation immediately poststocking should not be a density-dependent source of mortality.

JUSTIFICATION

Although annual stocking of juvenile striped bass in Smith Mountain Lake maintains a successful put-grow-take fishery, there has been the usual pressure by local anglers to increase the number stocked. However, the optimal stocking density under the present stocking regime is near 250,000 because of the inverse relationship between number of fingerling striped bass stocked and survival to age-1. Because growth rate of striped bass in the reservoir remains good, the reservoir may have the forage- fish resources to support a larger population of harvestable striped bass. To accomplish this, it is necessary to determine the source(s) of the recruitment bottleneck.

Possible sources of this striped bass bottleneck are intra- and interspecific competition for prey and predation mortality from various piscivores. Reservoir hydrology and water quality are relatively stable in Smith Mountain Lake, so these abiotic factors are not likely to lead to a significant recruitment bottleneck (Ney et al. 1990). The influence of competition on striped bass recruitment has been examined in a companion project. Predation by a number of species, especially largemouth and smallmouth bass *Micropterus dolomieu*, might also be a major factor restricting striped bass recruitment to the fishery. Predation on stocked fingerlings is probably most severe soon after stocking when the juveniles are near shore and have yet to disperse (Stein et al. 1981; Santucci and Wahl 1993). Increasing the number of stocking sites or size at stocking could help to alleviate predation and/or stocking stress impacts if they prove to be significant, and simply understanding the extent and nature of the stocking stress and predation problems may prove helpful in enhancing striped bass recruitment to the fishery.

OBJECTIVES

The goal of this research is to quantify the impact of predation and early death due to stocking stress on young-of-the-year striped bass survival in Smith Mountain Lake. Specific objectives of this project were to:

1. Quantify the effects of stocking stress on immediate poststocking survival.
2. Estimate percentage predation mortality until dispersal of stocked fingerling striped bass.
3. Describe patterns of consumption of striped bass by predators as functions of time since stocking and striped bass density.

STUDY AREA

Smith Mountain Lake is an 8,337 ha (20,600 acre) reservoir located in south-central Virginia. The reservoir consists of two long, narrow tributary arms, the Roanoke River (40 km) and the Blackwater River (20 km) segments , and a broad and deep (>40 m) lower lake extending 10 km above the dam (Figure 1). Smith Mountain Lake is a pumpback, hydroelectric reservoir with a maximum pool elevation of 241.7 m, a mean depth of 16.8 m, and a highly dendritic (805 km) shoreline (Moore 1988). It was impounded in 1963. The lower lake is mesotrophic with littoral areas containing only sparse fish cover. The upper tributary arms are more riverine, eutrophic, and contain larger vegetated littoral areas (Ney et al. 1990).

Smith Mountain Lake has a diverse fish fauna consisting of at least 44 game and non-game species (Hart 1978). Largemouth and smallmouth bass became the primary game species shortly after impoundment. In the early 1970s, stocking of striped bass and walleye began to add to sport fishing possibilities. Striped bass fingerlings are still stocked by the Virginia Department of Game and Inland Fishery (VDGIF), but walleye are now being stocked infrequently (Moore 1988). Forage fish consist primarily of clupeids: native gizzard shad *Dorosoma cepedianum* and the introduced alewife *Alosa pseudoharengus*. A third clupeid,

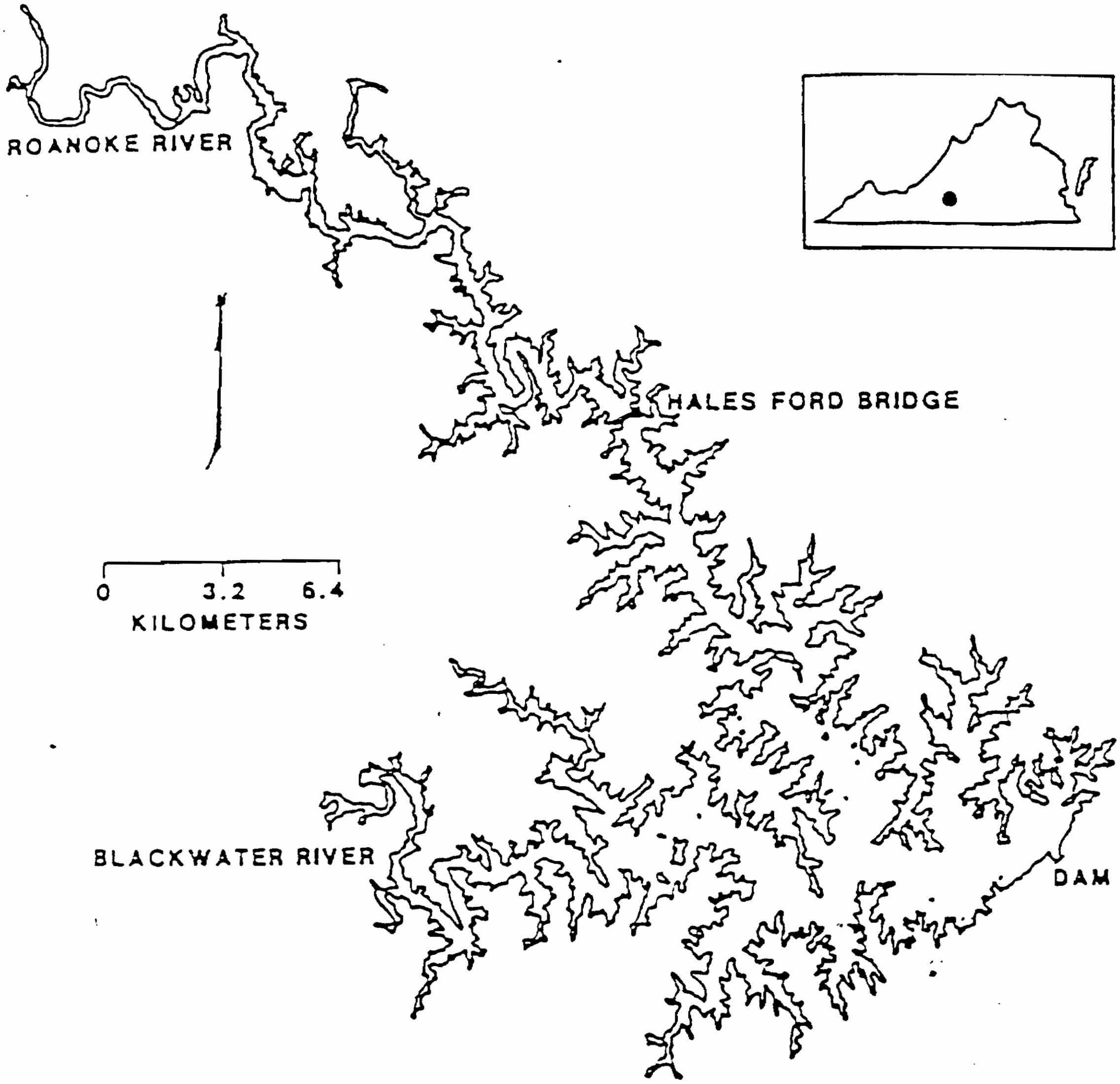


Figure 1. Smith Mountain Lake, Virginia.

threadfin shad *D. petenense*, has recently become established in Smith Mountain Lake. Other forage species consists of various minnows *Pimephales* spp., shiners (*Notemigonus crysoleucas* and *Notropis* spp.), crayfish *Orconectes* spp., and young-of-the-year sportfish (primarily *Lepomis* spp.) (Moore 1988).

Between 180,000 and 800,000 striped bass fingerlings have been stocked annually since 1973 (Moore et al. 1991). The figure has fluctuated between 197,534 and 384,047 in the years of 1984-1995. Fingerling striped bass are obtained from the Brookneal, Virginia hatchery and stocked at 30-50 mm total length in late June. Fingerlings are stocked in two approximately equal batches (125,000-150,000 each) into a cove near Hales Ford bridge on the Roanoke arm and a second cove near Penhook on the Blackwater arm. The stocking cove located near the Hales Ford bridge will be referred to as Waterwheel and the Blackwater stocking cove as Penhook (Figure 2). The Penhook cove is approximately 15 km down-lake from the Waterwheel cove. The portion of the Penhook cove which was sampled is much larger than the Waterwheel cove in terms of total surface area (61 ha vs. 37 ha), but shoreline sampled was roughly equal for both coves (5152 m at Waterwheel and 5957 m at Penhook). The Penhook cove is less dendritic and has a wider channel than the Waterwheel cove. Much of the shorelines of both coves are developed with houses and boat docks, but the Waterwheel

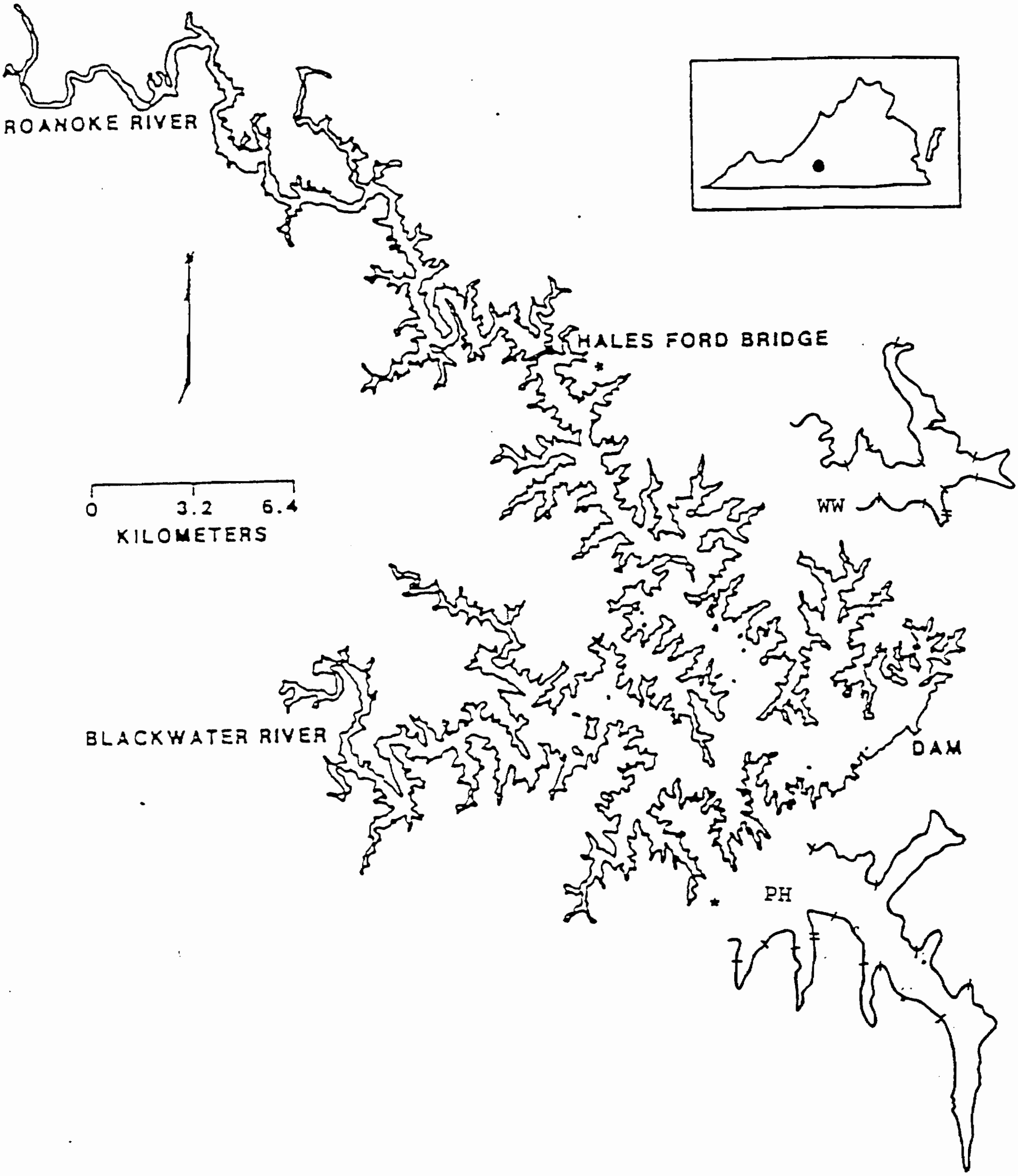


Figure 2. Waterwheel (WW) and Penhook (PH) coves. Transects between dash marks. Double dash represents stocking site.

cove is more densely developed than the Penhook cove. Each cove contains a great deal of habitat for largemouth bass and juvenile striped bass. The Waterwheel cove is more densely populated by largemouth bass, than the Penhook cove, possibly because it is a tournament release site for bass caught lake-wide rather than better habitat.

METHODS

HANDLING MORTALITY

To determine the extent of mortality due to transport and handling stress, an *in situ* cage study was performed. The experiment was conducted during the summers of 1994 and 1995 using different cage types in each year.

Stocked fingerling striped bass are subjected to a great deal of handling prior to transport to receiving waters. Striped bass are raised in rearing ponds at the Brookneal Virginia Hatchery, approximately 70 km southeast of Smith Mountain Lake. When fingerlings are to be stocked in early summer, the rearing ponds are drained and the striped bass are removed using seines. The fish are then placed into a 550 gallon (2100L) tanker truck for transport but must be held overnight due to time constraints involved with removal from the rearing ponds. To reduce stress, transport water is drawn from the Roanoke River which is the same source that is used to fill the rearing ponds. In addition, salt is added to transport water in a 0.5-1.0% solution to reduce ion loss related to stress. Fingerlings were transported in two truck hauls in 1994. Roughly half of the 300,000 fish were transported in one trip to Waterwheel and the other half in another trip to Penhook. In 1995, fish were transported from North Carolina hatcheries due to loss of fish through flooding at the Brookneal hatchery. These fish were transported in a series of trips with many fewer fish per haul, and thus densities in these hauls were about one third those in 1994 but the transport time was much longer (8 hours versus 1.5 hours).

The experiment was performed on fish raised in different facilities and stocked at different times. Fingerlings raised at VDGIF's Brookneal Hatchery and at McKinney Hatchery, Rockingham, North Carolina are referred to as Phase I fish based on size at stocking (mean TL 30 mm). An experimental group of fish raised at Virginia Tech's aquacuture facility from fry spawned at the Brookneal Hatchery are referred to as Phase II fish. These experimental fish were fed *ad libitum* to achieve the largest size possible (45 to 105 mm) by early July.

1994 Cage Trials

In 1994, the experiment was performed a total of three times (three trials) on Phase I and Phase II fingerlings. The first trial was performed on 22 June on Phase I fish raised at the Brookneal Hatchery. The two subsequent trials were performed on 6 July and 13 July on Phase II fish. These fish were netted and placed into a tanker truck and delivered the same day. Transport from Blacksburg to the Waterwheel cove was approximately 2 hours. Upon arrival at the stocking site, fish were acclimated to the lake water by replacing the transport water in the tanker truck with lake water in stages. Fingerlings were acclimated for approximately one hour in Trials 1 and 3 but for only 15-20 minutes for Trial 2 striped bass. In all three trials, four random subsamples of fingerling striped bass were netted out of a tanker truck after acclimation and caged at the Waterwheel boat dock located near the Hales Ford stocking site. An average of 70 striped bass was held in each of the four 125 L cages for 48 hours (actual water volume = 100 L when set in floating frame). I intended to place 50 fingerlings in each cage to avoid potential crowding stress. However, fish numbers were not counted upon netting to reduce unnecessary stress, and thus fingerling numbers were underestimated. Mortality of fingerlings in the cages over 48 hours was used to quantify hauling and handling stress.

Cages were constructed based on the design used by M. Van Den Avyle, University of Georgia, (unpublished) to hold stocked striped bass. Four 33-gallon (125 L) plastic garbage containers were modified to use as floating cages. To allow lake water to flow through the cage, four 20 x 40 cm holes were cut in the side and covered with 3/16" (5 mm) plastic mesh. A removable lid was secured to the top to prevent possible escape. This proved to be unnecessary and may have contributed to over-heating of the caged water. Temperatures were not measured in the cages during the experiments, but anecdotal evidence points toward temperature stress; fish held earlier in the summer when air temperatures were lower showed much lower mortality. Two cages were held in each of two 1/4" x 2' x 4' plywood frames and floated with styrofoam. These structures were then anchored to the underside of a Waterwheel boat dock which provided some protection from direct sunlight and boat traffic.

After 24 hours, dead fish were counted and removed. After 48 hours, number of additional dead fish and remaining live fingerlings were counted, and percent mortality was calculated. This percentage was expanded to estimate total number of striped bass lost to stocking stress by multiplying the percent by total number stocked on each date. The procedure was repeated in 1995 with different cages to correct the potential problem of heat stress in the 1994 cages.

1995 Cage Trials

To alleviate concern over possible thermal stress experienced in 1994 trials, three new cages were designed for 1995 by M.C. Duval, VDGIF. The same experimental procedure was followed as in 1994 except for use of three rather than four cages. Fish were acclimated with lake water, netted from the tanker truck, and transported to the cages. As in 1994, three trials were run on three different batches of striped bass. The 1995 trials consisted of two batches of Phase I fish and only one batch of Phase II fingerlings. Each 1995 cage consisted of a 1 m^2 frame at the top and bottom constructed of PVC pipe. The top remained open while the bottom was sewn shut. The cages were three meters deep with a volume of 3000 L. Each surface PVC frame was then set within an aluminum frame and supported on a styrofoam and plywood float. The cages were composed of 5-mm nylon mesh to allow free flow of water throughout and were thought to be deep enough to permit vertical migration away from direct sunlight. Cages were secured and floated underneath the Waterwheel dock for 48 hours for each trial.

Two different trials were performed on 30 June and 12 July on Phase I fish which were transported from McKinney Hatchery. The trip from the McKinney Hatchery to Smith Mountain Lake took approximately eight hours, about five times as long as the transport from Brookneal to Smith Mountain Lake. One Phase II trial was performed on 10 July on fish raised at the Virginia Tech aquaculture facility. Due to the size of the nets and potential stress to the fingerlings, fish were not checked after 24 hours as in 1994.

In 1995, cage controls were run at the Virginia Tech aquaculture facility on cages used in 1994 to test for cage effect mortality. The four cages were placed in plastic troughs which held water pumped directly from raceways being used to hold Phase II striped bass. The troughs were filled so that cages held approximately the same volume of water (100 L) as when used in the field. Approximately 50 striped bass were placed in each cage and held for 48 hours. The control can only eliminate hauling and acclimation stress as sources of mortality as fish had to be netted from raceways to be stocked into the cages. Any mortality that occurred in these cages should come from either cage effects or from handling in nets.

PREDATION MORTALITY

Predation pressure on fingerlings was examined in both the Penhook and Waterwheel coves in Smith Mountain Lake. Several steps were necessary to quantify the consumption of age-0 striped bass by predators. It was first necessary to estimate predator daily ration, C_D, using a bioenergetics model. Next, percent by weight of striped bass in predator diets was determined by evacuating stomachs in the field. Number of predators in each cove was estimated using the Jolly-Seber mark-recapture technique. The final component needed in estimating the total number of striped bass consumed by predators was the mean weight of striped bass eaten. This was calculated by capturing striped bass along with predators in each of the stocking coves. Using these parameters in the following formulae, percent predation mortality was calculated. The process was as follows:

1.) (C_D) **x** (% weight stripers in diet)=Wt s.b./day/predator

2.) $$\frac{\text{Wt. stripers/day}}{\text{(Mean live wt. stripers on that day)}} = \text{\# eaten/day/predator}$$

3.) $$\text{Total striped bass eaten} = (\text{\# eaten/day/predator}) \times (\text{\# sampling days}) \times (\text{\# predators})$$

4.) $$\frac{\text{total \# eaten}}{\text{total \# stocked}} = \textbf{\% Predation mortality}.$$

Methods to estimate daily consumption, diet composition, and predator abundance are described in detail below.

Fish Collection

In the summers of 1994 and 1995, potential striped bass predators were collected near shore at night by boat electrofishing. A Smith-Root Gas Powered Pulsator (GPP) unit powered a boom shocking apparatus. Three to six amps of pulsed direct current at a frequency of 60 pulses per second were used to immobilize fish species. In the first week of the 1994 sampling period, all potential predators were sampled for evidence of predation on striped bass. A sample of 10-15 bluegill *Lepomis macrochirus* captured from the Penhook sampling site the night after stocking were sacrificed to check for striped bass consumption. These fish contained no striped bass, so bluegill were subsequently ignored as potential predators. The list of potential predators was further reduced to include only black bass (largemouth and smallmouth bass) as other potential predators (e.g. catfish, crappie) were captured at extremely low frequencies and were found to contain no stocked fingerlings. Although smallmouth bass were sampled each summer, they too were excluded as predators in the calculation of predation mortality due to their infrequent capture and apparent lack of consumption of striped bass. From this point forward, potential predators will only include largemouth bass.

1994. - Weekly sampling began on 15 June when striped bass were stocked at the Penhook cove. Sampling began on 22 June at the Waterwheel cove following stocking earlier that day, and both coves were sampled one night per week subsequently. Sampling was terminated when no striped bass were found in predator stomachs for four successive weeks. Each stocking cove was divided into shoreline transects which were marked by permanent landmarks; total shoreline distance shocked was 5152 m at Waterwheel and 5957 m at Penhook (Figure 2, page 13). The transects varied in length from 321 m to 805 m at Penhook and from 160 m to 800 m at Waterwheel based on their proximity to the stocking site. Those transects closest to the stocking site were made shorter in the expectation that predators would be attracted to the stocking site. If attraction did occur, shorter transects should result in fewer predators to process and thus less stress on them.

Largemouth bass age 1+ and older were collected along each transect by slowly electrofishing close to shore where fingerling striped bass were observed. Bass were dip-netted, then placed in a 24 gallon (109 L) cooler to recover from the electric shock and to be processed. The anesthetic, MS-222, was only used when bass were unusually active because it slowed the procedure. Each black bass was measured to the nearest millimeter, weighed to the nearest gram using an electronic balance, and tagged in the side near the dorsal fin with an individually numbered anchor tag (Wydoski and Emery 1983). The stomach was then evacuated for later determination of diet composition. This was accomplished by inserting an acrylic tube of the appropriate diameter through the esophagus and into the stomach (Van Den Avyle and Roussel 1980). A small amount of water was poured down the tube to aid the process. The fish was then inverted and the stomach massaged to force food through the tube. It was occasionally necessary to insert a metal claw tool through the tube to remove food items lodged in the stomach (Dimond 1985). Upon removal, contents were preserved in a solution of 10% buffered formalin. Each fish was then released within the transect for possible recapture.

1995. - Sampling began later in 1995, 10 July, due to flooding of the Brookneal Hatchery prior to striped bass removal. The same sampling procedure was followed in 1995 as in the previous summer with two modifications. First, sampling effort was intensified in the Waterwheel cove and relaxed at the Penhook site. Sampling effort was increased to four nights per week for the first three weeks of the summer at the Waterwheel stocking site. These changes were made because it was determined in 1994 that predation pressure was probably highest the first two weeks poststocking. The Penhook cove was sampled in entirety only once after stocking. The choice to concentrate on Waterwheel rather than Penhook was based on the higher density of largemouth bass observed in the Waterwheel cove in 1994. Those sites in the Penhook cove where striped bass were consistently captured in 1994 and 1995 were sampled weekly for predators (approximately 30% of the shoreline sampled in 1994). The second modification in 1995 was to count alewives at electrofished transects because alewives were found to be heavily preyed upon by black bass in 1994, and may have buffered predation on striped bass. The relationship between relative alewife density over time and the number of striped bass in black bass stomachs over time could then be examined.

Population Estimation

Estimates of the abundance of largemouth bass in the two stocking-site coves were made by mark-recapture sampling (Seber 1965; Hightower and Gilbert 1984). Specifically, the

Jolly-Seber population estimate was used.

The formula is:

$$\hat{N}_i = \frac{B_i(C_i+1)}{m_i+1}; \quad \text{where,}$$

N_i=# of predators
B_i=# marked fish remaining prior to sample i
C_i=# caught and examined for marks in sample i
m_i=# recaptured in sample i (Seber 1973).

The computer package, JOLLY, was used to perform the actual calculations. The Jolly-Seber technique was appropriate because it is a multiple census technique, and both coves consisted of open populations (Jolly 1965; Seber 1965).

As black bass were sampled for gut content, each individual was given a numbered Floy anchor tag. Floy tags were inserted with a special tagging gun which was used to anchor the tag into the skeleton on the left dorsal side of the fish (Wydoski and Emery 1983). Because the Jolly-Seber technique is a multiple census technique, it is necessary to identify individual fish to determine when the fish was tagged and if it had been recaptured previously. Individual tags also allowed for growth determination from recaptured bass to be used in the bioenergetics model. Fish too small for tagging (< 150 mm) were given upper caudal clips. Marked fish were then released alive to be captured in future sampling runs. The number of marked fish that were recaptured on each sampling run (i.e. each time one entire cove was sampled) was input to the Jolly program to give a population estimate for each sampling run. In 1994, four estimates were generated for Waterwheel and five for Penhook. In 1995, eleven estimates were generated for Waterwheel only. A mean was then taken of the estimates which were generated when striped bass were apparently susceptible to predation, and this was used as a population estimate for each cove. The 1994 largemouth bass population estimate for Penhook was used again in 1995 because too few fish were sampled in 1995 to use the Jolly-Seber estimate.

To verify the mark-recapture population estimate, historical cove rotenone data (1990-1995) on largemouth bass abundance was examined (VDGIF, Management reports, unpublished). The VDGIF performs uplake and downlake rotenone sampling at four coves (mean size = 0.725 ha) each summer. Fish are then quantified to give an estimate of number of fish per hectare (Davies and Shelton 1983). To convert this average into number of fish per cove in the striped bass study, surface areas of the Penhook and Waterwheel coves were measured using topographic maps and a digital planimeter. Average number of largemouth bass per hectare in cove rotenone samples was then multiplied by the area (ha) of each cove to give a population estimate which could be compared to the mark-recapture estimates. This value was then corrected to account for the lower densities of largemouth bass in the larger, open-water stocking coves.

Because rotenone coves were small and contained a high percentage of littoral areas, the number of largemouth bass per hectare estimates were probably higher than would be expected in the larger Penhook (60.7 ha) and Waterwheel (36.9 ha) coves. The correction for open-water areas was based on adjustment factors determined by Aggus et al. (1980) and was calculated for two different size classes of predators. The multipliers used were 0.53 for 127-229 mm largemouth bass and 0.79 mm for 254-711 mm largemouth bass. These adjustment factors reduced the rotenone estimate to better reflect the largemouth bass densities of the larger, deeper stocking coves.

Diet Composition

Preserved stomach contents were identified to species for striped bass and alewife and to genus for sunfish and minnows. Invertebrate food items were identified only by common name. Fish digested to the extent where positive identification could not be made were referred to as PDUF (Partially Digested Unidentifiable Fish). Most of these fish were clupeids with heads missing; the PDUF category was included in bioenergetics modelling with alewives because this was the only clupeid identified in stomach samples. No PDUF examined matched the shape or size of fingerling striped bass and thus no fingerlings should have been included in the PDUF category. Following identification, individual items in the stomach contents were measured for total length and body depth (to the nearest mm). They were then blotted to remove excess liquid and weighed to the nearest 0.01 gram. Carapace length was measured to the nearest mm for crayfish in the event this information would prove useful to other researchers. These were blotted and weighed as with fish species. If fish and crayfish had undergone extensive digestion, blotted wet weight was the only measurement taken.

Because adult alewives were the predominant prey found in predator diets, a correction factor was necessary to adjust for differential digestion rates of alewives and the smaller striped bass. On average, size of stocked striped bass (mean weight = 0.50 g in 1994 and 0.72 g in 1995) found in largemouth bass stomachs were much less than size of adult alewives (mean weight = 5.5 g in 1994 and 7.0 g in 1995) and striped bass would thus be digested more rapidly than alewives. The correction factor was calculated by using a smallmouth bass sigmoid gastric evacuation model which was developed by Rogers and Burley (1991). The model can be used to calculate grams of food evacuated given inputs for temperature, time, meal weight, and predator weight (i.e. E_{90} calculated by age class). The sigmoid model used was (Rogers and Burley 1991):

$E = S(1-e^{-0.005tS\hat{}0.29e\hat{}0.15TW\hat{}0.23})^{1.95}$; where,

E=grams evacuated
t=time (hours)
S=meal weight (g)
T=water temperature (° C)
W=predator weight.

Given this formula, time to 90% evacuation (E_{90}) of food items was determined because predators will eat again at this level of evacuation (Rogers and Burley 1991). In general, it took twice as long for predators of all ages to digest 90% of an adult alewife than it did to digest 90% of an age-0 striped bass. The multipliers factored into diet composition determinations for age-0 striped bass are 2.0 for 1994 and 1.93 for 1995.

Bioenergetics Modelling

Another component of calculating number of striped bass lost due to predation mortality is estimating daily consumption by individual predators. This was accomplished using the Wisconsin bioenergetics model (Hewett and Johnson 1992). The bioenergetics model is a mass-balance equation which can be used to estimate total food consumption by an individual fish by partitioning the ingested energy into various fates. In general, these fates are growth, metabolism, and waste. More specifically, ingested food or consumption (C) can be partitioned into six different fates (Warren 1971):

$C=G+R_S+R_A+R_D+F+U;$

where,

G=Somatic and gonadal growth,

R_S=Standard metabolism,

R_A=Activity metabolism,

R_D=Apparent specific dynamic action (digestion energy),

F=Egestion of feces, and

U=Excretion of ammonia and urea.

Five different components are necessary for bioenergetics modelling of largemouth bass daily consumption, which is performed on an age-group specific basis. These components include:

(1) a mass balance equation with associated algorithms and parameter estimates representing largemouth bass energetics and physiology;

(2) initial and final weight estimates (difference equals growth) of largemouth bass which correspond to the beginning and end of the simulation interval;

(3) energy density estimates for largemouth bass and their prey (especially striped bass);

(4) diet composition by prey type (percentage wet weight);

(5) water temperatures.

Largemouth bass weights, diet composition, and water temperature components were site-specific inputs, energy densities were borrowed from the literature, and the mass balance equation was included in the model. Parameters used in the model's mass balance equation were specifically developed for largemouth bass (Hewett and Johnson 1992). Energy density estimates for the four age classes of largemouth bass were borrowed from research performed on Watts Barr Reservoir, Tennessee (Adams et al. 1982). Energy density estimates for prey were supplied from various sources. Striped bass, alewife, and crayfish energy density estimates were taken from research previously performed on Smith Mountain Lake (Moore 1988). The sunfish energy density estimate that I used was an estimate found in the Fish Bioenergetics Model 2 users manual (Hewett and Johnson 1992). Growth was estimated from tracking change in weight of recaptured predators in both coves. Surface water temperatures were measured each sampling night and were used in the bioenergetics model because largemouth bass inhabited the isothermal nearshore region. Diet composition was determined through predator stomach analysis and was necessary to estimate item-specific consumption. Estimating consumption with the bioenergetics model required the input of several parameters describing energetic equations associated with consumption, respiration, egestion, and excretion. Consumption was modeled as a function of maximum daily consumption rate (C_{max}) at the optimum temperature (T_{oc}) (Table 1). Daily consumption was estimated as a proportion of maximum daily consumption using the Fish Bioenergetics Model 2 developed at the University of Wisconsin-Madison for

Table 1. Parameter values used in bioenergetics model to estimate consumption by largemouth bass in Smith Mountain Lake, Virginia. Values were taken from Fish Bioenergetics Model 2 and were specifically developed for largemouth bass (Hewett and Johnson 1992; Ney 1993).

Symbol	Parameter Description	Value
	Consumption (C_{max})	
a_1	Coefficient for weight relationship to C_{max}	0.33
b_1	Exponent for weight relationship to C_{max}	-0.325
Q_c	Slope for temperature dependence of C_{max}	2.65
T_{oc}	Optimum temperature for consumption	27.5
T_{mc}	Maximum temperature for consumption	37
	Standard metabolism (R_S)	
a_2	Coefficient for weight relationship to R_S	0.00279
b_2	Exponent for weight relationship to R_S	-0.355
Q_r	Slope for temperature dependence of R_S	0.0811
T_{oc}	Optimum temperature for R_S	30
T_{mr}	Maximum temperature for R_S	37
	Activity metabolism (R_A)	
A	Active metabolism multiplier of R_S	1
	Digestion metabolism (R_D)	
S	Coefficient for apparent SDA	0.163
	Egestion/Excretion (F/U)	
f	Proportion of consumed food egested	0.104
u	Proportion of consumed food excreted	0.068

use on microcomputers.

Daily consumption of striped bass was estimated using actual predator diet composition data collected in the field. Alternate estimates of daily consumption of striped bass were also simulated to project predation impact under different scenarios. Simulations were performed using increased percent consumption of striped bass and higher largemouth bass population estimates. These simulations should account for "worst-case" scenarios of striped bass predation mortality at Smith Mountain Lake. Percent diet composition of striped bass was set at 10% and 25% in these four simulations (one per cove per year). In addition, two simulations were run to estimate potential upper limits of consumption if largemouth bass numbers were underestimated. This was accomplished by using the upper confidence limits of predator population sizes in the predation mortality equations.

Influences on Predator Consumption

Largemouth bass consumption of recently stocked striped bass could be influenced by predator attraction to striped bass aggregations and rate of striped bass dispersal. Determining if predators were attracted to stocking coves was difficult and hard to quantify. By calculating catch per unit effort (CPUE), fish captured per minute, of striped bass and largemouth bass over time and space, it was possible to detect the presence or absence of trends. If largemouth bass were attracted to stocking sites, CPUE of largemouth bass in transects where striped bass were found should increase as striped bass CPUE increases. Specifically, regressions were performed on striped bass CPUE versus largemouth bass CPUE to determine if there were more predators found where striped bass were abundant. If largemouth bass were attracted to striped bass aggregations, a positive regression should result. One regression was run for each stocking cove both years which included all CPUE data for all dates and transects. In addition, separate regressions were run on CPUE data from the first two nights poststocking to discover if attraction was occurring when stocked striped bass were most vulnerable (i.e. the first week poststocking). A more positive regression should have been observed on the second night poststocking if attraction was occurring.

Another way to detect the presence or absence of attraction was to plot the ratio of striped bass CPUE to largemouth bass CPUE over time. If largemouth bass were attracted to striped bass, there should be an inverse relationship between the ratio and time since stocking. Striped bass and largemouth bass CPUE was also plotted in this graph to determine if the ratio declines over time simply due to a reduction in striped bass CPUE over time.

If striped bass disperse rapidly poststocking, the effects of attraction should be dampened. Striped bass CPUE was used to describe the rate of dispersion from the specific stocking sites. I plotted striped bass CPUE over distance from stocking site at successive times (sampling sessions) to examine the dispersion patterns at both stocking sites in each year.

PREY PREFERENCE EXPERIMENT

In the summer of 1994, largemouth bass consumed alewives at a much higher percentage than any other prey species, resulting in the hypothesis that alewives were acting as a buffer to predation on striped bass. To determine if predators preferred alewives over striped bass, a laboratory experiment was performed during the summer of 1995 over a 33-day period. The experiment was initially planned to allow direct observation of predatory behavior, including measurement of handling time and capture efficiency (# of captures/# of strikes). However, bass would not feed in the presence of an observer, so the experiment was limited to an analysis of the numbers of each prey species eaten when largemouth bass fed without direct observation.

The analysis was performed using largemouth bass and alewives collected from Claytor Lake, Virginia on 20 and 21 June 1995. Largemouth bass used in the experiment ranged in size from 308 mm (170 g) to 445 mm (1139 g). Fish were collected by night electrofishing near shore, mostly in coves. Collected fish were immediately placed in aerated coolers. After 16 largemouth and approximately 75 alewives were collected, the fish were transported to the Virginia Tech aquaculture facility where they were placed in outdoor tanks. Bass were kept in one six foot (1.83 m) diameter, 4 foot tall (1.22 m) fiberglass tank which was equipped with a flow-through filter and aeration. Alewives were held in a four foot (1.22 m) diameter, four foot tall (1.22 m) fiberglass tank and aerated. Both tanks were covered to prevent escape and excited behavior and to provide shade. Alewives were fed brine shrimp once or twice a week, but it was unclear if they were feeding. Largemouth bass were fed twice during the one-month experiment but never within seven days of a trial. To prevent potential bias, they were fed minnows (*Notropis* sp. and *Pimephales* sp.) which were purchased from a Claytor Lake bait shop. Striped bass were already being raised in the aquaculture facility for later, Phase II stocking into Smith Mountain Lake and were thus captured from the indoor tanks as needed. Temperature in the test tank ranged from 23 to 26° C.

The first part of the experiment consisted of presenting one largemouth bass with its choice of five alewives (mean TL=109 mm, mean Wt.=10.0 g) and five striped bass (mean TL=66 mm, mean Wt.=4.0 g) fingerlings. The experiment was performed in a separate six foot (1.83 m) diameter tank filled to about 0.5 m depth. The only physical structure for the fish was provided by an aerator platform approximately 0.33 meters square and 0.33 m off of the bottom. This apparatus was often used as overhead cover for the predator upon disturbance of the tank.

Eight separate trials were performed with eight individual largemouth bass. The experiment began when the largemouth bass was removed from the holding tank and placed into the experimental tank. Prey were then immediately placed in the tank with the predator, and the fish were left in the tank for 48 hours. Fish were observed every 12 hours to record consumption. The second part of the experiment was identical to the first except five striped bass were presented to the predator without any alewives. This was done to mimic the natural conditions at Smith Mountain Lake. In late summer and early fall, alewives move away from shore following their spawn, increasing the potential vulnerability of striped bass to predation. This part of the lab experiment was designed to demonstrate what could happen if largemouth bass were given no other prey choices except striped bass.

STATISTICAL ANALYSES

Statistical procedures used to analyze Smith Mountain Lake data are listed in Table 2. Tests to detect statistically significant differences in means were used in the handling mortality experiment and also in the prey preference laboratory experiment. A two sample t-test was used to determine if mean handling mortalities were significantly different between years and between Phase I and II fingerlings (Zar 1984). If the data did not pass a test for equal variance, the non-parametric Mann-Whitney Rank Sum Test was used. Jolly-Seber population estimates were bound by 95% confidence limits. Upper confidence limits were used to simulate potential striped bass predation mortality if predator numbers were higher than estimated. To determine if largemouth bass were attracted to aggregates of striped bass, simple linear regressions were used and were determined significant when slopes were different from zero. Striped bass CPUE was plotted against largemouth bass CPUE. A positive correlation should indicate largemouth bass attraction. A t-test for regression coefficients was used to test for significant differences in mean regression slopes between days. A Mann-Whintey Rank Sum Test was used to determine if there was a significant difference in the number of alewives versus striped bass consumed in the laboratory experiment. All comparisons were made with an acceptable Type I error rate

Table 2. Statistical procedures applied to analyze various data sets, Smith Mountain Lake, Virginia, 1994-1995.

Statistical Procedures

Data Set	**Statistical Procedure**
Test for normality	Shapiro-Wilks
Phase I mortality vs. Phase II mortality	t-test
Phase I mortality vs. Phase II mortality if unequal variance	Mann-Whitney Rank Sum Test
Phase I mortality in 1994 vs. Phase I mortality in 1995	t-test
Phase II mortality in 1994 vs. Phase II mortality in 1995	t-test
Striped bass CPUE vs. largemouth bass CPUE	Simple linear regression
Significant differences in linear regression slopes	t-test for regression coefficients
Mean number striped bass consumed vs. mean number alewives consumed	Mann-Whitney Rank Sum Test
Jolly-Seber population estimates	Bound by 95% confidence limit

of $\alpha = 0.05$ and were considered significant at $P<0.05$.

RESULTS

HANDLING MORTALITY

Handling stress has the potential to result in significant mortality of stocked striped bass. In this study, mortality rates among cage trials and between years, as well as between Phase I and Phase II fish varied considerably.

1994 Cage Trials

Fingerling striped bass were caged for three separate trials in 1994. Trial 1 fish were Phase I fingerlings from the Brookneal Hatchery while Phase II fish reared at Virginia Tech were caged in Trials 2 and 3 (Table 3a). Fingerlings were stocked into cages in densities ranging from 62 to 146 (0.2 to 6.7 g/L). Trial 1 fingerlings were stocked at the lowest densities (mean = 75 fish at 0.2 g/L) and Trial 3 fingerlings at the highest densities (mean = 129 fish at 5.9 g/L) (Table 3b). Originally, I planned to place only 50 fingerlings in each cage but striped bass numbers were underestimated upon netting from the tanker trucks. Parker et al. (1992) report that striped bass fingerlings can be hauled at densities as high as 60 g/L for 15 hours, therefore caging densities as low as those in this experiment probably did not lead to increased mortality.

Table 3a. Experimental conditions of 1994 Phase I and Phase II fingerling striped bass handling mortality. Mean weights, mean total lengths, and surface temperatures are in mm, grams, and ° C respectively.

Trial #	**Date**	**Fingerling Phase**	**Weight**	**TL**	**Lake Temperature**
1	6/22	I	0.28	31.8	26
2	7/6	II	3.67	68.4	27
3	7/13	II	4.56	74.1	27

Table 3b. Fingerling striped bass percentage handling mortality in 1994. Number and density of stocked fingerlings are in parentheses (total number,g/L).

Trial #	**Cage 1**	**Cage 2**	**Cage 3**	**Cage 4**
1	2.38 (82,0.2)	0 (62,0.2)	3.19 (91,0.2)	1.56 (63,0.2)
2	100 (70,2.6)	100 (70,2.6)	98.1 (102,3.7)	100 (88,3.2)
3	37.2 (121,5.5)	39.0 (105,4.8)	56.6 (143,6.5)	74.7 (146,6.7)

Hatchery trucks from Brookneal transport fish at about 40 g/L, and these fish are held in the trucks for at least 16 hours prior to stocking at these high densities. Tanker trucks are aerated to maintain oxygen levels for this density of fish, but Smith Mountain Lake surface oxygen levels remain high in the summer (at least 8 mg/L), and the densities of fingerlings in the cages should be less stressful than in tanker trucks. Pitman and Gutreuter (1993) performed several stocking mortality cage studies on striped bass stocked into several Texas reservoirs. Caging densities used in these experiments were over 22 g/L and mean mortalities in these studies were as low as 8%.

Mortality rates in 1994 were low, ranging from 0 to 3.19% (mean of 1.78%), in the Phase I Brookneal raised striped bass (Table 3b). These fish were transported from water that was within 1-2° C of Smith Mountain Lake water and thus thermal shock was probably not a factor. Phase I fish were tempered gradually by adding lake water (26° C, Table 3a) to the tanks over a period of approximately one hour. In contrast, Phase II mortalities were much higher. Phase II fingerlings used in Trials 2 and 3 were raised at the Virginia Tech aquaculture facility, and water temperature was 5° C cooler than lake temperature (22° C vs. 27° C). Trial 2 striped bass mortality was nearly complete (mean = 99.5%). Fingerlings in this trial were tempered in 15-20 minutes and were thus subjected to potentially significant stress from changes in water temperature and/or water chemistry. To determine if the short tempering time for Trial 2 striped bass resulted in higher mortalities than occurred for Phase I fish in Trial 1, one final trial was performed on the second batch of Phase II fingerlings. Transport and lake water temperatures in Trial 3 were identical to Trial 2 temperatures. Trial 3 fish were again tempered for approximately one hour as Phase I fingerlings were and this may have led to the decreased mortality (mean mortality = 51%) in this trial (Table 3b). Density of Phase II fingerlings stocked into cages was at least ten times Phase I densities, but even these densities should not have resulted in increased Phase II mortality. Both Phase II trials (Trials 2 & 3) exhibited mean mortalities which were significantly higher than the Phase I mean mortality trial (Trial 1) ($P<0.01$ and $P=0.0286$ respectively).

Water chemistry differences between Virginia Tech aquaculture water and Smith Mountain Lake water did not appear to be great enough to result in significant mortality (Table 4). Changes in pH and alkalinity were minor (a difference of only 0.6 and 28 mg/L $CaCO_3$ respectively), and nitrogen values were much lower in lake water than in aquaculture water. It appears that temperature stress was a much more important source of stress than changes in water chemistry for phase II fingerlings.

In 1994, no control was run to test for cage effect

Table 4. Water quality parameters for Smith Mountain Lake versus the Virginia Tech aquaculture facility in 1994. Alkalinity is measured in mg/L $CaCO_3$ and nitrogen and dissolved oxygen in mg/L.

Parameter	**Smith Mountain Lake**	**VA Tech Aquaculture**
pH	8.1	7.5
Alkalinity	97	125
NO_2	0.1	0.3
NO_3	0.37	60
NH_4	0.04	1.5
D.O.	10.4	5.0

mortality. Cage effects would be death due to handling and caging alone, without the experience of transport and temperature/water chemistry change.

1995 Cage Trials

In 1995, a control was run to determine if 1994 cage design could have led to fingerling mortality. Control cages were stocked with aquaculture-reared striped bass at densities ranging from 46 to 54 fingerlings (0.36 g/L to 0.42 g/L). Fewer fish were placed in cages than in the 1994 Phase I trial, but densities (g/L) were higher than in 1994 (0.17 g/L to 0.25 g/L) due to the larger size of 1995 striped bass (Table 5a). The control densities were much lower than 1994 Phase II densities, but should dispel concerns about cage-induced mortality in the normal, Phase I stocking program. No mortality was observed in any of the four cages after fingerlings were held for 48 hours at the Virginia Tech aquaculture facility (Table 5b). The control runs could only eliminate cage effects and transport as sources of mortality. These fish were not hauled or subjected to water chemistry and temperature changes as with stocked fish. This points to hauling stress and inadequate tempering as remaining sources of mortality in 1994 cages.

In 1995, three field trials were also run. Two Phase I trials (Trials 1 and 3) were run because high mortality was experienced in the first trial. Only one Phase II trial

Table 5a. Experimental conditions of 1995 Phase I and Phase II fingerling striped bass handling mortality. Mean weights, mean total lengths, and surface temperature are in mm, grams, and ° C respectively.

Trial #	**Date**	**Fingerling Phase**	**Weight**	**TL**	**Lake Temp.**
Control	6/30	I	0.78	39.2	26
1	6/30	I	0.45	36.5	27
2	7/10	II	3.19	64.3	28
3	7/12	I	0.96	45.2	28

Table 5b. Fingerling striped bass percentage handling mortality in 1995. Number and density of stocked fingerlings are in parentheses (total number, g/L).

Trial #	**Cage 1**	**Cage 2**	**Cage 3**
1	29.3 (181,0.027)	63.0 (127,0.019)	49.1 (173,0.026)
2	0 (55,0.058)	10.9 (64,0.068)	5.66 (53,0.056)
3	13.1 (160,0.051)	29.7 (158,0.051)	28.9 (128,0.041)

(Trial 2) was run in 1995. Fingerlings used in each trial varied by size and were again subjected to different lake water temperatures (Table 5a). From 55 (Phase II) to 181 (Phase I) fish were stocked into the larger cages, resulting in a 10 to 100-fold decrease in densities versus the 1994 trials (0.019 g/L to 0.068 g/L) (Table 5b). Density should not have been a factor in the 1995 field trials given the high volume, 3000 L, of water in each cage. These cages held 30 times more water than the 1994 cages, so crowding stress was probably not a factor in these trials.

The new cages were also used in 1995 field trials to allow greater vertical migration and potentially greater temperature refugia for stocked fingerlings. Water temperatures did not change more than 2° C in the three meters of depth of the cages, but fish could better escape direct sunlight than in the 1994 trials. Fingerlings were observed to congregate no shallower than a depth of one meter during the day. The 1995 trials were also not directly equivalent to 1994 tests because Phase I fingerlings were transported by tanker truck for 6-8 hours (from North Carolina) versus 1.5 hours (from Brookneal).

Results in 1995 were almost opposite those in 1994. Phase II fingerlings (Trial 2) suffered low mortality (mean = 5.52%) whereas Phase I fish (Trials 1 & 3) suffered much higher mortality (means of 47.1% and 23.9% respectively) than in 1994 (Table 5b). The differences in mean mortality between the two Phase I fingerling trials (Trial 1 & 3) and the Phase II fingerling trial (Trials 2) were statistically significant (P=0.0155 and P=0.0424 respectively). In addition to transport time, water temperature differences between transport water and reservoir water were much more marked than in 1994. Transport water was 21° C upon arrival because McKinney Hatchery, North Carolina fish were transported in well water. Lake temperatures on the two days of Phase I stocking were 27° C and 28° C.

Mortality of Phase II fingerlings was also much different than in 1994. Phase II fish showed much reduced mortality (at least a ten-fold decrease in percentage mean mortality) compared to 1994, possibly because of extended time spent tempering prior to stocking (approximately 1.5 hours) and a lower temperature gradient between transport and lake water temperature (3° C vs. 5° C in 1994).

Fingerling mortalities were also compared between years to test for significant differences. Phase I mean mortalities in 1995 were significantly higher than in the Phase I trial conducted in 1994 (P<0.01). However, Phase II mortalities were significantly lower in the 1995 trial than in either of the trials in 1994 (P<0.01).

PREDATION MORTALITY

Estimates of striped bass losses to predation by largemouth bass were made separately for Waterwheel and Penhook coves in 1994 and 1995. Potential "worst-case" simulations were also performed to estimate predation losses should predator numbers be underestimated or, in the unlikely event that striped bass become a larger percentage of largemouth bass diets. Estimating numbers of largemouth bass in each cove was the first step in estimating number of striped bass lost to predation.

Population Estimation

Age 1+ and older largemouth bass numbers in each cove and in both sampling periods were estimated by mark-recapture using the computer program JOLLY. Estimates of largemouth bass abundance based on VDGIF rotenone data (1990-1995) at four coves located uplake and downlake are also included for comparison. Rotenone estimates were calculated as average largemouth bass densities (44 fish/ha) for the four coves and for the six years of data. Jolly-Seber estimates were used in calculating number of striped bass lost to predation because these estimates were calculated for the specific stocking coves. Estimated number of largemouth bass for Penhook could not be calculated in 1995 because of a lack of recaptured largemouth bass in the reduced sampling in 1995. Because of this, the esimated number of largemouth bass used in the 1995 Penhook predation calculations were the same as for 1994.

1994. - Because the Jolly-Seber estimator is a multiple census mark-recapture technique, estimates were calculated for each cove over the sampling period. Population estimates began to vary after the first three sampling dates at Penhook and after the first two sampling dates at Waterwheel. Estimates at Penhook were consistently lower than at Waterwheel, and the final estimate of largemouth bass numbers was 132 fish greater at Waterwheel. Penhook was a much larger cove, but did not seem to hold as many largemouth bass as did Waterwheel. This may have been a result of tournament bass releases at Waterwheel or simply habitat differences between the coves. As the sampling seasons progressed and lake temperatures increased, fewer largemouth bass were near shore, leading to a decline in number of recaptures, m_i (Table 6). This resulted in a proportional increase in the estimate of largemouth bass numbers (N_i). Low number of recaptures inflated the population estimate in two ways. First, number of recaptures was used as the denominator in the calculation of B_i (number of marked fish remaining prior to sample i, accounts for emigration) and also in the final calculation of N_i. Consequently, low number of recaptures resulted in a high B_i which was used in the final calculation of N_i. The

Table 6. Largemouth bass Jolly-Seber population estimates for Penhook (top) and Waterwheel (bottom) in 1994. Cove rotenone estimates are also included. See page 23 for symbol definitions. * not included in mean estimate.

		Jolly-Seber Statistics			
Sample #	**Date**	**B_i**	**C_i**	**m_i**	**Population estimate (95% CI)**
1	6/15	-	97	-	-
2	6/19	40	40	3	409 (40 to 930)
3	6/28	79	64	7	638 (64 to 1277)
4	7/5	107	35	6	549 (35 to 1221)
5	7/11	86	38	8	372 (38 to 810)
6*	7/19	157	27	3	1099 (27 to 3613)

Total mean estimate: 492 (44 to 1160)
Cove rotenone estimate: 2671
Adjusted cove rotenone estimate: 1700

By age class:
Age 1+ - 92
Age 2+ - 208
Age 3+ - 120
Age 4+ - 72

		Jolly-Seber Statistics			
Sample #	**Date**	**B_i**	**C_i**	**mi**	**Population estimate (95% CI)**
1	6/22	-	80	-	-
2	6/26	88	110	12	751 (110 to 1315)
3	7/6	149	67	13	724 (67 to 1345)
4	7/13	108	54	14	397 (54 to 763)
5*	7/18	165	52	6	1249 (52 to 3021)

Total mean estimate: 624 (77 to 1141)
Cove rotenone estimate: 1624
Adjusted cove rotenone estimate: 1033

By age class:
Age 1+ - 145
Age 2+ - 107
Age 3+ - 296
Age 4+ - 76

combination of high B_i and low m_i resulted in high final estimates of largemouth bass numbers (Table 6 asterisked values). These values were eliminated from the calculation of mean population size because they were not representative of the largemouth bass population size when striped bass were most vulnerable to predation (i.e. the first week poststocking). The fifth estimate at Penhook and the fourth estimate at Waterwheel were not excluded because the number of recaptured largemouth bass was consistent with previous population estimates.

Cove rotenone estimates of largemouth bass numbers were five times greater at Penhook and 2.5 times greater at Waterwheel than the Jolly-Seber estimate prior to the adjustment multiplier. After adjusting rotenone densities for the larger stocking coves, values were still 2-3 times higher than the mark-recapture estimates.

1995. - The 1995 population estimates for the Waterwheel cove were initially higher than in 1994 but began to decline after the fifth sampling session. Total number of fish caught (C_i) in the first five sampling sessions was lower than in the 1994 season and declined further beginning with sample six. By the ninth sampling session, marked fish caught began to decline along with total fish captured (Table 7). In 1994, the total number of largemouth bass sampled began to decline about the same date that the 1995 season began. Unlike 1994, 1995 recapture numbers were very

Table 7. Largemouth bass Jolly-Seber population estimates for Waterwheel in 1995. Cove rotenone estimates are also included. * not included in mean estimate. The Penhook estimate is the same as in 1994.

		Jolly-Seber Statistics			
Sample #	Date	B_i	Ci	mi	Population estimate (95% CI)
1	7/9	-	41	-	-
2	7/10	36	69	1	1260 (69 to 3881)
3	7/11	54	42	1	1159 (42 to 3454)
4	7/12	148	46	7	870 (46 to 1780)
5	7/13	437	42	7	2349 (42 to 7285)
6	7/17	138	27	7	482 (27 to 1212)
7	7/19	148	23	4	710 (23 to 2258)
8	7/24	145	39	6	834 (39 to 2677)
9*	7/26	57	15	1	456 (15 to 1710)
10*	7/31	33	18	5	106 (18 to 334)
11*	8/8	31	28	2	300 (28 to 1133)
12*	8/14	26	11	3	78 (11 to 300)

Total averaged estimate: 1094 (41 to 3221)
Cove rotenone estimate: 1624
Adjusted cove rotenone estimate: 1033

By age class:
Age 1+ - 62
Age 2+ - 323
Age 3+ - 520
Age 4+ - 189

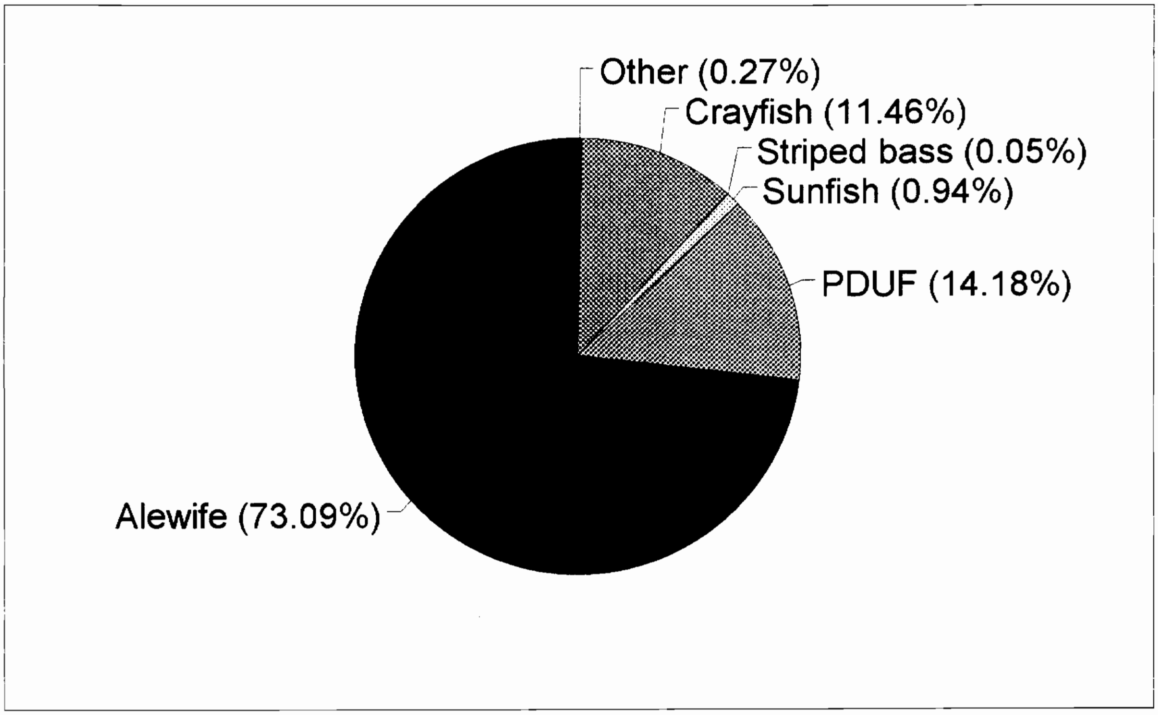
low throughout the summer. Number of recaptures was especially low for the first two sampling nights (only one recapture each of the first two nights). Beginning on the third sampling session, recaptures increased but to only one-half the number of recaptures in 1994. Low number of recaptures (i.e. small denominator) led to an estimate of largemouth bass that was 1.75 times higher than in 1994 (Table 7). As with the 1994 population estimate, estimation of N for each sampling session was not consistent, and thus not all estimates were included in the calculation of mean population size. The final four estimates (beginning with 26 July) were discarded due to the low number of largemouth bass sampled. All observed striped bass consumption by largemouth bass in 1995 occurred within the first week poststocking, as it did in 1994. Therefore, the population estimates used in the total predation mortality equations were those made within two weeks of stocking. Because sampling at Penhook in 1995 resulted in only two largemouth bass recaptures, a Jolly-Seber estimate could not be calculated. The estimated number of predators used for 1995 simulations was the same as the estimate used for 1994. As in 1994, the cove rotenone estimate was included as a comparison for the mark-recapture estimate (Table 7). In 1995, the cove rotenone estimate without the adjustment multiplier was still 1.6 times higher than the Jolly-Seber estimate but the disparity was not as great as in 1994 (2.5

times higher in 1994). After adjusting the estimate, the rotenone estimate was only 61 fish lower than the Jolly-Seber estimate.

Note that no age-5 and older largemouth bass were included in the population estimates. Fewer than ten age-5 largemouth bass were captured each year and they were never observed to have consumed striped bass. Based on their large size (probably would not target a 30-50 mm striped bass) and low estimated number in the coves, this age class was not used in the bioenergetics model or included in the population estimates. No age-6+ largemouth bass were captured either summer.

Diet Composition

1994. - Of the 774 largemouth bass stomachs checked in both the Penhook and Waterwheel coves combined, 28% contained food items. Striped bass comprised a minute fraction of largemouth bass stomach contents (Figure 3). Striped bass accounted for only 0.07% and 0.05% by weight of largemouth bass diets at Penhook and Waterwheel, respectively. In 1994, only a total of three striped bass were identified in largemouth bass stomach contents. This predation occurred within the first week poststocking at both coves. At Penhook, one age-4 largemouth bass contained one fingerling striped bass four days poststocking (19 June) and at Waterwheel, two fingerlings were consumed by one age-



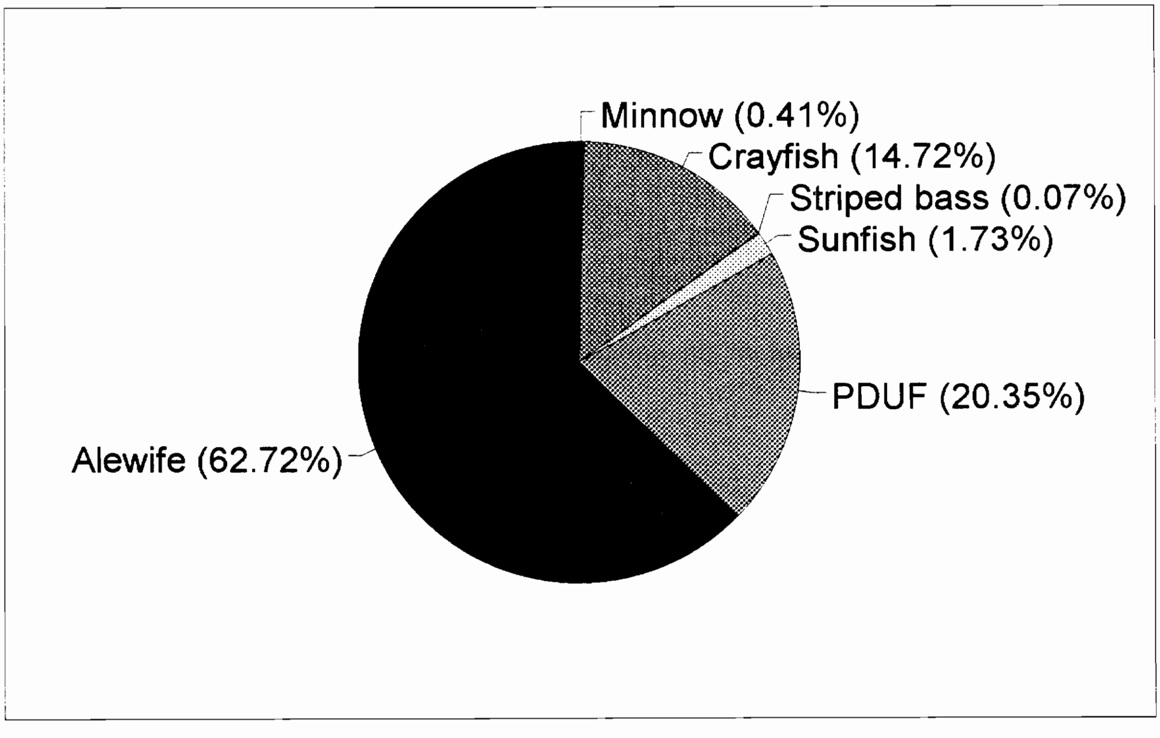
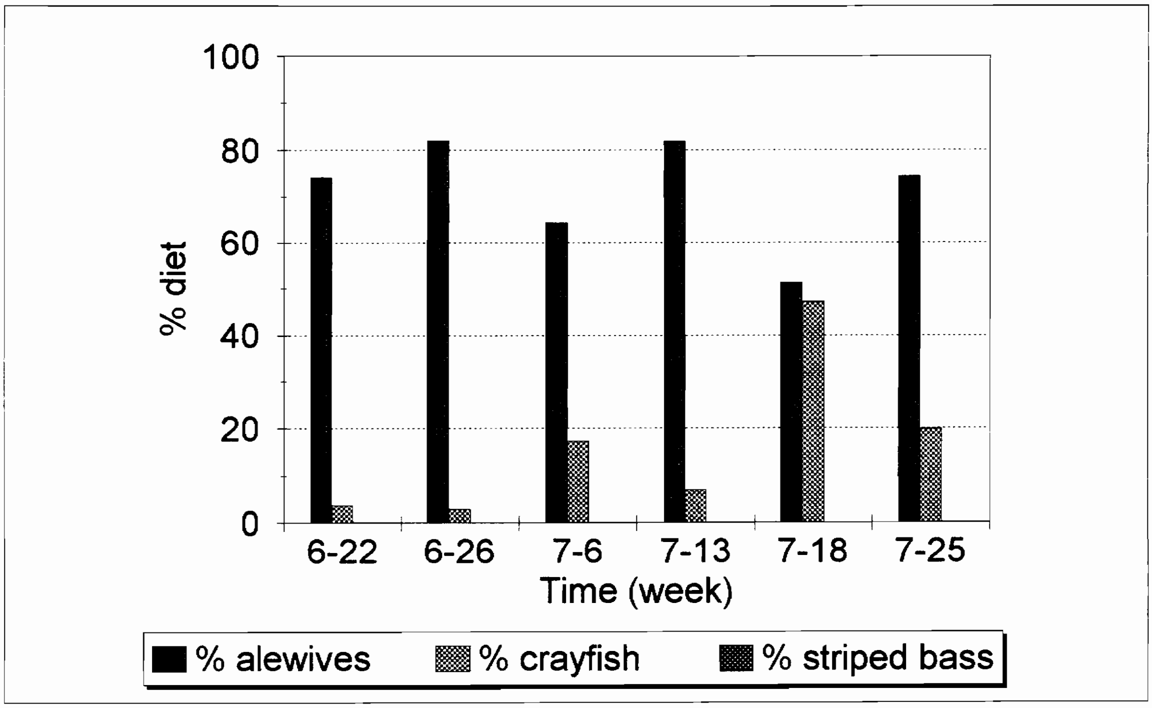


Figure 3. Largemouth bass percentage diet composition by weight in 1994 at Waterwheel (top) and Penhook (bottom) coves.

1 largemouth bass on the night of stocking (22 June). No more striped bass predation was detected for the rest of the 1994 sampling season.

Preferred prey of largemouth bass in both coves appeared to be adult alewives (mean TL = 100 mm, mean maximum body depth = 23 mm). Alewives were the principal prey of largemouth bass, making up over 62% of largemouth bass diets. Crayfish (mean carapace length = 35 mm) were also an important largemouth bass prey item, accounting for over 11% of total largemouth bass diets. Crayfish consumed by largemouth bass greatly increased later in the summer (mid-July), possibly when the alewife spawn had begun to decline (Tisa and Ney 1991). This shift seemed to coincide with the period that alewives began moving offshore and became less prominent in largemouth bass diets. This same pattern probably would have been observed at Waterwheel if sampling had continued into August as it did in 1995 (Figure 4). Other prey species such as sunfish and minnows made up a relatively small percentage of total largemouth bass diets (Figure 3). No gizzard shad or threadfin shad were identified in largemouth bass stomachs although they seemed to be available as prey.



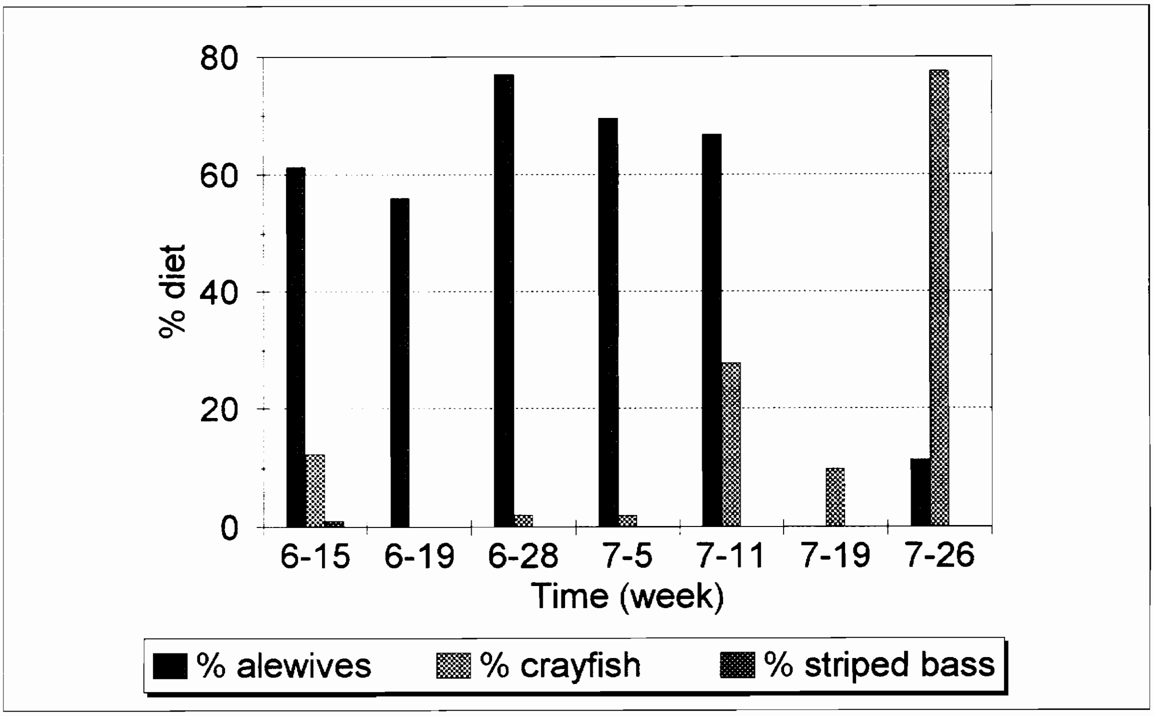


Figure 4. Largemouth bass diet composition over time at the Waterwheel (top) and Penhook (bottom) coves in 1994.

1995. - Of the 373 largemouth bass stomachs checked in the Waterwheel cove in 1995, 28% contained food items. Because the Penhook cove was only spot-checked for striped bass predation and because no striped bass were found in largemouth bass stomachs, Penhook diet composition data was not pooled with Waterwheel data. Striped bass again made up only a small proportion (1.29%) of predator diets (Figure 5). This was a marked increase from 1994, but still a relatively minor component of largemouth bass diets. Four largemouth bass (three age-2 and one age-1 fish) contained a total of 11 striped bass. All of the predation occurred within the first three days poststocking, and no more predation was detected in the following weeks.

In both years, diet analysis showed that adult alewives made up over 61% of largemouth bass diets. During the mid-June to early August period, alewives were extremely numerous on the nearshore areas, probably due to spawning (Tisa 1988), and were thus readily available to near-shore predators that may have otherwise preyed on fingerling striped bass. An adult alewife weighed about eight times as much as an age-0 striped bass, and alewives were probably energetically more profitable for largemouth bass to consume. In general, 1995 largemouth bass predation patterns were similar to 1994 patterns (Figure 5). Alewives (mean TL = 97 mm, mean maximum body depth 21 mm) were again the principal prey item followed by crayfish (mean carapace

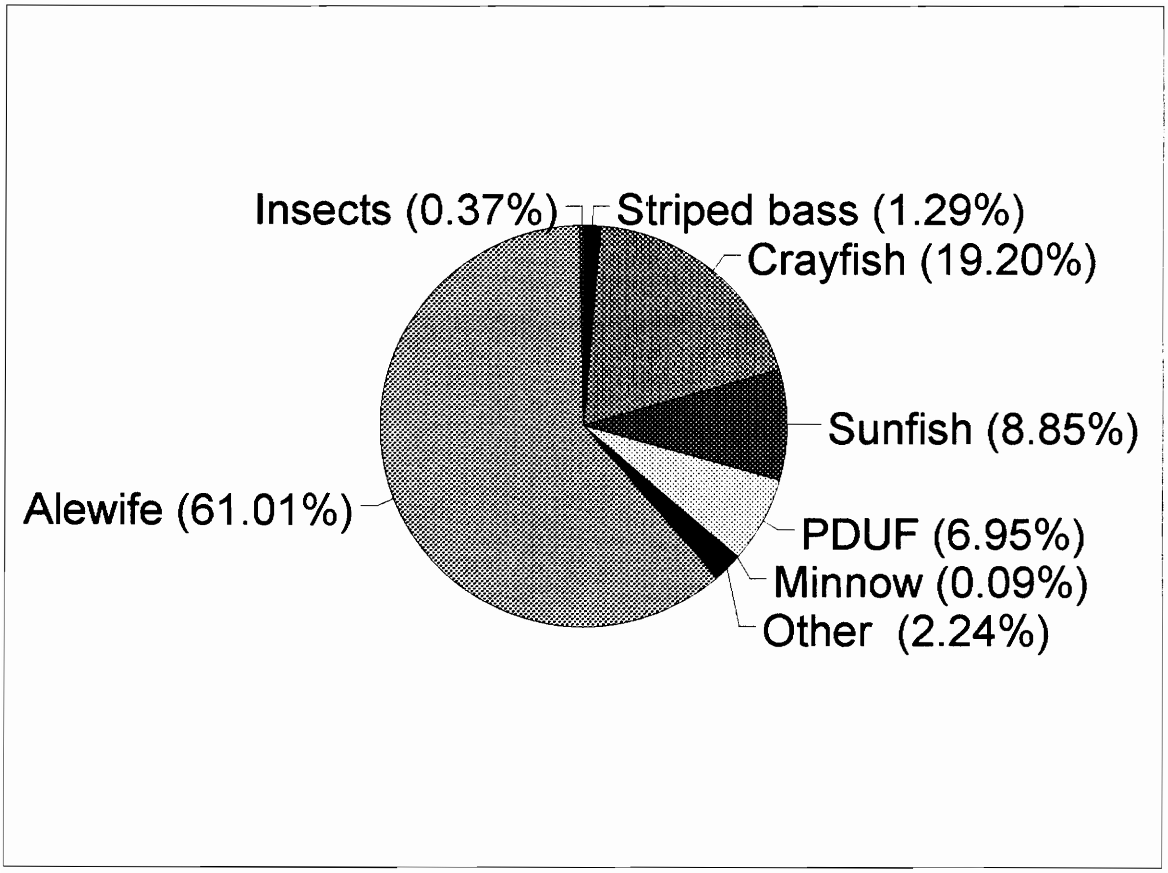


Figure 5. Largemouth bass percentage diet composition by weight at the Waterwheel cove in 1995.

length 31 mm). As in 1994, diet composition began shifting in mid-July as alewives began moving away from shore and crayfishreplaced them in the diet (Figure 6). This shift in diet may have been observed at Waterwheel in 1994 if sampling had continued into August as it did in 1995.

Although alewife density, as indicated by electrofishing counts, declined sharply by mid-July in 1995, no relationship between alewife CPUE and consumption of striped bass could be described because striped bass were only found in largemouth bass stomachs in early July (Figure 7). To further test the hypothesis that alewives might act as a buffer to striped bass predation, a laboratory experiment was performed in 1995.

To correct for differential rates of digestion between alewives and striped bass, a multiplier was factored into percent of striped bass consumed in 1994 and 1995. This multiplier was calculated to be 2.00 in 1994 and 1.93 in 1995 (i.e. 2.00 X % striped bass in largemouth bass diets). The multiplier was higher in 1994 because stocked striped bass in 1995 were larger than in 1994. The corrections increased the observed percent striped bass in largemouth bass diets to 0.1% at Waterwheel and to 0.14% at Penhook in 1994, and to 2.49% at both coves in 1995. These values for percent striped bass in largemouth bass diets were used in the bioenergetics model.

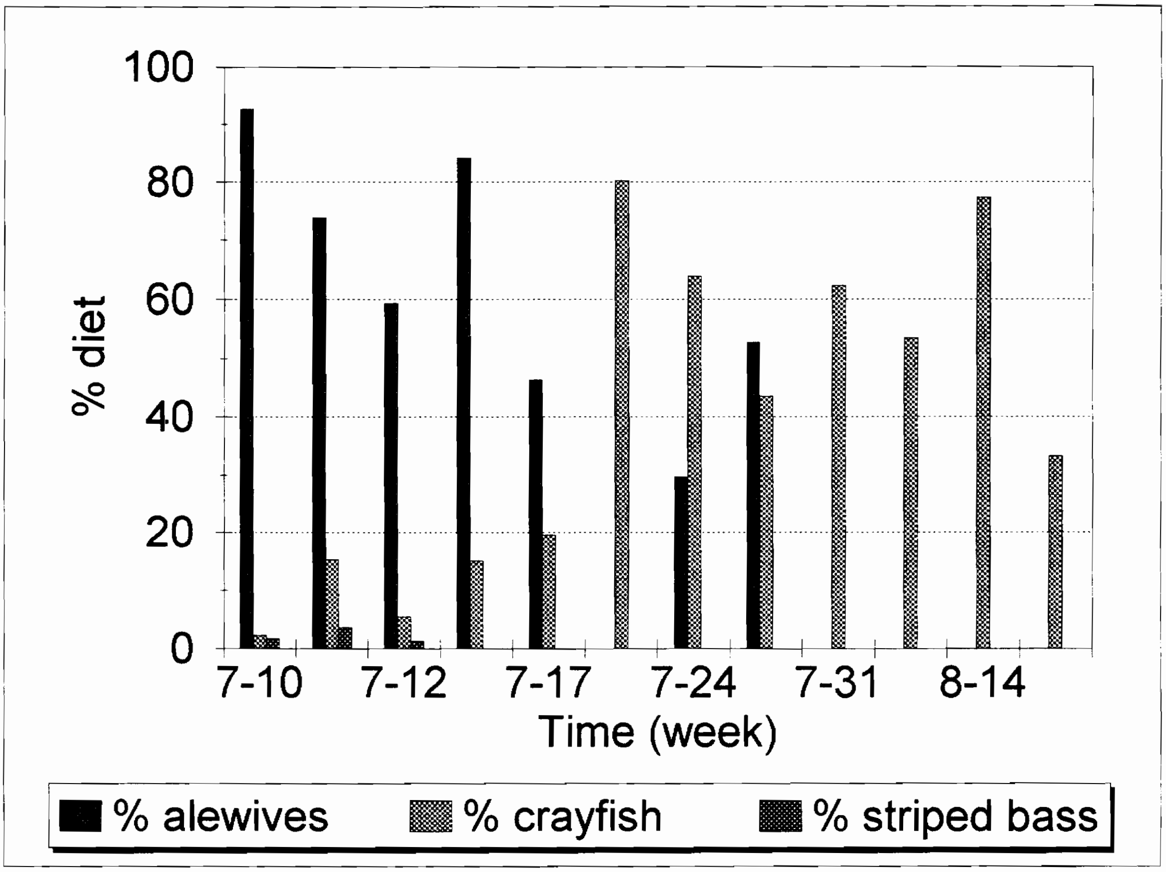


Figure 6. Largemouth bass diet composition over time at Waterwheel in 1995.

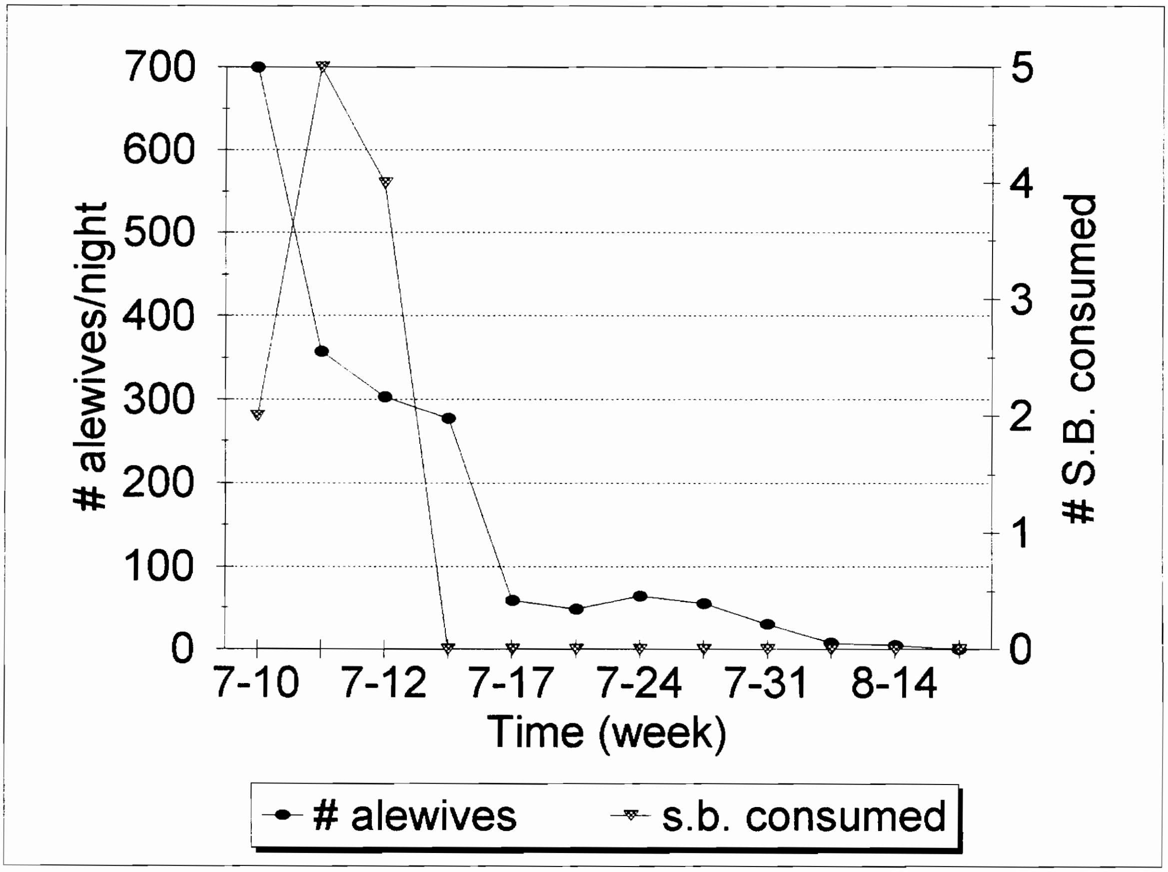


Figure 7. Alewife density versus striped bass consumed at Waterwheel in 1995.

Bioenergetic Modelling

Total daily consumption by individual largemouth bass of each cohort (age-1 to age-4) was estimated using bioenergetic modelling. Penhook and Waterwheel diet composition data used in the model were pooled because percent diets were very similar for both coves in 1994. For 1995, only Waterwheel diet composition was used because so few stomachs were examined at Penhook in 1995. Diet compostion data were based on samples taken over a 45-day period the summer of 1994 and a 42-day period during the summer of 1995. Each predator cohort was assigned the same diet composition in the model.

Individual daily consumption. - The model was used to calculate total daily consumption (grams) of striped bass fingerlings, alewives, sunfish, and crayfish by individual largemouth bass. This was performed on each age-class of predator. Total daily consumption by individual predators was dominated by alewives, but I was primarily interested in daily consumption of striped bass (Table 8a & 8b). On an absolute basis, total daily consumption by individual predators increased with age of the predator in both 1994 and 1995. When predator weights were factored into daily consumption (weight-specific consumption), age-1 one predators were modelled to consume almost twice as much prey by weight than any other cohort (Table 8a). Note that total daily consumption estimates were the same between years.

Table 8a. Total daily consumption (C_D) and weight-specific consumption per individual largemouth bass. C_D value includes striped bass, alewives, sunfish, and crayfish.

Year	Cohort	Mean LMB wt. (g)	C_D (mg)	Total Wt-Specific Consump. (mg/g)	Striped bass Wt-Specific Consump. (mg/g)
1994					
	I	58	1384	23.86	0.01193
	II	260	3741	14.39	0.00720
	III	515	6182	12.00	0.00600
	IV	785	8254	10.51	0.00526
1995					
	I	58	1384	23.86	0.3084
	II	260	3741	14.39	0.1857
	III	515	6182	12.00	0.1549
	IV	785	8254	10.51	0.1357

Table 8. Quantity of C_D (mg) made up by each prey item used in the model.

Year	Cohort	Striped bass	Alewife	Crayfish	Sunfish	C_D
1994						
	I	0.69	1204	166.1	13.15	1384
	II	1.87	3255	448.9	35.54	3741
	III	3.09	5378	741.8	58.72	6182
	IV	4.13	7181	990.4	78.41	8254
1995						
	I	17.86	969	272.8	124.6	1384
	II	48.27	2619	737.5	336.8	3741
	III	79.76	4328	1219	556.4	6182
	IV	106.5	5779	1627	743.0	8254

This occurred because the same growth rates of largemouth bass in the model were used for both years because little growth data was collected in 1995 due to a lack of recaptures. Although total daily consumption was the same both years, daily consumption estimates for each of the four prey used in the model were not identical (Table 8b).

Patterns of striped bass consumed followed the same pattern as total daily consumption by individual largemouth bass. On an absolute basis, age-1 predators consumed the least food, but when predator weights were factored in, age-1 largemouth bass had a weight-specific consumption value about two times any other cohort (Table 8a). Daily consumption estimates of striped bass for individuals of each of the four predator cohorts were very low. At the maximum, striped bass only made up 106.5 mg of daily ration of age-4 largemouth bass predators in the model (Table 8b). In contrast, alewives made up over 7000 mg of the daily ration of age-4 largemouth bass in 1994. Estimated daily consumption of striped bass was about 30 times higher in 1995 because more striped bass were found in largemouth bass stomachs and because striped bass stocked and consumed were larger than in 1994 (mean weight 1994 = 0.4 g; 1995 = 1.0 g). Age-1 predators displayed the highest rates of consumption when daily consumption was converted to a weight-specific weight of striped bass consumed (mg striped bass consumed/mean weight of predator). In 1994, age-1 largemouth bass were estimated to consume 0.01193 mg/g of striped bass versus 0.3084 mg/g in 1995 (Table 8a). The absolute consumption estimate was used to calculate striped bass lost to predation.

Total consumption of striped bass. - With daily consumption estimated, total number of striped bass lost due to predation could be calculated. The first step in this process was to convert the grams of striped bass eaten per day per predator (i.e. daily consumption value) into number of striped bass eaten per day per predator. This value was calculated by simply dividing the daily consumption value by the average weight of striped bass when consumed. Once number eaten per predator per day was calculated, total number of striped bass consumed during the poststocking period was estimated by multiplying number of striped bass consumed per day by the number of field season days (45 in 1994, 42 in 1995) and the number of largemouth bass in the cohort (Table 9). This process was repeated for each predator cohort and for both years of the study.

Estimated number of striped bass consumed by largemouth bass predators of the four age-groups ranged from 22 to 1170. In both 1994 and 1995, age-3 largemouth bass consumed the most fingerlings (more than twice any other cohort) because they constituted the largest cohort in the population estimates. Even though age-1 predators were calculated to have the highest weight-specific consumptions

Table 9. Expansion from individual daily consumption (C_D) to total striped bass consumed.

Year	Cohort	C_D (mg)	Number of LMB	Total Days of Simulation	Number Striped Bass Consumed
1994					
	I	0.692	237	45	22
	II	1.871	315	45	80
	III	3.091	416	45	176
	IV	4.127	148	45	82
1995					
	I	17.86	154	42	79
	II	48.27	531	42	732
	III	79.76	640	42	1458
	IV	106.5	261	42	793

rates, they were estimated to have consumed the fewest striped bass because of their small size and low absolute growth in weight. The estimated total number of fingerlings consumed was 360 in 1994 and 3062 in 1995 (Table 10). This represents 0.1% of the striped bass stocked in 1994 and 1.2% of fingerlings stocked in 1995.

Table 10. Estimated number of striped bass fingerlings consumed in the Penhook and Waterwheel coves in 1994 and 1995 (95% Confidence Interval based on populations estimates).

Largemouth Bass Age Group	**Number Consumed**	
	1994	**1995**
Age 1+	22 (3-46)	79 (2-179)
Age 2+	80 (8-179)	732 (33-2629)
Age 3+	176 (20-338)	1458 (91-6988)
Age 4+	82 (9-175)	793 (43-3368)
Total	360 (40-738)	3062 (169-13,164)

<u>Simulated predation on striped bass</u>. - To account for "worst-case" scenarios, several different bioenergetic simulations were run with changes in percent of striped bass in largemouth bass diets and with upper confidence limits of largemouth bass population estimates. Percent of striped bass in predator diets was increased to either 10% or 25%. The same age-specific patterns of consumption by age class of predator exist as in Table 10, but total number of fingerlings consumed increased by at least 200 times in 1994 and at least eight times in 1995. In 1994, total number of striped bass lost at the simulated 10% and 25% values was 200 and 500 times greater than actual estimates (Table 11). At 25% of largemouth diet, half of the stocked fingerlings would have been lost to predation, in 1994. When the 95% confidence limit of largemouth bass population estimates was used in the 10% and 25% simulations, number of striped bass consumed increased to half of the population lost at the 10% consumption rate and to total loss of stocked striped bass at the 25% consumption rate. When the 95% confidence limit of predator abundance was input in a simulation using observed striped bass diet contribution, the estimated number of striped bass consumed was only twice that calculated with the actual 1994 population estimate. Total striped bass lost under these simulations in 1995 was not as high as in 1994 because the striped bass consumed were 2.5 times heavier than in 1994, and thus fewer striped bass had

Table 11. Simulated number of striped bass consumed at 10% and 25% of largemouth diet. The 95% confidence limits of population estimates in parenthesis.

Largemouth Bass Age Group	**Year**	**Striped Bass Consumed** **Observed Diet Contribution**	**10% of Diet**	**25% of Diet**
Age 1+	1994	(46)	4504 (9256)	11258 (23139)
Age 2+		(178)	16110 (35741)	40275 (89357)
Age 3+		(350)	35090 (70264)	87728 (175671)
Age 4+		(176)	16572 (35086)	41427 (87710)
Total		**(750)**	**72,276 (150,347)**	**180,688(375,877)**
Age 1+	1995	(100)	608 (1390)	1521 (3477)
Age 2+		(1362)	5671 (20378)	14178 (50946)
Age 3+		(3620)	11295 (54143)	28235 (135353)
Age 4+		(2754)	6150 (26248)	15374 (65622)
Total		**(6836)**	**23,724 (102,159)**	**59,308 (255,398)**

to be consumed to make up 10% and 25% of largemouth bass diets. In 1995, total number of striped bass lost at the simulated 10% and 25% values was eight times and 20 times actual estimated predation losses. When the upper confidence limit was used in the 10% and 25% simulations, the total number of striped bass lost to predation increased to 40% (only 250,000 stocked in 1995). When the 95% confidence limit was used with the observed striped bass diet composition, the simulated number lost was only twice the estimated number lost with the actual population estimate (Table 11). From these simulations, it appears that local largemouth bass stocks have the potential to inflict substantial losses on fingerling striped bass in Smith Mountain Lake in the unlikely event that percent of striped bass in largemouth bass diets increase to 10%. That potential was largely unrealized in 1994 and 1995 because striped bass comprised only a tiny component of the largemouth bass diet.

Influences on Predator Consumption

I found no evidence of predator attraction to aggregates of striped bass fingerlings in comparisons of striped bass versus largemouth bass CPUE over time in sampling transects. No significant positive correlations were detected in either cove or either sampling year (Figures 8 & 9). Both Waterwheel and Penhook regressions

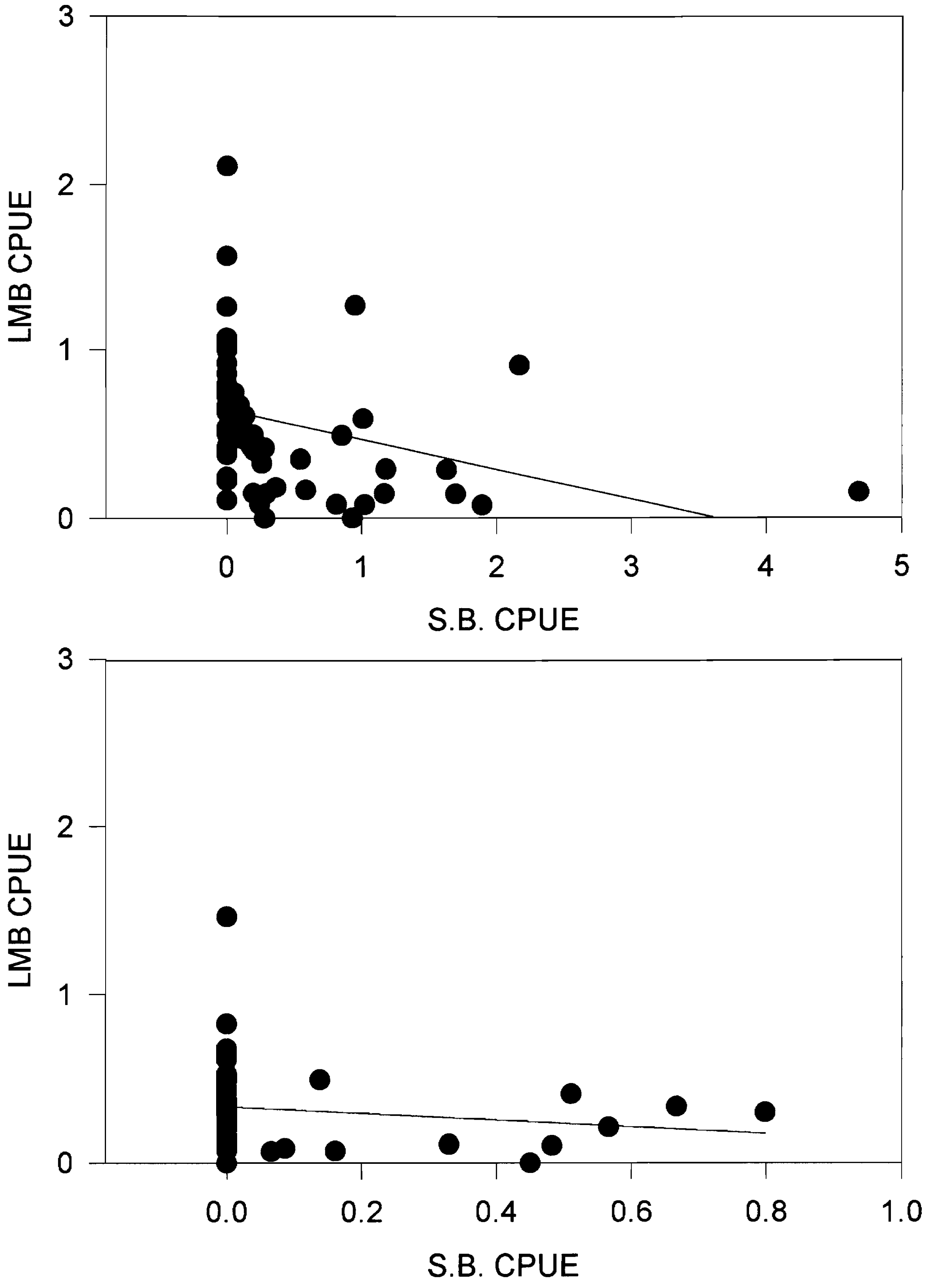


Figure 8. Relationship between largemouth bass and striped bass catch per unit effort (CPUE) in Waterwheel (top) and Penhook (bottom) coves from 15 June to 25 July 1994.

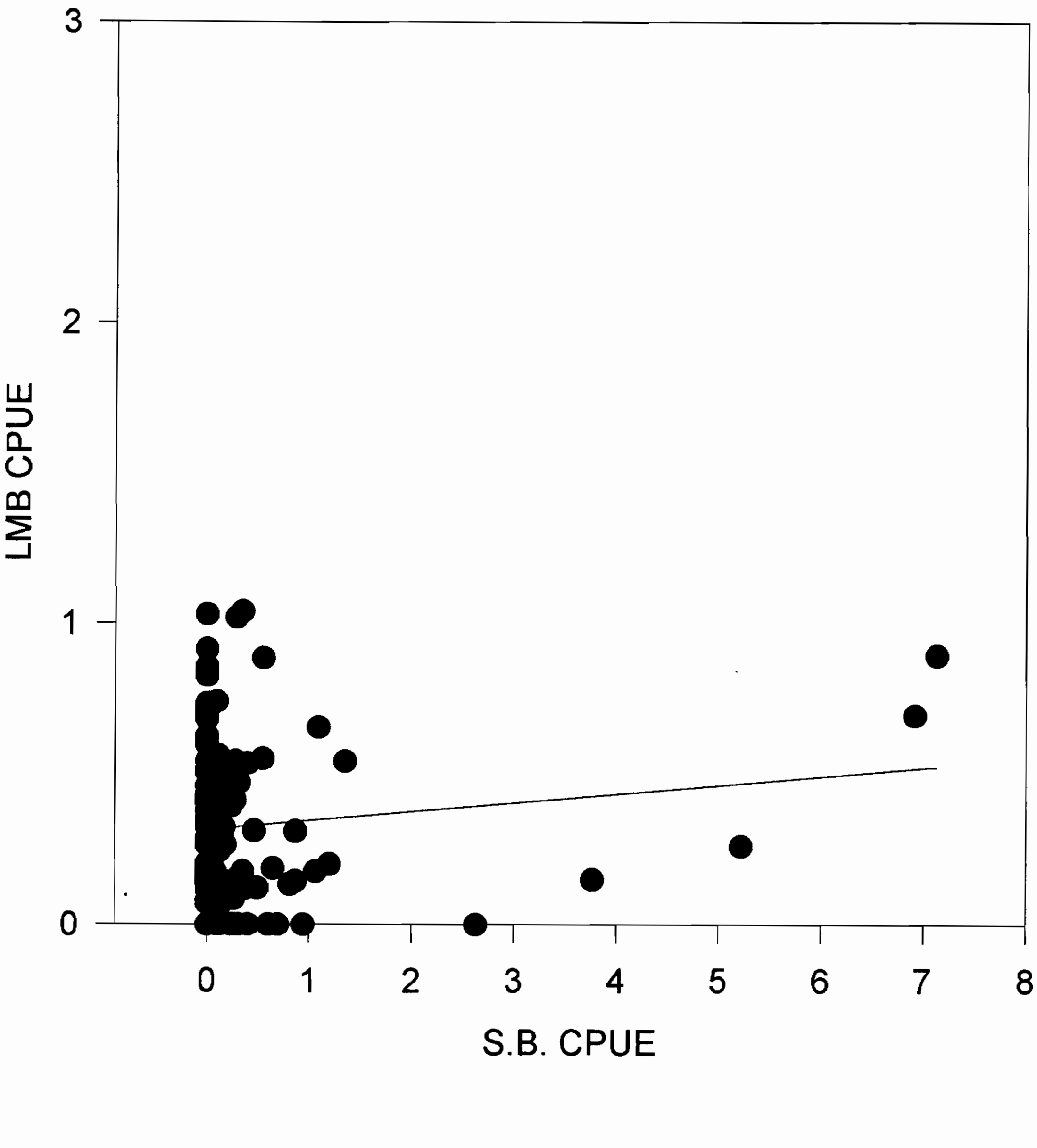


Figure 9. Relationship between largemouth bass catch per unit effort (CPUE) and striped bass CPUE at Waterwheel from 10 July to 20 August 1995.

in 1994 exhibited slightly negative slopes of -0.177 and -0.207, respectively, ($P<0.01$ & $P=0.23$) but there was a slightly positive slope of 0.0289 for the Waterwheel regression in 1995 ($P=0.20$). The Waterwheel regression slope in 1994 was significantly different from zero ($P<0.01$), but the slope of the regression line was negative which indicates a lack of attraction of largemouth bass to striped bass. Largemouth bass CPUE values seemed to depend more on habitat than on striped bass fingerlings and most largemouth bass were found in transects where no striped bass aggregated. In 1995, two additional regressions were run for CPUE data at the Waterwheel cove for the first two nights poststocking. These tests were performed to detect potential attraction of largemouth bass to striped bass when fingerlings were still highly aggregated around the stocking site. The slope of the second day regression was significantly different from the first day ($P<0.01$), but neither the slope of the first day ($P=0.95$) nor the second day ($P=0.45$) was significantly different from zero. These two additional tests still do not indicate attraction of largemouth bass to striped bass.

I also investigated potential predator attraction to striped bass aggregates by examining CPUE ratios over time. I plotted the ratio of striped bass CPUE over largemouth bass CPUE over both sampling summers (Figure 10). The ratio should decline if largemouth bass are attracted to striped

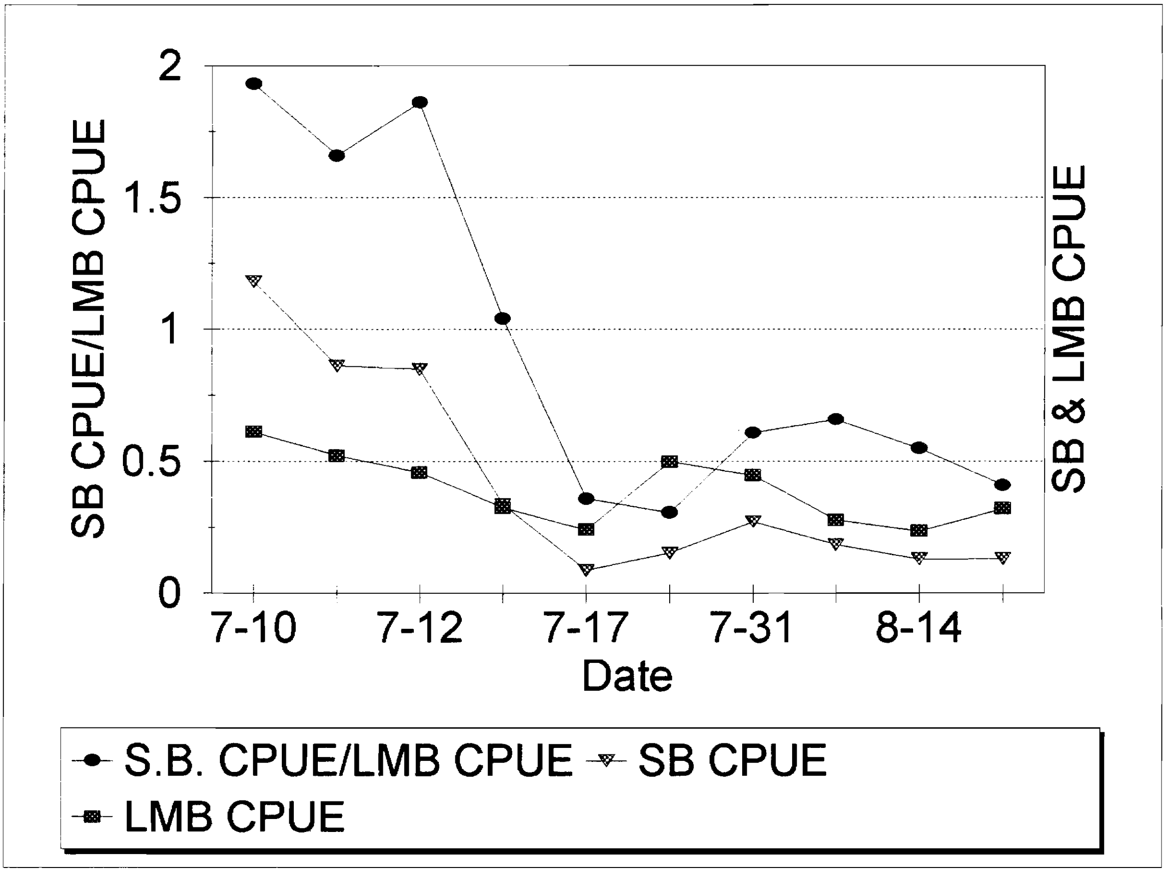


Figure 10. Ratio of striped bass to largemouth bass CPUE over time at Waterwheel in 1995.

bass (i.e. largemouth CPUE increases, decreasing the ratio). This relationship was observed, but was influenced more by declines in striped bass CPUE than increases in largemouth bass CPUE. Largemouth bass CPUE was consistently around 0.5 fish per minute for the entire sampling season.

Another component that could have influenced the extent of predation on striped bass was the rate of striped bass dispersal poststocking. The quicker striped bass spread out from the stocking site, the better their chances of avoiding the attraction of predators to an aggregate of prey. Again, CPUE was the only way to describe dispersal of striped bass. Dispersal refers to the movement of striped bass away from the stocking transect, in both coves (around 0 m). To describe the relative rate of dispersal, distance from the stocking site was plotted against striped bass CPUE values on four sampling nights (Figures 11 and 12). In 1994, CPUE values were plotted 5, 15, 22, and 38 days poststocking at Waterwheel and 14, 21, 27, and 35 days poststocking at Penhook. Dispersal varied considerably by cove and year. Striped bass moved from the immediate stocking areas within one or two days but then seemed to hold in transects with suitable habitat, (sandy substrate). In 1994, striped bass numbers were not accurately tracked until 28 June at Penhook (14 days poststocking) and 26 June (five days postocking) at Waterwheel due to initial problems collecting striped bass fingerlings. Striped bass CPUE in 1995 gives a better

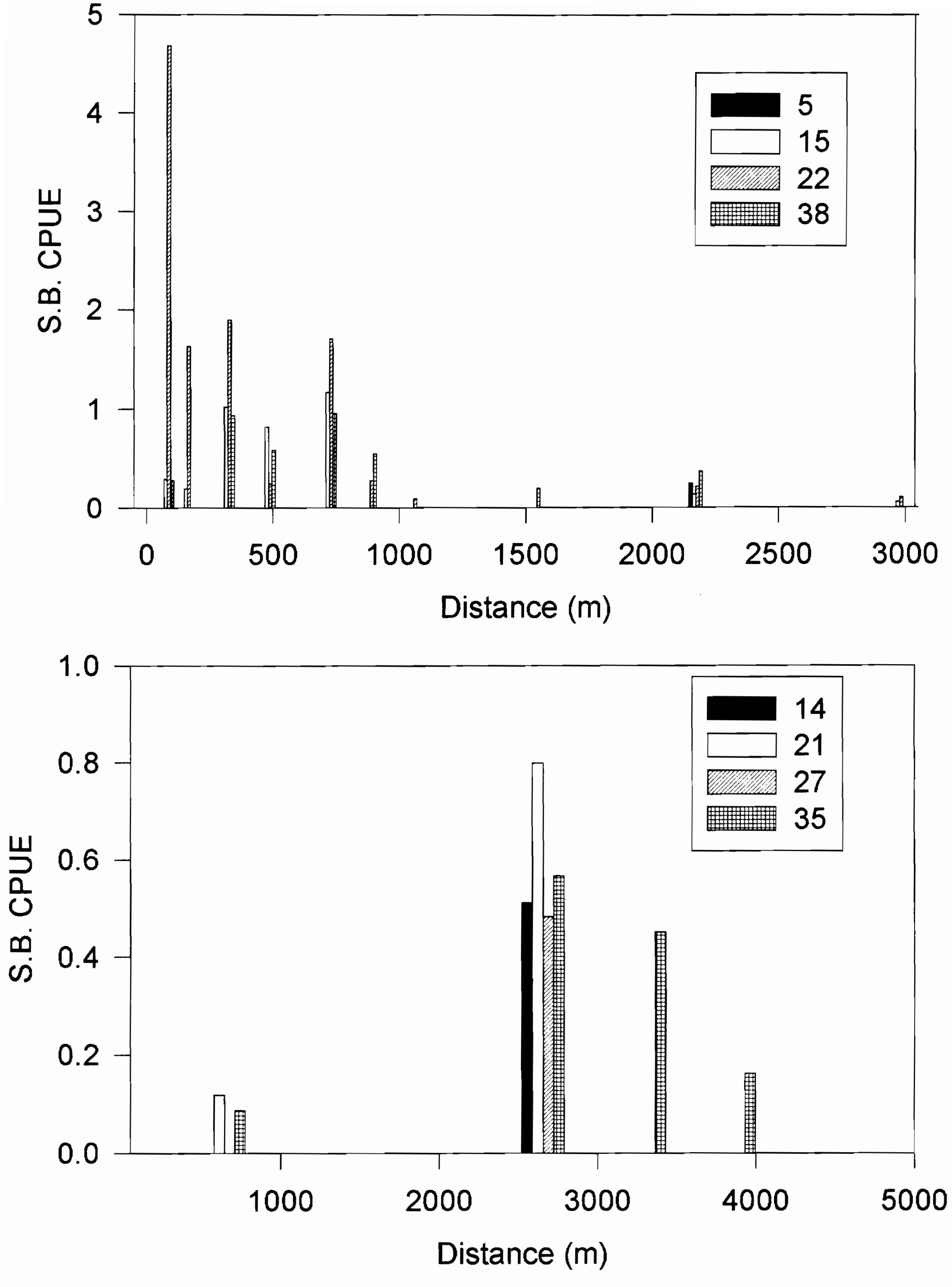


Figure 11. Striped bass CPUE by distance from stocking site at Waterwheel (top) and Penhook (bottom) in 1994. Legend is number of days poststocking.

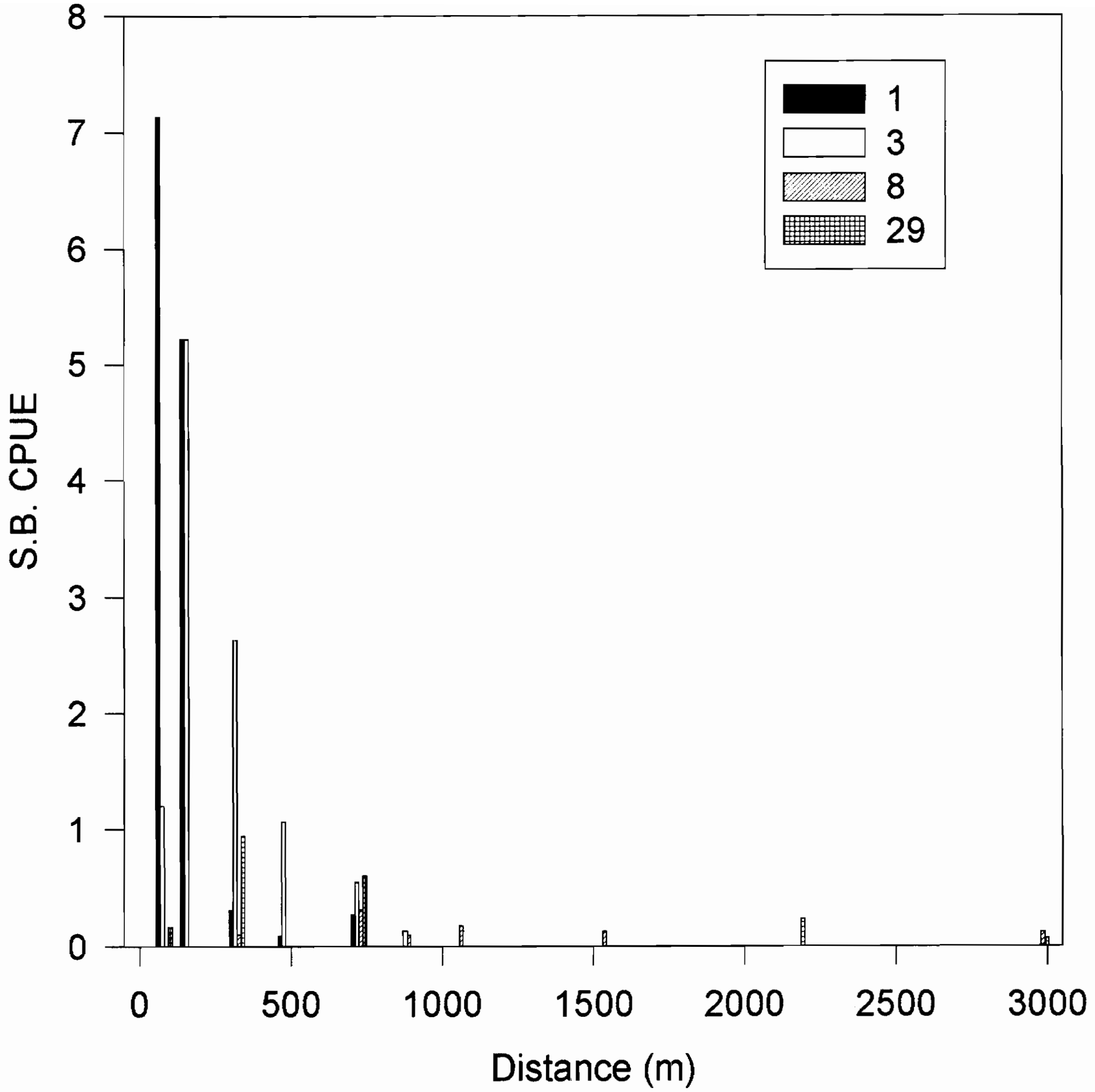


Figure 12. Striped bass CPUE by distance at the Waterwheel cove in 1995. Legend is number of days poststocking.

indication of first week dispersal poststocking because striped bass were tracked from the night of stocking. CPUE values were plotted 1, 3, 8, and 29 days poststocking (Figure 12). Many striped bass stayed within the first transects (within 300 m) adjacent to the stocking site on the first night, 10 July. They proceeded to disperse about 750 m on the third night and up to 3000 m by 8 August (29 days poststocking). Fingerlings quickly moved from the immediate stocking site on the first night, but aggregates remained within 1000 m of the stocking site for the first week before reaching the main channel of the lake (about 800 m at Waterwheel if dispersed to the right) or simply moving away from shore. In general, speed of dispersal was probably not an important predator avoidance behavior because largemouth bass did not prey on striped bass to any extent even when they remained in the same location for several days.

PREY PREFERENCE EXPERIMENT

To test the hypothesis that alewives may act as a buffer to largemouth bass predation, a laboratory experiment was performed in the summer of 1995. The experiment was divided into two parts with eight trials in each half. In the first part of the experiment, individual largemouth bass were presented with their choice of striped bass or alewives for 48 hours, stocked at equal densities of five per tank. A mean of 0.625 striped bass (mean specific weight=10.8 mg/g) and 2.88 alewives (mean specific weight=51.8 mg/g) were consumed (Table 12a). Both the mean number (2.88) and specific weight (mg/g) of alewives eaten were significantly greater than for striped bass ($P<0.01$, both tests). At least one alewife was eaten in every trial, but in half of the trials no striped bass were consumed; the maximum number of striped bass consumed was only two in any of the trials.

In the second part of the experiment only striped bass were presented to largemouth bass, and an average of 2.50 striped bass (mean weight specific weight=28.6 mg/g) was consumed (Table 12b). The mean number and specific weight of striped bass eaten was not significantly greater when alewives were absent ($P=0.12$ and 0.08, respectively). However, three trials resulted in no striped bass consumption and three resulted in total consumption; consumption in this part of the experiment was either nearly complete or nearly zero. It is possible that once the predator consumed one or two striped bass, they were better able to identify the small fish as a prey source.

Table 12a. Number and specific weight (mg prey/g predator) of prey items consumed by largemouth bass when presented with a prey choice.

Trial #	**Date**	**Number St. Bass**	**Number Alewives**	**Specific Wt St. Bass**	**Specific Wt Alewives**
1	6/26-6/28	1	3	6.11	42.8
2	6/28-6/30	1	3	15.1	106
3	7/1-7/3	0	2	0	28.7
4	7/3-7/5	0	1	0	13.4
5	7/5-7/7	1	4	8.37	78.1
6	7/7-7/9	0	5	0	56.7
7	7/9-7/11	0	3	0	23.8
8	7/11-7/13	2	2	27.9	65.1
		Mean=0.625	**2.88**	**7.19**	**51.80**

Table 12b. Number and specific weight of striped bass eaten by largemouth bass in the absence of alewives.

Trial #	**Date**	**Number Striped bass**	**Specific Weight Striped Bass**
1	7/13-7/15	1	21.2
2	7/15-7/17	5	98.4
3	7/17-7/19	0	0
4	7/19-7/21	5	37.3
5	7/21-7/23	4	45.7
6	7/23-7/25	0	0
7	7/26-7/28	0	0
8	7/28/7/29	5	26.5
		Mean=2.50	**28.6**

DISCUSSION

This study investigated two sources of potential poststocking mortality of fingerling striped bass, handling and predation. Results indicate that both sources may be insignificant in their effects on first-year survival in Smith Mountain Lake under the conditions that existed in 1994 and 1995. However, the study necessarily included assumptions and study designs which could have influenced the estimates of true mortality due to handling or predation.

HANDLING MORTALITY

Poststocking handling mortality had seldom been considered in stocking programs throughout the U.S. (Wallin and Van Den Avyle 1995), and the Smith Mountain Lake striped bass stocking program was no exception. Handling and transport result in stress for the fish which may ultimately lead to significant mortality. Physiological stresses such as endocrine changes are induced by handling during harvest from rearing ponds, transport, and stocking into receiving water (Mazeaud et al. 1977). Pitman and Gutreuter (1993) found that survival of stocked striped bass depended on hauling time, pH, conductivity of the reservoir water, and temperature changes. Short-term mortality has also been linked to size at stocking and to duration of tanker truck haul in largemouth bass (Carmichael et al. 1984; Dolman 1985). The physiological responses to stress by fish have been the focus of studies for several years. Mazeaud et al. (1977) defined the effects of stress on coho *Onchorhynchus kisutch*, sockeye *O. nerka*, and chinook *O. tshawytsha* salmon as primary and secondary. Primary effects occur early on in the stress event and are characterized by endocrine changes, often increases in adrenaline. Secondary effects are the result of primary effects and include increase in blood glucose and either an increase or decrease in plasmatic fatty acid. Several studies have shown that most hauling and stocking stress mortality occurs within the first 24 hours poststocking, but metabolic disruptions resulting from the stress event have been shown to be as long as eight days in duration (Barton et al. 1980; Hammerschmidt and Saul 1984, cited in Pitman and Gutreuter 1993; Dolman 1985; Hammerschmidt 1986, cited in Pitman and Gutreuter 1993).

Because most mortality occurs within the first day poststocking, experiments which quantify handling mortality require relatively little effort and provide potentially valuable information about the fate of stocked fish species. Poststocking mortality of striped bass has been reported to vary between 0 and 100% (Pitman and Gutreuter 1993; Wallin and Van Den Avyle 1995). Mortality in 48 hours in the Smith Mountain Lake trials reflected this variability, ranging from a mean mortality of 1.78% for 1994 Phase I fish to 99.5% for 1994 Phase II fingerlings. However, mortality in trials of this nature may be due to real handling/transport stress, artifacts of study design (caging effects), or a combination of these factors. In the Smith Mountain Lake study, both stocking stress and possibly caging appeared to contribute to the observed 48-hour mortality over the seven trials.

1994 Cage Trials

In 1994, Phase I fingerling mortality in cages was nearly nonexistent (mean mortality = 1.78%). Relatively low water temperature may have played a role in low mortality. The water temperature when these fish were stocked was 26° C, the lowest of any trial, and was within one to two degrees of Brookneal rearing pond water temperature. Davis and Parker (1990) found that high temperature (near 30° C) was detrimental for holding or handling striped bass. Fish acclimated to water at high temperatures were found to have greater changes in hematocrit, osmolality, chloride, and cortisol following handling than fish held in cooler water (20-25° C). In the Smith Mountain Lake situation, it was impossible to stock fingerlings at their optimal temperature (24° C; Cox and Coutant 1981) due to the time of year that striped bass were stocked. Phase I fish probably showed high survival because they were taken from Brookneal rearing pond water that was very near both the ambient temperature of Smith Mountain Lake and their optimal temperature. They were also tempered in the tanker truck for one hour to acclimate to the 1° C temperature differential. It is standard procedure to temper at 1° C per hour prior to stocking fish (Dr. George Libey, Department of Fisheries and Wildlife, Virginia Tech, personal communication).

Conversely, Phase II fish showed very high mortality in each of two trials (99.5% and 51.0%, respectively). This high mortality was probably due mainly to large temperature gradients between Virginia Tech Aquaculture water and lake water. Reservoir water temperature had increased to 27° C when these fish were stocked, and the Phase II fish were reared at 22° C. The greater water temperature difference between rearing water and stocking water may have led to thermal stress which in turn caused higher rates of mortality. Both Phase II trials (Trial 2 & 3) required at least five hours to properly acclimate the fingerlings to receiving water, but Trial 3 fish were tempered for approximately one hour and Trial 2 fish for only 15-20 minutes. This short tempering time probably led to the extreme mortality in trial 2 and the high mortality in Trial 3. Another potential source of high mortality could have been temperature inside the cages themselves. The one meter deep (100 L of water), floating cages were constructed of plastic garbage containers covered with a lid and were exposed to direct sunlight for half of the day. The temperature inside the cages may have been higher than the deeper, adjacent lake water. However, cage water temperatures were not measured during the experiment.

Other differences in water quality parameters between hatchery/transport and lake waters, such as pH, alkalinity, dissolved oxygen, and nitrogen can cause an immediate stress response in stocked fish (Parker et al. 1992). However, the differences in these parameters in this study were slight and much less than reported to result in poststocking stress (Parker et al. 1992; Pitman and Gutreuter 1993).

1995 Cage Trials

The handling mortality cage experiment was repeated in 1995 with a few changes. The first change was the addition of a control trial to eliminate potential questions regarding cage induced mortality in 1994. No mortality was observed in the control trial, so caging itself should not have been a source of mortality in any trials. Cage materials were not toxic and thus were not a source of fingerling mortality.

Because temperature stress inside 1994 cages was suspected as a possible contributing source of mortality, larger cages which would allow striped bass to migrate vertically were built. Cages were also moved to an area where they received shade for most of the day to combat potential temperature extremes inside the cages. In 1995, cages were constructed entirely of porous nylon net material which allowed complete interchange with lake water. The new 1995 cage construction should have alleviated potential temperature extremes leading to mortality in the 48 hour test period.

The third difference in 1995 was the source of Phase I fingerlings. Phase I fish were transported from North Carolina (8 hours) rather than from Brookneal or the Virginia Tech Aquaculture facility (1.5-2 hours). Pitman and Gutreuter (1993) found an inverse relationship between hauling time of fingerling striped bass and poststocking survival.

Mortalities in the three trials in 1995 were nearly opposite 1994 mortalities. Phase I (Trials 1 & 3) mean mortalities (47.1% and 23.9%, respectively) were at least 13 times higher than in 1994. Conversely, Phase II mean mortality in Trial 2 was only 5.52%, at least nine times less than Phase II mortality in 1994. The much longer hauling time in 1995 may have been one of the factors which led to increased Phase I mortality when compared with 1994 Phase I fish. Also, fish transported from North Carolina appeared to be in worse overall condition than fish trucked from Brookneal or the aquaculture facility. These fish showed signs of fin damage, possibly due to the increased duration of the haul. This evidence was qualitative but may have been an important source of increased Phase I mortality when compared to 1994 fingerlings. As in 1994, the most significant source of cage mortality was probably a large temperature gradient between hauling water and receiving water. Fingerlings from North Carolina were transported in 21° C well water and stocked into water that was 27° C for Trial 1 and 28° C for Trial 3. These fish should have been tempered for a minimum of six hours but were again tempered for only one hour. Extended duration of hauling and short tempering times in combination probably resulted in the much higher 1995 Phase I mortality.

Phase II handling mortality rates in 1995 were also much different than 1994 rates. Unlike the nearly complete mortality in Trial 2 of 1994, Phase II fish showed mortality rates at least nine times lower in 1995. There were two possible reasons for the decreased mortality of 1995 Phase II fingerlings as compared to 1994. First, the change in cage design may have reduced mortality. Because the new cages had a much higher volume than 1994 cages, fish densities were much lower (0.6 g/L in 1995 versus 3.03 g/L in 1994) and thus fingerlings should have been subjected to less stress. Barton et al. (1980) found that at densities of 255 g/L ("severe confinement") of fingerling rainbow trout, plasma cortisol levels increased rapidly and mortality was nearly 100%. Based on the striped bass densities recommended for transport by Parker et al. (1992)

and caging by Pitman and Gutreuter (1993), density-related stress was probably not a siginificant source of stress to fingerlings in either year. Because of increased size of the nets (3 m deep), fingerlings were able to migrate vertically if surface temperature became too high as it may have in 1994 cages. The second and probably more important factor influencing increased Phase II survival in 1995 was again water temperatures and tempering time. In 1995, Phase II fish were tempered for approximately one hour as opposed to 15-20 minutes as in the second trial of 1994. This allowed the fish a longer interval to acclimate to the lake temperature. In 1995, Virginia Tech Aquaculture water was 25° C as opposed to 22° C in 1994. This reduced the gradient between transport and receiving water (5° C change in 1994, 3° C change in 1995) and thus reduced the stress on fingerlings stocked. It appears that water temperature changes between transport and receiving water were the most significant sources of mortality in both years. It is important that the duration of tempering is sufficient to reduce a potentially controllable source of striped bass mortality.

Although results from the handling mortality experiment were variable and not entirely conclusive, some valuable information was gained from the effort. Phase I mortality of Brookneal fingerlings was insignificant in 1994, probably due to the relatively short transport and similar water temperature. The scenario of rearing striped bass at Brookneal and transporting to Smith Mountain Lake seems to be much more advantageous than transporting much further from North Carolina. If at all possible, the transport distance should be kept to a minimum. It is probable that if transport and temperature conditions in 1995 would have been similar to those in 1994 (i.e. fingerlings from Brookneal), mortalities would have been similarly low both years. Stocking of Phase II fingerlings still seems a worthwhile practice despite the high mortalities observed in 1994. In 1995, this mean mortality was reduced to 5.52%, probably due to the smaller gradient between transport and stocking water temperatures. With adequate tempering times, Phase II fingerlings should show low mortality rates like those observed in 1995.

PREDATION MORTALITY

Predation on stocked fish species has been regarded as one of the major limiting factors in establishing a fishable population in many U.S. waters. This appears to be most true when the waterbody has high predator fish populations and when the stocked fish species are fry or small fingerlings (Keith and Barkley 1971). The Smith Mountain Lake striped bass stocking program meets both of these criteria and has the potential for serious predation impacts. Predation on stocked fish species in other systems has sometimes been reported to be severe. Resident largemouth bass were found to consume as much as 45% of the 175 mm tiger muskellunge stocked in Ohio reservoirs (Stein et al. 1981; Carline et al. 1986). Keith and Barkley (1971) found that stocked rainbow trout (mean total length 230 mm) in Lake Ouachita, Arkansas were preyed upon heavily by two piscivore species. In that study, 91% of 18 inch or larger largemouth bass collected had consumed trout and all chain pickerel 19 inches or larger had consumed trout. The authors did not quantify the rainbow trout lost to predation but did term the predation as "extensive". Santucci and Wahl (1993) discovered consumption of stocked walleye (48-216 mm total length) by largemouth bass predators reached mean levels as high as 17% in Ridge Lake, Illinois. In a similar study, consumption of three stocked species of esocids by largemouth bass in Ohio reservoirs was as much as 31% (Wahl and Stein 1989). In the Columbia River, juvenile salmonids were found to make up 59% of smallmouth bass diet by weight. This equalled 1.0-1.4 salmonids per predator per day in May and June (Tabor et al. 1993). Similar rates of consumption (0.7 prey/predator/day) of juvenile salmonids by northern squawfish *Ptychocheilus oregonesis* were detected in John Day Reservoir, Columbia River (Vigg et al. 1991).

With the findings of these and other studies, substantial predation on stocked fingerling striped bass in Smith Mountain Lake seemed likely. Surprisingly, predation on stocked striped bass in Smith Mountain Lake was insignificant (0.1% in 1994 and 1.2% in 1995). I am more confident in the 1995 estimate of 1.2% because of the increased sampling performed the first two weeks poststocking at Waterwheel in 1995. This level of effort was impossible in 1994 because I sampled both coves completely in 1994 and sampling of each cove could not be completed in one night. Because predation on striped bass fingerlings was so slight, the existence of functional responses of largemouth bass to striped bass can be discounted. The low estimated losses could be partially attributable to sampling error or inaccurate inputs to the process of estimating predator consumption. I assess the potential for these biases to have influenced my estimates of predation losses below.

Potential Sources of Error

Three procedures were necessary to determine total number of striped bass lost to largemouth bass predation. The first step was to estimate number of largemouth bass predators using the Jolly-Seber estimator. The second step was to analyze diets of largemouth predators to determine the extent to which striped bass were preyed upon. The final step was to estimate individual daily consumption by largemouth bass using bioenergetics. Each of these steps have assumptions that must be considered and contain potential sources of bias which could influence the final estimate.

Population estimation. - Quantification of predator number has been ignored in many of the studies of predator impacts on stocked fingerlings, preventing estimation of the magnitude of impact. At the two coves studied at Smith Mountain Lake, the Jolly-Seber multiple census population estimate was chosen to quantify the number of largemouth bass predators because it accounts for open populations of fish. Several assumptions must be considered when using this estimator (Jolly 1965; Begon 1983). These include that:

1. Each collection trip results in a random sample of the target fish population.
2. After release, the fish distribute themselves so as to have equal probability of capture in subsequent samples.
3. Marks are not lost and are identifiable upon recapture.
4. Equal mortality occurs between marked and unmarked fish.

Assumption of random sampling was met to the best of the shocking crew's ability as every effort was made to net all marked and unmarked largemouth bass. In addition, age-0 largemouth bass and striped bass were targeted in a companion project and thus smaller (age-1 and -2) largemouth bass were sought along with larger fish. Also, the same total shoreline distance was electrofished on every trip.

It was difficult to determine if the second assumption, equal probability of capture, was violated. Tagged fish were captured in a relatively constant proportion throughout the study (10% to 33% of total captures per night). Often tagged fish were recaptured in the same or adjacent transects even weeks after being marked, an indication that electroshocking did not induce emigration from the area. Cross and Stott (1975) reported that repeated electrofishing decreased the catchability of various fish species for 3-24 hours. No transects in Smith Mountain Lake were sampled more than once in a 24 hour period. It appeared that marked fish did redistribute themselves and were not captured more or less frequently due to the tagging process. Assumption three, tag retention, was a concern when the project began but was probably not violated to any extent. Anchor tags are retained well if applied properly (i.e. t-bar must interlock with skeleton) (Wydoski and Emery 1983). Anchor tags were lost (less than 3% of marked fish on each sampling night) during the study, but marked fish could still be identified due to the scar caused by tag insertion. It was not clear how long scars lasted after tags were shed, but tag loss should not have been a problem because the study was only six weeks long. Wilbur and Duchrow (1972) discovered that anchor tags identical to those used in this study became dislodged in 12% of largemouth bass tagged after three months in hatchery ponds. Assumption four, equal mortality, also did not seem to be violated. In the two summers of field work, only two tagged fish were reported dead. These were discovered by anglers and reported to VDGIF. Tranquilli and Childers (1982) found that anchor tag use on largemouth bass did not result in reduced growth or condition.

The electrofishing technique itself may have also contained some bias or limitations because several factors can affect the efficiency of electrofishing (Reynolds 1983). These factors include characteristics of the fish, characteristics of the aquatic habitat, and characteristics related to sampling conditions. Fish characteristics which can influence sampling efficiency include mainly size and species targeted. Selectivity for larger largemouth bass by netters was actively avoided in this study. Larger fish are also more efficiently stunned by electric pulse and may thus be more susceptible to collection (Reynolds 1983). Because smaller fish were targeted along with larger predators, this should not have led to bias. Based on catch-curve analyses of largemouth bass, the decline in number (% mortality) of age-2 to age-4 largemouth bass was lower than that calculated by Moore (1988). Ages-2 and -3 largemouth bass were the most often captured age groups in both coves for both years. More age-3 largemouth bass were captured than age-2 largemouth in the Waterwheel cove (both years) probably because of tournament release of these larger fish into the cove. Age-1 largemouth bass numbers may have been lower than age-2 and age-3 estimated numbers if they avoided larger predators near shore and were thus not effectively sampled with shoreline electrofishing. In addition to size-selective sampling, Reynolds (1983) also found that littoral species such as centrarchids are more efficiently sampled than pelagic species.

Habitat characteristics can also affect the efficiency of electrofishing. Variables such as temperature, water transparency, and substrate did not appear to be major problems in Smith Mountain Lake as they did not vary markedly over the 4-6 week sampling period. Operating conditions such as weather, time of sampling (i.e. time of day), and reliability of equipment must be considered. Often storm fronts will influence CPUE but this cannot be controlled. Different CPUE due to weather was dealt with by simply sampling intensively in all conditions that safely allowed. Night sampling was chosen because largemouth bass move inshore to feed when all fish seem less able to avoid capture (Reynolds 1983). The electrofishing unit was always reliable and the same personnel always did the sampling. In general, biases and limitations of electrofishing were recognized and avoided to prevent bias in the population estimate.

Calculated population estimates varied between coves and between years. The values that I used to calculate mean largemouth bass population size did not include estimates after the second week of July in 1994 or after 26 July in 1995 when striped bass were not found in largemouth bass stomachs. These late summer estimates were also excluded because of the reduced number of recaptured predators after this time. Recaptures probably declined because of largemouth bass migration from shore when alewives began to move out of the littoral area and epilimnetic water temperatures increased to their annual maximum of 30° C. The difference in the Waterwheel population estimate between years appears to be due to the later start date of sampling in 1995. Trends in 1994 showed that fewer largemouth bass were captured as the summer progressed. The 1995 sampling season began later in the summer, and fewer total predators were captured on each sampling night, leading to a lower number of recaptures than the previous year. This low number in the denominator of the equation resulted in a larger estimated predator population size in 1995.

Even though most assumptions and limitations were dealt with, possible violation of Jolly-Seber assumptions and associated limitations of electrofishing could still result in population estimate errors. To examine these potential errors and differences in estimates between years, largemouth bass population estimates were compared to historical cove rotenone estimates of largemouth bass density over the past six years (VDGIF Management reports, unpublished). Four coves (mean area = 0.725 h) are poisoned each August in uplake and downlake reaches of the reservoir. Because these coves are so much smaller than Waterwheel (36.9 ha) and Penhook (60.7 ha), a correction factor was used to adjust these estimates for open water area (Aggus et al. 1980). In addition, rotenone-sampled coves have less deep, pelagic water and larger percentages of littoral zones where fish densities will be higher. The estimated number of largemouth bass after the corrections was 1033 at Waterwheel and 1700 at Penhook. These values are still about two times larger than the mark-recapture estimates for 1994, but the estimate for Waterwheel in 1995 is very similar (Jolly-Seber = 1094 vs. rotenone = 1033). The largemouth bass which were important in this estimate were those which occupied the same littoral region where striped bass aggregated. It is difficult and probably unnecessary to compare rotenone estimates with mark-recapture estimates other than to verify that the Jolly-Seber estimate was reasonable. My estimates seemed to meet all of the assumptions of the model, and weekly estimates were consistent when striped bass seemed to be most susceptible to predation. It appears that the Jolly-Seber model gave estimates reliable enough to be used to model predation mortality.

Diet analysis. - There were two potential sources of error in analysis of largemouth bass diets at Smith Mountain Lake. The first potential error was the underrepresentation of striped bass in largemouth bass stomachs due to fast evacuation times of the small fingerlings. Based on the sigmoid model of evacuation rate developed by Rogers and Burley (1991), fingerling striped bass are 90% digested in approximately 2.5 hours versus approximately 4.5 hours for adult alewives. Because striped bass are digested more rapidly than alewives, the predominant prey of largemouth bass, it was necessary to adjust the percentage of striped bass in largemouth bass diets. The calculated correction factor roughly doubled the percent of striped bass in predator diets to compensate for fast evacuation rates and thus underrepresentation of fingerlings in predator stomachs. Another potential source of bias in determining diet composition of largemouth bass was misidentification of striped bass in stomachs. Because striped bass were so characteristic in shape and very few other potential prey items share this shape, I am confident that I identified all striped bass in largemouth bass stomachs.

Bioenergetic modelling. - The final component in quantifying striped bass lost to predation was the bioenergetics model. The model requires site-specific inputs (external variables) and species-specific physiological parameters. Bioenergetics is a useful simulation tool which can be used to predict predator consumption of various species (Ney 1993). Predator consumption is calculated in terms of daily consumption, and this daily consumption can then be expanded to estimate total prey lost to predation.

Like all fisheries models, bioenergetics is not without limitations and/or deficiencies (Ney 1993). These include unknown activity costs, extrapolation of allometric functions, unjustified species borrowing, and inadequate estimation of external variables. Historically activity metabolism (R_A) has been dealt with in the model as a multiplier of standard metabolism, which is imprecise and probably inaccurate. This largemouth bass bioenergetics model uses values for standard respiration (R_S) which were determined by calculating resting metabolism as an allometric function of weight, then incorporating factors representing activity (Stewart et al. 1983). Activity respiration is given as a multiplier of one of R_S in Table 1 because activity is incorporated into R_S. Allometric functions, which are necessary to describe changes in maximum consumption and standard metabolism with weight of the predator, are often calculated for juveniles and then applied to adult fish. This can lead to substantial error (Post 1990; Madon and Culver 1993). Borrowing bioenergetic parameters from other species is routinely done because of the expense and effort of species-specific determinations. Parameters used for largemouth bass modelling were developed specifically for largemouth bass (i.e. no species borrowing). The model was also evaluated by Rice and

Cochran (1984) and was found to predict food consumption to within 8.5% of food consumption estimated using direct measurements from field data.

Finally, external variables such as diet composition, predator and prey energy densities, temperature, and largemouth bass growth must be obtained through field sampling (Ney 1993). Diet composition and water temperature were determined during Smith Mountain Lake field seasons. Largemouth bass energy densities by age class were borrowed from a study performed on Watts Bar Reservoir, Tennessee (Adams et al. 1982). This reservoir is similar in size and forage composition to Smith Mountain Lake, so values derived for predators and prey in this system should be adequate for use in the bioenergetics model. Prey energy densities (alewives, striped bass, and crayfish) were derived for Smith Mountain Lake by Moore (1988), and sunfish energy density was borrowed from the Fish Bioenergetics Model 2 (Hewett and Johnson 1992).

Growth of largemouth bass was determined by tracking changes in lengths of recaptured largemouth bass in Smith Mountain Lake. The bioenergetics model requires inputs for growth in terms of weight so, growth in length was converted to growth in weight using a logarithmic formula. In order to compare largemouth bass growth observed at Smith Mountain Lake to similar research, growth was converted to the standard calories per gram per day measure. Mean growth of all four age groups of largemouth bass in Smith Mountain Lake was 3.85 cal/g/day. This was less than the growth calculated for June through August at Watts Bar Reservoir by Adams et al. (1982) by 1.1 cal/g/day (mean growth=4.95 cal/g/day). There are two potential reasons why my growth rates are lower than those reported at Watts Bar Reservoir. The first is the lack of observed growth of most age-1 largemouth bass in Smith Mountain Lake, resulting in a lower mean growth than at Watts Bar Reservoir. The other largemouth bass age groups showed growth rates similar to the mean summer growth rate for largemouth bass at Watts Bar Reservoir. The second potential reason growth was lower at Smith Mountain Lake was the use of anchor tags on captured largemouth bass. These tags may have resulted in stress or altered feeding behavior. However, the percent of recaptured largemouth bass with prey items (31%) was similar to the the overall estimate of percent of largemouth bass with prey items (28%). Because growth rates used in the bioenergetics model may have been conservative, the total number of striped bass lost to predation may have been underestimated. Because predation on striped bass in Smith Mountain Lake was found to be minute, these growth rates should not have greatly influenced the estimates of total number of striped bass lost to predation.

Largemouth Bass Prey Consumption

Field consumption patterns. - In 1994, striped bass made up 0.1% of Waterwheel predator diets and 0.14% of predator diets at Penhook. In 1995, the percent of striped bass in largemouth bass diets increased to 2.49%. To explain why striped bass were such a small percent of total predator diets, it is necessary to examine largemouth bass diet composition.

Largemouth bass diet composition was very similar in 1994 and 1995. In both years, alewives made up the largest percent of largemouth bass diets, and striped bass were a minimal portion of total prey consumed. The contribution of alewives to largemouth bass diets did decline by 12% at Waterwheel and 19% at Penhook in 1995. This phenomenon is probably attributed to the later starting date of the 1995 field season. The 1994 field season began on 15 June and the 1995 season on 10 July. This delay of over three weeks probably corresponded with a decline in the alewife spawn, and alewives were likely already moving off-shore when sampling began in 1995. Tisa and Ney (1991) discovered that the alewife spawn begins in mid-May with peaks in late June and early July, although some spawning activity continues until early August.

Alewives were clearly the predominant prey for largemouth bass in both coves and both years. Alewives appeared to act as a buffer against striped bass predation.

Alewives have several characteristics that would seem to make them preferred prey for largemouth bass. These include nearshore abundance, physical appearance, and behavior. The first advantage was the shear abundance of alewives near shore at the time of striped bass stocking. Alewives were extremely numerous near-shore in both coves and also probably more easily detected by largemouth bass because alewives occur in the water column as opposed to occupying the benthic region as do fingerling striped bass. Alewife electroshocking counts exceeded 700 fish per night on 10 July 1995 and remained consistent for about one week poststocking, the period when striped bass were most vulnerable to predation. Abundance of alewives was not quantified in 1994, but was also extremely numerous nearshore that summer. Physical appearance (size and coloration) of alewives would also seem to make them preferred prey for largemouth bass. Alewives have shiny, reflective scales which would make detection by the sight-oriented largemouth bass more likely than for the smaller, darker striped bass fingerlings. Size is another advantage which alewives possess as potential prey over striped bass. Over the past several years, striped bass have averaged around 30-60 mm (approximately 0.7 g) when stocked. When compared to the average size of alewives (approximately 90 mm and 8.0 g) in the lake at the same time, it is clear that alewives present a potential energetic advantage over the smaller striped bass. Finally, behavior of alewives during spawning may increase their susceptibility to predation, making them a more obvious prey item than striped bass. Alewives move inshore at night to spawn in groups of three or in pairs. The movements of alewife schools inshore have been described as a "roller-coaster" and milling type of motion which may result in predator attraction (Scott and Crossman 1973). The alewife is a pelagic-oriented fish species which spawns near shore and migrates to the pelagic zone of the lake when the spawn is complete (Tisa and Ney 1991). This leads to a potential increase in striped bass vulnerability to predation due to the loss of the alewife buffer later in the summer. In Smith Mountain Lake, largemouth bass did not switch to striped bass after alewives moved away from shore, but instead consumed a greater proportion of prey species such as crayfish. Alewives stayed on shore long enough for striped bass to grow and disperse.

Further evidence that largemouth bass in Smith Mountain Lake did not target striped bass as prey is provided by the lack of attraction of largemouth bass to concentrations of striped bass. Regressions of striped bass CPUE versus largemouth bass CPUE did not reveal any general patterns of attraction of predators to stocked fingerlings. Based on these analyses and the extremely low number of striped bass consumed by predators, I conclude that largemouth bass were not attracted to striped bass aggregations. Cushing (1995) states that marine predators might aggregate to prey species but that the process of predator attraction has not been observed very often. I found no reseach performed specifically on freshwater predator attraction to prey species, although it probably occurs in many systems.

Rate of dispersal of stocked striped bass was also considered an important component of predator avoidance when the study began. Striped bass moved quickly from the immediate stocking site, but then remained in certain locations for several days. Rate of dispersal of striped bass was not an important predator avoidance behavior because largemouth bass seemed to prefer prey other than striped bass and largemouth bass were not attracted to striped bass aggregates.

Total estimated number of striped bass lost to predation was calculated based on percent of striped bass in largemouth bass diets, daily ration of largemouth bass, largemouth population estimates, and the number of sampling days. The estimated number of striped bass lost was less than one percent of striped bass stocked in 1994 and 1.2% of fingerlings stocked in 1995. Predation mortality in the immediate post-stocking period does not control first-year survival of striped bass in Smith Mountain Lake if predation rate remains low as in 1994 and 1995. Although only the largemouth bass was considered as a striped bass predator in my study, I cannot completely exclude predation by other piscivores in Smith Mountain Lake. Predation could have also occurred later in the year after I quit sampling. This predation was probably incidental and did not significantly influence first year survival of striped bass. Between April 1983 and December 1984, 1871 largemouth bass, smallmouth bass, walleye, and adult striped bass stomachs were examined and no juvenile striped bass were discovered (Moore 1988).

Under extreme conditions, largemouth bass predation could become a severe impact on striped bass survival. Conditions necessary for this to occur are highly unlikely in Smith Mountain Lake. Different simulations were performed to consider the effect on predation mortality of potential increases in percentage of striped bass in predator diets or increases in the number of largemouth bass. Percentage predation mortality was modelled to be as high as 25% and 60% of stocked fingerling when percentage of striped bass in diets was increased to 10% and 25%. When the 95% confidence limits of predator population sizes was input with the 10% and 25% simulations, percentage predation mortality increased to 50% and 100%, respectively. When the 95% confidence limit of largemouth bass numbers was used alone, predation mortality was only double the observed estimate which was based on field data (i.e. non-simulation estimate). An increase in the number of largemouth bass predators would not have as severe an impact as an increase in the percentage of striped bass in largemouth bass diets. Based on my findings in 1994 and 1995, increasing the percentage of striped bass in largemouth bass diets to even 10% is extremely unlikely to occur in Smith Mountain Lake because of the abundance of other prey items. Even if the heavily preferred alewife should suffer heavy winter-kill losses, largemouth bass would likely switch to crayfish or other prey species. Patterns at Penhook in 1994 and at Waterwheel in 1995 show that when alewives became less available, largemouth bass still did not switch to striped bass as prey.

Prey preference experiment. - Field data in 1994 indicated that striped bass were not consumed when alewives were abundant near shore. This could have simply been a result of the sheer number of alewives available at the time of stocking, or largemouth bass may prefer alewives to striped bass fingerlings. To test the hypothesis that adult alewives were preferred over fingerling striped bass by largemouth bass predators, a laboratory experiment was performed in 1995.

Originally, I intended to quantify three aspects of largemouth bass predation on each prey species: percent of alewives or striped bass consumed, capture efficiency, and handling time. I hypothesized that alewives would be eaten in a higher proportion, that alewives would be captured more efficiently, and that alewives would require less handling time for consumption. In general, predators select prey based on ease of capture and handling prior to consumption. Soft-rayed clupeids like alewives are superior prey items to spiny-rayed species like striped bass in terms of capture efficiency and handling time. Moody et al. (1983) quantified the preference of soft-rayed prey by tiger muskellunge. Tiger muskellunge displayed much lower capture efficiency (# captures/# strikes) when pursuing spiny-rayed bluegills than soft-rayed fathead minnows *Pimephales promelas*. Studies on prey preference by esocids showed similar results. Tiger muskellunge and northern pike *Esox lucius* selected soft-rayed prey over spiny-rayed prey (Wahl and Stein 1988). In my laboratory experiment, soft-rayed alewives were selected in a statistically higher proportion than spiny-rayed striped bass. It was not possible to quantify capture efficiency and handling time because largemouth bass would not feed in the presence of an observer. Whether alewives were preferred because they were easier to capture and/or handle prior to consumption due to their lack of spiny rays could not be determined.

Another potential reason striped bass were selected in a lower proportion than alewives could have been a difference in elusive behavior between the two prey species. Certain studies have discovered that predators will "learn" to select less evasive prey. Vinyard (1980) observed this in an experiment where sunfish selected *Daphnia* over copepods due to the superior evasive capabilities of copepods. Research performed by Wahl and Stein (1988) on prey selection by esocids resulted in similar findings. Esocids selected prey which relied on speed and schooling rather than prey which could outmaneuver them. Prey species in my experiment were observed in the tanks and in general, striped bass tended to remain further away from the largemouth bass predator and associated more closely with the bottom of the tank and with each other than did alewives. When the predator was in motion, striped bass appeared to initiate evasive activity away from the largemouth bass at a greater distance from the predator and with greater speed. Neither of these observations could be quantified because a human presence disrupted predator behavior. Also, largemouth bass seemed to remain motionless during the day, so evasive behavior by prey was only observed when the largemouth bass was spooked by an observer's presence. All predation occurred in the absence of an observer, and most occurred from dusk to dawn.

Spiny rays and evasive behavior were probably not the only predator avoidance advantages that stocked striped bass possessed over alewives in this experiment and in the field. Size probably also played an important role in the preference of alewives over fingerling striped bass. Average size of striped bass and alewives in the experiment was 66 mm (3.6 g) and 109 mm (8.4 g) respectively. Studies on rainbow trout and also largemouth bass presented with prey of various sizes showed a strong positive correlation between prey size and reactive distance. An increase in reactive distance speeds the rate of prey discovery and thus results in higher predation on larger prey items (Ware 1972; Howick and O'Brien 1983). This relationship holds until prey become too large to handle efficiently. Mouth size was not a limiting factor in this experiment as the smallest predator (290 mm) in the first part of the experiment was able to consume three alewives. Based on ingestibility limits of largemouth bass, the maximum size alewife that the 290 mm largemouth bass could eat was 122 mm (Tisa 1988). No alewife used in the experiment was larger than 115 mm. Therefore, the smaller relative size of striped bass may have also made it more difficult for largemouth bass to detect them. Even with a white background in the holding tank, I found striped bass harder to detect than alewives when counts were made.

The second part of the experiment tested the hypothesis that largemouth bass would utilize striped bass if no other prey were available. Predators were presented with only striped bass as potential prey to mimic the situation when alewives migrate offshore in Smith Mountain Lake after spawning. Largemouth bass did show an increase in average number of striped bass eaten from 0.625 to 2.5 in the second half of the experiment. This difference between average number of striped bass consumed with and without alewives present was not statistically significant because the pattern of predation was all (four or five striped bass consumed) or nothing (no striped bass consumed). It appeared that if a largemouth bass ate one striped bass, it was more likely to eat others, perhaps because of positive reinforcement and the development of a search image or attack behavior. The exclusion of alewives in this part of the experiment may mimic natural migration off-shore after spawning, but the experiment could not account for all natural conditions. Even after near-shore alewife numbers declined later in the summer, other potential prey items existed in the lake in addition to fingerling striped bass. Instead of switching to striped bass as they did in the artificial system of the laboratory experiment, largemouth bass ate other prey items such as crayfish in Smith Mountain Lake. This switch to prey items other than striped bass was probably due to the dispersal of striped bass over time and possibly also due to increased predator avoidance abilities of striped bass after spending several weeks in the lake. In addition, fewer largemouth bass were captured later in the summer and those caught often had empty stomachs. Largemouth bass may have moved off shore later in the summer as lake temperature increased. No striped bass were discovered in predator stomachs after the first week poststocking.

SUMMARY AND CONCLUSIONS

1. Hauling/handling mortality was insignificant for Phase I fingerlings transported from the Brookneal Hatchery in 1994. Hauling Phase I fish the longer distance from North Carolina in 1995 resulted in higher mortality and should be avoided.

2. Phase II mortality was very high in 1994 probably due to a lack of adequate tempering time to allow acclimation to stocking water. When fingerlings were tempered adequately in 1995, mortality declined significantly.

3. Largemouth bass (ages-1+ to 4+) was the only predator considered in the calculation of predation mortality on striped bass. Other potential predator species were captured in low frequencies throughout the study and were not found to have consumed striped bass. Calculation of total number of striped bass lost to predation was based on largemouth bass population estimates, percentage diet composition, and bioenergetics modelling.

4. The Jolly-Seber population estimates varied somewhat but were probably representative of largemouth bass numbers in the littoral areas of the stocking coves. These mark-recapture estimates agreed reasonably well with independently derived cove rotenone estimates of largemouth bass abundance when the latter were adjusted for whole-lake

densities. In 1994, the mark-recapture estimate was 624 at Waterwheel and 492 at Penhook. The cove rotenone estimate was 1033 at Waterwheel and 1700 at Penhook In 1995, the Waterwheel estimate was 1094 and the Penhook cove was not estimated due to lack of largemouth bass sampled (rotenone estimates same for both years).

5. Analysis of largemouth bass diets revealed that striped bass made up only 0.1% and 0.14% of largemouth bass stomach contents by weight at Waterwheel and Penhook in 1994 and 2.5% at Watherwheel in 1995 during the four weeks immediately poststocking. Striped bass were most susceptible to predation in the first week poststocking. Alewives made up at least 61% of largemouth bass diets in both years.

6. When alewives became less abundant near shore in late July, largemouth bass predation on striped bass did not increase. Rather, largemouth bass switched to crayfish and other prey items in mid-July.

7. Total daily consumption of striped bass was found to be insignificant. In 1994, only 360 striped bass (0.1% of fingerlings stocked) were estimated lost to predation and in 1995, the estimate increased to 3062 (1.2% of fingerlings stocked). The 1995 estimate is probably more accurate

because sampling effort was much greater the first two weeks poststocking when striped bass seemed to be most susceptible to predation.

8. Bioenergetic simulations were run to account for potential "worst-case" predation scenarios. Simulations included increasing the percent of striped bass in largemouth bass diets to 10% and 25% and also using the upper 95% confidence limits of largemouth bass population estimates. These simulations increased percent of striped bass lost to predation markedly and could even result in total loss of stocked striped bass at the 25% diet composition level in combination with the upper population estimate. Increasing the percent of striped bass in largemouth bass diets had a much more marked impact on number of striped bass lost to predation than did simply increasing the number of largemouth bass in the simulation. These simulations show that largemouth bass have the potential to inflict substantial losses on striped bass stocks at stocking sites, but this was largely unrealized in 1994 and 1995 because striped bass comprised only a tiny component of largemouth bass diets.

9. Largemouth bass attraction to aggregates of striped bass fingerlings was not evident in comparisons of striped bass versus largemouth bass distributions over time or space.

10. Striped bass moved from the immediate stocking areas within one or two days, but then appeared to hold in transects where suitable habitat was found. Dispersal of striped bass in 1994 and 1995 was not an important factor in predator avoidance because predation pressure was light at all times.

11. A prey preference experiment demonstrated that largemouth bass preferred adult alewives to fingerling striped bass when both prey were presented in equal numbers. When fingerling striped bass were present without alewives, some largemouth bass consumed them readily, while others ate none. This experiment supports the hypothesis that adult alewives may function to buffer predation by largemouth bass on recently stocked fingerling striped bass in Smith Mountain Lake.

Based on the results of this investigation, neither handling/hauling stress (Phase I, 1994) or predation led to significant striped bass mortality. Handling mortality was high for Phase II fingerlings in 1994 and Phase I mortality was high in 1995, but this was probably a result of extended hauling time and/or inadequate tempering times. When fingerlings were transported from Brookneal and tempered no faster than 1-2° C, mean mortality was less than 5%. Based on my results, Phase I stocking of Brookneal Hatchery striped bass is adequate.

Predation impacts in the month following striped bass stocking at Smith Mountain Lake were found to be insignificant in 1994 and 1995. Simulations indicate that predation losses could become severe if striped bass become a major prey item for nearshore largemouth bass. From the diet analysis and prey preference experiment, it appears that adult alewives in the littoral areas of stocking coves act as a buffer to largemouth bass predation on newly stocked fingerling striped bass. However, largemouth bass showed no attraction to aggregates of stocked striped bass. Later, largemouth bass in Smith Mountain Lake shifted their diets to crayfish (not striped bass) when alewives became less abundant in the littoral areas and striped bass had dispersed. These three factors (preference for alewives, diet shift, and lack of attraction) help explain why largemouth bass predation on fingerling striped bass is not significant.

Because predation losses are slight, they do not justify reducing localized stocking densities by spreading the annual fingerling striped bass stocking quota over more sites. However, this study did not consider the other potential density-dependent influence on survival, competition. If trophic competition is density-dependent and results in starvation mortality, the use of additional stocking sites may be beneficial.

LITERATURE CITED

Adams, S.M., R.B. McLean, and M.M. Huffman. 1982. Structuring of a predator population through temperature-mediated effects on prey availability. Canadian Journal of Fisheries and Aquatic Sciences 39:1175-1184.

Aggus, L.R., D.C.Carver, L.L. Olmsted, L.L. Rider, and G.L. Summers. 1980. Evaluation of standing crops of fishes in Crooked Creek Bay, Barkley Lake, Kentucky. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33:710-722.

Axon, J.R., and D.K. Whitehrust. 1985. Striped bass management in lakes with emphasis on management problems. Transactions of the American Fisheries Society 114:8-11.

Bailey, W.M. 1974. An evaluation of striped bass introductions in the southeastern United States. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 28:53-68.

Barton, B.A., R.E. Peter, and C.R. Paulencu. 1980. Plasma cortiol levels of fingerling rainbow trout (*Salmo gairdneri*) at rest, and subjected to handling, confinement, transport, and stocking. Canadian Journal of Fisheries and Aquatic Sciences 37:805-811.

Begon, M. 1983. Abuses of mathematical techniques in ecology: applications fo Jolly's capture-recapture method. Oikos. 40(1):155-158.

Carline, R.F., R.A. Stein, and L.M. Riley. 1986. Effects of size at stocking, season, largemouth bass predation, and forage fish abundance on survival of tiger muskellunge. American Fisheries Society Special Publication 15:151-167.

Carmichael, G.J., J.R. Tomasso, B.A. Simco, and K.B. Davis. 1984. Characterization and alleviation of stress associated with hauling largemouth bass. Transactions of the American Fisheries Society 113:778-785.

Cox, D.K., and C.C. Coutant. 1981. Growth dynamics of juvenile striped bass as functions of temperature and ration. Transactions of the American Fisheries Society 110:226-238.

Cross, D.G., and B. Stott. 1975. The effect of electric fishing on the subsequent capture of fish. Journal of Fish Biology 7:349-357.

Cushing, D. 1995. Population production and regulation in the sea: a fisheries perspective. Cambridge University Press, New York.

Davies, W.D., and W.L. Shelton. 1983. Sampling with toxicants. Pages 199-213 in L.A. Nielsen and D.L. Johnson, editors. Fisheries Techniques, American Fisheries Society, Bethesda, Maryland.

Davis, K.B., and N.C. Parker. 1990. Physiological stresss in striped bass: effect of acclimation temperature. Aquaculture. 91:349-358.

Dimond, William F. 1985. Device to increase efficiency of acrylic tubes for removing stomach contents of fish. North American Journal of Fisheries Management. 5:214.

Dolman, W.B. 1985. Evaluation of factors associated with survival of introduced striped bass larvae in Lake Texana. Final Report of Texas Parks and Wildlife Department to U.S. Bureau of Reclamation, Austin, Texas.

Hambright, K.D. 1991. Experimental analysis of prey selection by largemouth bass: role of predator mouth width and prey body depth. Transactions of the American Fisheries Society 120:500-508.

Hammerschmidt, P.C, and G.E. Saul. 1984. Initial survival of red drum fingerlings stocked in Texas bays during 1984-1985. Texas Parks and Wildlife Department, Coastal Fisheries Branch, Management Data Series 106, Austin.

Hart, L.G. 1978. Smith Mountain Lake research study. Virginia Dingell-Johnson Project F-30-R. Virginia Commission of Game and Inland Fisheries Richmond, VA.

Hewett, S.W., and B.L. Johnson. 1992. An upgrade of a generalized bioenergetics model of fish growth for microcomputers. University of Wisconsin, Sea Grant Institute publication WIS SG-92-250, Madison, Wisconsin.

Hightower, J.E., and R.J. Gilbert. 1984. Using the Jolly-Seber model to estimate population size, mortality, and recruitment for a reservoir fish population. Transactions of the American Fisheries Society 113:633-641.

Holling, C.S. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. Memorial Entomological Society of Canada 45:3-60.

Howick, G.L., and W.J. O'Brien. 1983. Piscivorous feeding behavior of largemouth bass: an experimental analysis. Transactions of the American Fisheries Society 112:508-516.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika. 52:225-247.

Keith, W.E., and S.K. Barkley. 1971. Predation of stocked rainbow trout by chain pickerel and largemouth bass in Lake Ouachita, Arkansas. Proceedings of the Annual Conference of the Southeastern Association of Game Fish Commissioners 24:401-407.

Libey, G. 1995. Department of Fisheries and Wildlife, Virginia Tech, personal communication.

Madon, S.P., and D.A. Culver. 1993. Bioenergetics model for larval and juvenile walleyes: an in situ approach with experimental ponds. Transactions of the American Fisheries Society 122:797-813.

Mauzeaud, M. M., F. Mauzeaud, and E. M. Donaldson. 1977. Primary and secondary effects of stress on fish: some new data with a general review. Transactions of the American Fisheries Society 106:201-211.

Moody, R.C., J.M. Holland, and R.A. Stein. 1983. Escape tactics used by bluegills and fathead minnows to avoid predation by tiger muskellunge. Environmental Biology of Fishes 8:61-65.

Moore, C.M. 1988. Food habits, population dynamics, and bioenergetics of four predatory fish species in Smith Mountain Lake, Virginia. Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Moore, C.M., R.J. Neves, and J.J. Ney. 1991. Survival and abundance of stocked striped bass in Smith Mountain Lake, Virginia. North American Journal of Fisheries Management 11:393-399.

Murdoch, W.W. 1973. The functional response of predators. Journal of Applied Ecology 10:335-342.

National task force for public fish hatchery policy. 1974. Report/ National task force for public fish hatchery policy, Denver, Colorado: The Task Force.

Ney, J.J., C.M. Moore, M.S. Tisa, J.J. Yurk, and R.J. Neves. 1990. Factors affecting the sport fishery in a multiple-use Virginia reservoir. Lake and Reservoir Management. 6:21-32.

Ney, J.J. 1993. Bioenergetics modeling today: growing pains on the cutting edge. Transactions of the American Fisheries Society 122:736-748.

Parker, N.C., G.T. Klar, T.I.J. Smith, and J.H. Kerby. 1992. Special considerations in the culture of striped bass and striped bass hybrids. Pages 191-215 in R.M. Harrell, J.H. Kerby, and R.V. Minton, editors. Culture and propagation of striped bass and its hybrids, Maryland Sea Grant College, University of Maryland, College Park, Maryland.

Peterman, R.M., and M. Gatto. 1978. Estimation of functional responses of predators on juvenile salmon. Journal of the Fisheries Research Board of Canada 35:797-808.

Pitman, V.M., and S. Gutreuter. 1993. Initial poststocking survival of hatchery-reared fishes. North American Journal of Fisheries Management 13:159-159.

Post, J.R. 1990. Metabolic allometry of larval and juvenile yellow perch (*Perca flavescens*): in situ estimates and bioenergetic models. Canadian Journal of Fisheries and Aquatic Sciences 47:554-560.

Pritchard, D.L., O.D. May, Jr., and L. Rider. 1978. Stocking of predators in the predator-stocking-evaluation reservoirs. Proceedings of the Annual Conference of the Southeastern of Fisheries and Wildlife Agencies 30(1976):108-113.

Readshaw, J.L. 1973. The numerical response of predators to prey density. Journal of Applied Ecology 10:342-351.

Reynolds, J.B. 1983. Electrofishing. Pages 147-163 in L.A. Nielsen and D.L. Johnson, editors. Fisheries Techniques, American Fisheries Society, Bethesda, Maryland.

Rice, J.A., and P.A. Cochran. 1984. Independent evaluation of a bioenergetics model for largemouth bass. Ecology. 65:732-739.

Rogers, J.B., and C.C. Burley. 1991. A sigmoid model to predict gastric evacuation rates of smallmouth bass (*Micropterus dolomieui*) fed juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 48:933-937.

Santucci, V.J., and D.H. Wahl. 1993. Factors influencing survival and growth of stocked walley (*Stizostedion vitreum*) in a centrarchid-dominated impoundment. Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1558.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Journal of the Fisheries Research Board of Canada, Bulletin 184.

Seber, G.A.F. 1965. A note on the multiple-recapture census. Biometrika. 52:249-259.

Seber, G.A.F. 1973. The estimation of animal abundance and related parameters. Charles Griffin, London, England.

Shireman, J.V., D.E. Colle, and R.W. Rottman. 1978. Size limits to predation on grass carp by largemouth bass. Transactions of the American Fisheries Society 107:213-215.

Stein, R.A., R.F. Carline, and R.S. Hayward. 1981. Largemouth bass predation on stocked tiger muskellunge. Transactions of the American Fisheries Society 110:604-612.

Stewart, D.J., D. Weininger, D.V. Rottiers, and T.A. Edsall. 1983. An energetics model for lake trout, *Salvelinus namaycush*: application to the Lake Michigan population. Canadian Journal of Fisheries and Aquatic Sciences 40:681-698.

Tabor, R.A., R.S. Shively, and T.P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:831-838.

Tisa, M.S. 1988. Compatibility and complementarity of alewife (*Alosa pseudoherengus*) and gizzard shad (*Dorosoma cepedianum*) as forage fish in Smith Mountain Lake, Virginia. Ph.D. Dissertation, Virginia Polytechnique Institute and State University, Blacksburg, VA.

Tisa, M.S., and J.J. Ney. 1991. Compatibility of alewives and gizzard shad as reservoir fish. Transactions of the American Fisheries Society 120:157-165.

Tranquilli, J.A., and W.F. Childers. 1982. Growth and survival of largemouth bass tagged with Floy anchor tags. North American Journal of Fisheries Management 2:184-187.

Van Den Avyle, M.J. 1994. Department of Fisheries and Wildlife, University of Georgia, personal communication.

Van Den Avyle, M.J., and B.J. Higginbotham. 1979. Growth, survival, and distribution of striped bass stocked into Watts Bar Reservoir, Tennessee. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 33:361-370.

Van Den Avyle, M.J., and J.E. Roussel. 1980. Evaluation of a simple method for removing food items from live black bass. Progressive Fish-Culturist 42:222-223.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Vinyard, G.L. 1980. Differential prey vulnerability and predator selectivity: effects of evasive prey on bluegill (*Lepomis macrochirus*) and pumkinseed (*L. gibbosus*) predation. Canadian Journal of Fisheries and Aquatic Sciences 37:2294-2299.

Virginia Department of Game and Inland Fisheries management reports, unpublished.

Wallin, J.E., and M.J. Van Den Avyle. 1995. Interactive effects of stocking site salinity and handling stress on survival of striped bass fingerlings. Transactions of the American Fisheries Society 124:736-745.

Wahl, D.H., and R.A. Stein. 1988. Selective predation by three esocids: the role of prey behavior and morphology. Transactions of the American Fisheries Society 117:142-151.

Wahl, D.H., and R.A. Stein. 1989. Comparative vulnerability of three esocids to largemouth bass (*Micropterus salmoides*) predation. Canadian Journal of Fisheries and Aquatic Sciences 46:2095-2103.

Ware, D.M. 1972. Predation by rainbow trout (*Salmo gairdneri*): the influence of hunger, prey density, and prey size. Journal of the Fisheries Research Board of Canada 29:1193-1201.

Warren, C.E. 1971. Biology and Water Pollution Control. W.B. Saunders Company, Philadelphia.

Wilbur, R.L., and R.M. Duchrow. 1972. Differential retention of five Floy® Tags on largemouth bass (*Micropterus salmoides*) in hatchery ponds. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 24:407-413.

Wydoski, R., and D.H. Bennett. 1981. Forage species in lakes and reserviors of the western United States. Transactions of the American Fisheries Society 110:746-771.

Wydoski, R., and L. Emery. 1983. Tagging and marking. Pages 215-235 in L.A. Nielsen and D.L. Johnson, editors. Fisheries Techniques, American Fisheries Society, Bethesda, Maryland.

Zar, J.H. 1984. Biostatistical Analysis, 2nd Edition. Prentice Hall, New Jersey.

VITA

Daniel P. Michaelson was born on April 21, 1971 to parents Stanley and Nancy Michaelson. He was born in St. Joseph, Missouri, raised in Holts Summit, Missouri, and graduated from Jefferson City High School in 1989. He received his Bachelor of Science degree in fisheries and wildlife from the University of Missouri-Columbia in 1993 and began the Master of Science degree program at Virginia Polytechnic Institute and State University in 1993. Daniel graduated from this institute in July of 1996.

Daniel P. Michaelson

Daniel P. Michaelson