ASSESSMENT OF THE RESPONSE OF PISCIVOROUS SPORTFISHES TO THE ESTABLISHMENT OF GIZZARD SHAD IN CLAYTOR LAKE, VIRGINIA

by

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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
(Fisheries Option)

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February 2000

Blacksburg, Virginia

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(ABSTRACT)

Gizzard shad were illegally introduced to Claytor Lake in the late 1980s and soon established a thriving population. This study assessed 1) the degree to which gizzard shad were utilized by piscivores (pelagic - striped bass *Morone saxatilis*, hybrid striped bass *M. chrysops x M. saxatilis*, and walleye *Stizostedion vitreum*, and three littoral black basses *Micropterus* spp.), 2) the availability of gizzard shad as potential prey as determined from age and growth analysis, and 3) the performance (growth rates, relative weight, and relative abundance) of piscivores before versus after gizzard shad establishment.

Gizzard shad were more highly utilized by pelagic predators (especially striped bass and their hybrids) than black basses. Rapid growth of gizzard shad (mean back-calculated length at age-1 = 155 mm TL) meant that almost all morphologically available shad were age-0. The reliance on one edible age class of gizzard shad resulted in an unstable food supply as evidenced by much greater striped bass shad consumption in Summer 1998 (63 % by weight) when age-0 shad were more abundant than in Summer 1997 (7 % by weight).

Striped bass was the only species to exhibit faster growth rates and mean relative weight (Wr) values in the 1990s versus pre-shad years. Walleye (except age-1) and black bass growth rates declined, and mean Wr values either remained consistent or declined. Largemouth bass and walleye were the only sportfish to show increases in relative abundance.

Benefits of gizzard shad as a forage fish appear to be limited to striped bass and its hybrid species. It is possible that gizzard shad have had, directly or indirectly, an adverse impact on the black basses of Claytor Lake, but explanatory analysis of these relationships was beyond the scope of this study.

ACKNOWLEDGEMENTS

Several individuals and groups deserve recognition for their assistance throughout this project. Dr. John J. Ney, my major professor, through his guidance and mentoring, provided me with the foundation and framework on which to build and improve my research and writing skills to better serve me in my profession. I thank him for sharing his witty humor and patience as I stumbled along the road to completion.

The faculty members who have served on my graduate committee, Drs. Steve L. McMullin and Donald J. Orth, offered insightful comments and advice during the development and completion of this project. I thank each of you for enriching my graduate school experience.

The Virginia Department of Game and Inland Fisheries not only provided the principle funding for this research project, but also cooperated with acquiring data for my study and sharing historical information on Claytor Lake. Several members of this organization contributed greatly in my efforts to conduct this study. Victor DiCenzo recognized the need for this study, provided creative advice, and sacrificed several nights to assist me with data collection. John Copeland, aside from serving on my graduate committee, proved invaluable in the compilation and interpretation of much of the historical information from the VDGIF database on Claytor Lake. Joe Williams contributed additional aid in field collections and his good-natured character made gill netting in December almost enjoyable.

My field technician, Troy Thompson, spent many long, grueling nights assisting me with fish sampling. Although I called them sleep deprivation experiments, Troy’s tireless efforts and humor kept me going.

Numerous graduate and undergraduate students from VPI&SU gave freely of their time to help me in my fish collections. Their unselfishness and friendship made my experience at Virginia Tech more rewarding.

I could never fully express my sincere gratitude to my loving family for the support and encouragement they have bestowed on me not only during this research study, but throughout my academic career.

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INTRODUCTION

Forage fish serve as the major food source for most sportfish in reservoir systems. State fisheries agencies routinely attempt to augment growth and production of sportfish through the expansion of the forage base, mainly through fertilization and the introduction of new prey species (Li and Moyle 1981). Potential benefits of a particular forage species should be weighed against its possible ecological impacts on resident fishes prior to introduction. Preceding a planned introduction, fisheries managers and researchers have the responsibility of using past experiences and knowledge of the biology and ecological requirements of a nonnative forage species to predict its suitability to a new system. In cases of illegal introductions, the culprits most likely omit any prior research and fail to consider future ecological consequences. Fisheries managers and researchers are then required to examine those consequences and revise their management strategies accordingly. Consequences can range from negligible (if the species fails to adapt) to beneficial or, in the worst case, catastrophic (Kohler et al. 1986). Claytor Lake, a 1820 ha mainstream hydroelectic reservoir in southwestern Virginia, was illegally stocked with gizzard shad (*Dorosoma cepedianum*) in the late 1980s, and this forage fish rapidly established a burgeoning population. Before-and-after assessment of the impacts of an introduced gizzard shad population on a reservoir fish assemblage has not been previously reported. This study was designed to assess the benefits of a newly established gizzard shad population on the resident piscivorous sportfishes of Claytor Lake.

Claytor Lake: Prior Management

The management history of Claytor Lake since its impoundment in 1939 has featured the intentional introduction of at least 14 species and two hybrid fishes with the primary objective of diversifying and expanding the fishery. The entire spectrum of outcomes has been illustrated by these stockings (Kohler et al. 1986). While salmonid species (*Salmo trutta* and *Oncorhynchus mykiss*), northern pike (*Esox lucius*) and threadfin shad (*Dorosoma petenense*) introductions proved unsuccessful due to habitat limitations, white bass (*Morone chrysops*), crappie (*Pomoxis* spp.), black bass (*Micropterus* spp.), channel catfish (*Ictalurus punctatus*), and *Lepomis* species became self-sustaining. Flathead catfish (*Pylodictis olivaris*), native to the New River drainage, also provide angling opportunities. Striped bass (*Morone saxatilis*), hybrid striped bass (*M. chrysops x M. saxatilis*), walleye (*Stizostedion vitreum*), and muskellunge (*Esox masquinongy*) have been maintained through periodic stocking. With the creation of a pelagic fishery, alewife (*Alosa pseudoharengus*) were introduced in the 1960s as forage. Kohler et al. (1986) reported that sportfish annual growth declined between 1960 and 1980. Striped bass growth lagged 10-20% behind other Virginia reservoirs. Competitive interactions between introduced and resident species were cited as contributing factors for the observed declines in growth, especially in younger age groups.

Claytor Lake's fish assemblage further expanded in the late 1980s when gizzard shad began to appear in sampling gear. The shad population quickly grew to constitute up to a third of the lake's fish biomass as represented in Virginia Department of Game and Inland Fisheries (VDGIF) cove rotenone and fall gill net samples, and many grew to > 300 mm total length (TL) (VDGIF unpublished data). In 1993, the *Roanoke Times and World News* printed a letter from an anonymous angler claiming credit for the introduction. Included in the letter was the boast of the much improved fishing conditions since the surreptitious act took place. Anglers are aware that adequate forage is necessary to produce large populations of game fish, and as a result, the introduction of minnows and other small fishes is a popular pastime (Li and Moyle 1993). Some fishermen may agree with the anonymous angler's argument of improved fishing, but there has been no scientific evidence to prove or contradict his/her reasoning.

Gizzard Shad In U.S. Reservoirs

The gizzard shad is the dominant forage fish in many southern and midwestern U.S. reservoirs, but its presence is not an uncontested blessing. The ideal forage fish should be, among other criteria, not only prolific but also vulnerable to predation throughout its life cycle and harmless to other resident fishes (Ney 1981). Gizzard shad can rapidly grow too large to be eaten by most predators, and they have the propensity to develop high biomass and interfere with the recruitment and production of centrarchid species and other sport fishes (Noble 1981). Yako et al. (1996) concluded that gizzard shad were facultative detritivores above 30 mm TL, feeding less on zooplankton with increasing size. Smaller age-0 gizzard shad have been shown capable of rapidly decimating zooplankton populations (Dettmers and Stein 1992). Therefore, negative effects of gizzard shad may occur as the result of trophic competition between larval/juvenile shad and young-of-year sportfish for reservoir zooplankton resources.

Cases for and against gizzard shad can be built from available literature. Consumption of gizzard shad by large predators is well documented (Dubets 1954; Schneidermeyer and Lewis 1956; Kutkuhn 1958; Jester and Jensen 1972; Moore et al. 1985; Anderson and Rabeni 1988) as are studies showing the adverse effect on sportfish growth and recruitment (Swingle 1946; Jenkins 1957; Smith 1959; Miller 1960; Bodola 1966; Kirk and Davies 1985). Other studies suggested that competition between young shad and crappies as well as black basses may be slight (Pope and DeVries 1994; Hirst and DeVries 1994). DeVries and Stein (1990) reviewed the literature on shad manipulations in North America and reported that before vs. after changes in sportfish abundance and growth ranged from negative to neutral to positive. However, these authors did not distinguish between gizzard shad and threadfin shad, which does not outgrow its predators.

Biology of Gizzard Shad

Feeding

Gizzard shad possess gill rakers, pharyngeal pockets, a muscular esophagus, gizzard, and in adults, an intestine measuring over 3 times the fish’s length. These attributes aid in pump-filtering and digesting small particles from the water column. Four to five days after hatching, gizzard shad feed on protozoa and unicellular algae. After reaching a length of 15 mm TL, the shad primarily eat zooplankton. Once the shad reach 30 mm TL, the adult shape is acquired and the gizzard is developed. Phytoplankton and detritus become increasingly important as shad grow in length (Bodola 1966). In laboratory and field, gizzard shad > 30 mm TL have been shown to eat primarily detritus but they will feed on zooplankton, if it is present at high density, in increasing amounts as more became available (Yako et al. 1996).

Growth

Gizzard shad growth varies with water bodies. In western Lake Erie, gizzard shad grew to 285 mm in two years (Bodola 1966). Gizzard shad in Elephant Butte Lake, New Mexico reached a comparable size after six years of growth (Jester and Jensen 1972). Mean gizzard shad length-at-age in Virginia reservoirs ranges from 104 - 221 mm TL, age- 1; 154 - 236 mm TL, age-2; 177 - 288 mm TL, age-3; 217 -306 mm TL, age-4; and 239 - 314 mm TL, age-5 (Banach 1989). DiCenzo et al. (1996) related gizzard shad growth and abundance to reservoir trophic state in Alabama. As eutrophication levels increased, shad growth rates declined and abundance increased. Lakes displaying mesotrophic conditions exhibited larger and faster growing shad, but a lower abundance relative to eutrophic lakes.

Spawning

Spawning begins in late spring and persists well into summer. Specific times depend on latitude and water temperature. Swingle (1946) reported gizzard shad spawning from April through August in Alabama ponds. Gizzard shad spawned from early May through late June in Elephant Butte Lake (Jester and Jensen 1972), and from early June through July in western Lake Erie (Bodola 1966). In each water body, spawning peaked with water temperatures of approximately 21° C. Tisa et al. (1985) reported gizzard shad spawning in Smith Mountain Lake, Virginia, from mid May until late June at water temperatures between 22° and 28° C. Larval gizzard shad densities were bi-modal with a minor peak in late May and a major peak in mid June. The gizzard shad spawning season began as early as the first week of April in two Missouri reservoirs when epilemnetic water temperatures reached 13° C, and lasted 12 – 15 weeks (Michaletz 1997a). In that study, changes in water level and temperature appeared to regulate the duration and intensity of gizzard shad spawning activity. Intense periods of spawning activity during rising water levels resulted in high peaks in larval abundance and relatively few large weekly cohorts. But, in the absence of water level rises, peaks in larval abundance were much lower and the abundance of larvae more evenly distributed among several weekly cohorts.

Eggs are broadcast in shallow water mainly at night, and adhere to submerged vegetation and bottom substrate. Male to female ratio during spawning is near 3:1. Eggs are not guarded (Bodola 1966).

Both male and female gizzard shad typically reach sexual maturity in their third year, but male gizzard shad may attain sexual maturity at age one (Bodola 1966 and Heidinger 1983). Fecundity is highest at ages two to three, and then declines with age (Miller 1960 and Bodola 1966). Age-2 female shad in Lake Erie averaged 378,990 eggs (Miller 1960).

Mortality

Survival from egg to age-1 was determined as 0.011 percent in Lake Erie (Bodola 1966). Larval survival to the juvenile stage (from 10 mm to 25 mm TL) averaged 6.8 % (0.01 – 60.5 %) among weekly cohorts and 1.8 % (0.04 – 4.2 %) among years (1987 – 1991) in Pomme De Terre and Stockton Reservoirs, Missouri (Michaletz 1997a). In this study, higher survival among weekly cohorts was attributed to later hatching date (warmer water temperatures) and fewer initial larvae (10 mm TL) within the cohort. Compared to the larval stage, the juvenile stage was far less dynamic, with mortality rates among juvenile cohorts lower and less variable than those of larvae. Hence, Michaeletz (1997a) suggested that relative year-class strength was set by the end of the larval stage. Annual mortality rates averaged 62 % for age-3 and older gizzard shad in 15 Missouri reservoirs (Michaletz 1998a).

In Lake Erie, annual survival was 5.5 %, 7.9 %, and 14.6 % for the second, third, and fourth years, respectively (Bodola 1966). In this study, the increase in survival with age was attributed to reduced predation on older, larger shad and the tendency of larger shad to select deeper waters where they are less vulnerable to drastic changes in water temperatures. Mass mortality occurs when water temperatures fall to 3.3° C, or as a result of quick changes in water temperature (Jester and Jensen 1972). Gizzard shad may attain the age of ten, but seldom live longer than 5 – 7 years (Miller 1960 and Bodola 1966). Younger ages of gizzard shad succumb to predation from a host of piscivorous fishes, including temperate basses, black basses, catfishes, walleye, crappie, esocids, lake trout (*Salvelinus namaycush*), freshwater drum (*Aplodinotus grunniens*), bowfin (*Amia* *calva*), and gars (Lagler and Hubbs 1940, Bonham 1941, Lagler et al. 1943, Dendy 1946b, Summerfelt 1968, Moore 1988, Michaletz 1997b), as well as waterfowl (Campo et al. 1993).

Goals and Objectives

Scientific literature demonstrates that the gizzard shad can be a major but less than ideal forage fish. Because past experiences with gizzard shad give such varied results, a system-specific analysis of benefits to potential predators and detriments to potential competitors in Claytor Lake was undertaken. My research focuses on assessment of the benefits to resident piscivorous sport fishes. Before-and-after analysis of the impacts of gizzard shad introduction into a mainstrean reservoir have not been published; only the response to gizzard shad introductions into small water bodies or reductions in shad biomass have been documented (DeVries and Stein 1990). This is the first study to evaluate the utilization of gizzard shad on such a broad range of predators (three moronids, three black basses, and walleye). The goal of this two-year study was to assess the contribution of the gizzard shad as a forage fish resource for piscivorous sport fishes in Claytor Lake. Specific objectives were to:

1) **Quantify the contribution of gizzard shad to the diets of piscivores;**

Previous studies have revealed that the majority of gizzard shad eaten by predators are age-0 (Ott and Malvestuto 1981; Lewis 1983; Knight et al. 1984; Moore 1988) and that the production of age-0 shad can vary among years within a reservoir (Michaeletz 1997a). Variability of age-0 shad among years can result in an unstable food supply. Percent contribution of gizzard shad to predator diets was calculated over two years to describe the annual and seasonal variability in shad consumption for piscivores in Claytor Lake.

2) **Describe the population characteristics of gizzard shad; and**

Growth information for gizzard shad in Claytor Lake was calculated and these data were related to the sizes of shad collected from piscivore stomach samples to determine the contribution of successive age classes of shad to predator diets. Fast growing age-0 shad quickly outgrow their vulnerability to predation, especially for smaller, gape-limited piscivores. Emphasis was placed on estimating gizzard shad lengths-at-ages one and two. Length-frequency distributions of shad were used to evaluate size structure and catch-at-age data were used to calculate adult mortality rates. These data also provided information on the longevity of the age classes of shad that offer poor forage because of their invulnerability to predation.

3) Compare growth, condition, and abundance of piscivores pre and post gizzard shad establishment.

Provided that food was the limiting factor for piscivore performance in Claytor Lake, utilization of a new prey species (gizzard shad) could result in benefits to sportfish through increases in growth, condition, abundance or any combination of these. If gizzard shad were utilized but no benefits were realized, then we could assume that the shad only replaced other prey items and did not increase the total amount of available forage in Claytor Lake.

METHODS AND MATERIALS

Study Area

Claytor Lake is a mainstream hydroelectric impoundment of the New River located in Pulaski County, Virginia. Construction of the dam was completed in 1939 by the Appalachian Power Company. The 21.7 km long reservoir has a maximum depth of 37.5 m, a mean depth of 29 m, and a surface area of 1820 ha at a standard normal pool elevation of 663 m above mean sea level (Rosebery 1950). Claytor Lake is riverine in nature with a 451 m mean width and a retention time of approximately 63 days (Nigro 1980). The littoral zone is typically narrow, rocky, exposed to continuous wave action, and grades steeply into the profundal zone (Kohler 1980; Kelso 1983). Restricted littoral zones coupled with an annual water level fluctuation of 1.6 m limits the establishment of aquatic vegetation.

Claytor Lake is dimictic, exhibiting spring and fall overturns. A distinct thermocline exists throughout summer lying superior to an anoxic hypolimnion (Boaze 1972). Secondary-treated effluent from the Pulaski sewage treatment plant enters Peak Creek, the lake's only major tributary, and provides the primary source of nutrient input. Claytor Lake averaged 29.8 ppb total phosphorus concentration, 5.4 ppb chlorophyll A concentration, and a secchi depth of 1.5 m from 1996 through 1998 (Thomas and Johnson 1998). Based on these values, Claytor Lake could be characterized as meso- to moderately eutrophic (Carlson 1977; Reckhow and Chapra 1983).

Field Collections

Pelagic Sampling

Collection of three pelagic piscivores (striped bass, hybrid moronids, and walleye) was necessary to describe diet composition and collect information on age and growth.

Pelagic piscivorous fishes were collected from horizontal gill nets 61 m in length, 2.4 m in depth, and consisting of four 15.3 m panels of 38, 51, 64, and 76 mm bar mesh. Gill netting was conducted twice a month from May through September 1997 and 1998. Between three and five nets were set at each of three to five sites (Figure 1) at dusk. Successful sites were chosen following initial trials to maximize catch per effort. Suspending nets over long tapering points and flats proved to be the most efficient

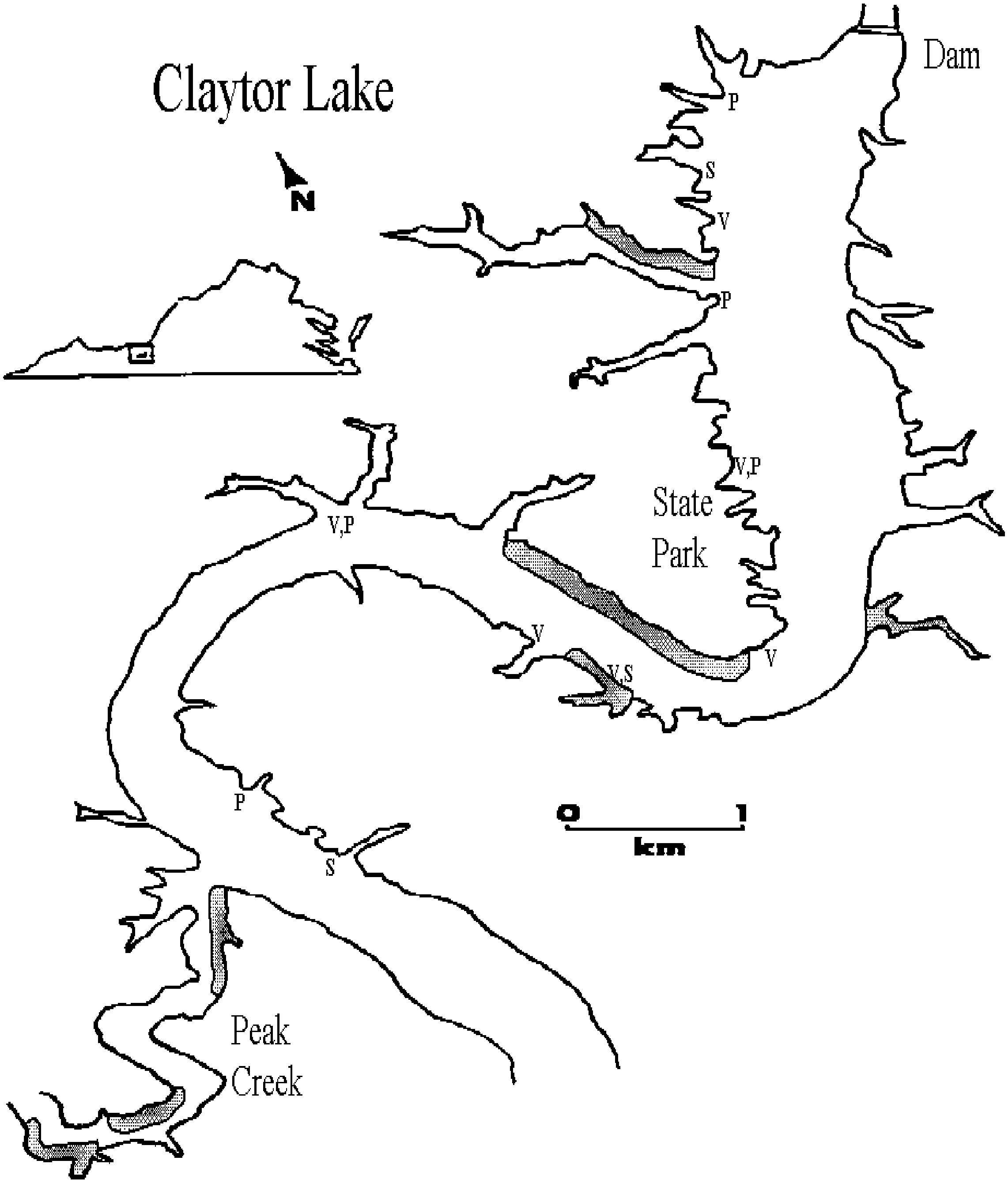

Figure 1. Sampling sites on Claytor Lake 1996 – 1998. Shaded areas indicate electrofishing sampling locations. V = VDGIF fall gill net site. P = pelagic piscivore gill net site. S = shad gill net site.

capture method. Nets were retrieved before dawn in May and early June. Between mid-June and September, nets were pulled an additional time during the night in order to minimize stomach evacuation rates. The maximum length of time that the nets were set between pulls was 6.5 hours during the summer, 12 hours in spring, and 15 hours in fall. Sampling at night also reduced net avoidance by fish and negative public opinion.

The VDGIF's annual fall gill net sampling supplied predator stomachs in sufficient numbers to characterize their fall diets. Six experimental gill nets consisting of 19, 32, 41, 51, and 64 mm bar mesh were set at six separate sites (Figure 1) once or twice a month from October through December in 1996 and 1997. Nets were set during early evening hours and pulled in the next morning by VDGIF personnel.

Once collected, pelagic sportfish were measured to the nearest 1 mm TL. Predator stomachs were excised and contents were immediately preserved in 10% formalin for laboratory analysis. Scales were obtained for the purpose of developing age and growth information.

Gizzard shad were sampled to determine age structure and size distributions for both years. Experimental gill nets 61 m long, 2.4 m deep, and consisting of five 12.2 m panels of 12, 19, 25, 31, and 38 mm bar mesh were deployed for the collection of shad. This was the recommended mesh size distribution for sampling gizzard shad ranging from the largest individuals down to approximately 60 mm TL (Van Den Avyle et al. 1995). Two to three shad nets were set at separate sites (Figure 1) concomitantly with predator nets twice a month from May through November in 1997 and 1998. Each site was selected in the effort to maximize catches of age-0 shad. A variety of habitat types (points, tributary creeks, main lake flats, sampling depths, etc.) and areas of the lake (dam, state park, Peak Creek, and further up lake) were sampled in an attempt to increase CPUE of age-0 shad. An effort was made to collect an arbitrary target number of 100 individuals (50 age-0 and 50 adults) per sampling date. Although sample sizes of adult shad were usually much greater than 50, success at catching age-0 shad was minimal. Repeated attempts at capturing age-0 shad with an electrofishing boat were also unsuccessful. Emphasis was placed on collecting young gizzard shad to determine when they outgrew their predators. Individuals were measured in the field, to the nearest 1 mm

TL. Scales and otoliths were taken from a subsample (Ricker 1975), and an age-length key (DeVries and Frie 1996) was used to assign ages to the remaining shad in the sample. Age and growth information was used to describe age compositions and annual growth rates. Numbers caught at successive ages were used to estimate adult (> age 3) mortality rates by calculating the slope of $\log_{10}$ transformed catch-at-age data (Ricker 1975).

Littoral Sampling

Littoral piscivores were sampled in order to describe their seasonal diets and obtain age and growth information. Black bass species (largemouth bass, smallmouth bass, and spotted bass) were collected with a pulsed DC electrofishing boat at night. Electrofishing was conducted twice a month from May through October 1997 - 1998, and in October 1996. At least four sites (Figure 1) were sampled, and effort was dependent on catch rates and stomach fullness. Each night, an attempt was made to collect 20 stomach samples containing food items from each black bass species, but actual sample sizes were usually less. The VDGIF's annual spring electrofishing survey (daytime) supplemented seasonal black bass collections in April and May.

Black bass mortality was minimized by the use of clear, plastic tubes of various sizes to remove stomach contents (Van Den Avyle and Roussel 1980). Occasionally, long forceps aided in the removal of stomach contents. Food items were then immediately preserved in 10% buffered formalin for laboratory analysis. All bass were measured to the nearest 1 mm TL, weighed with a 6 kg digital scale to the nearest 1 g then released. Scales were obtained from a representative sample of all three bass species for the purpose of age and growth information.

Laboratory Analysis

Diet Composition

Stomach contents of all predator fish were analyzed under a fume hood to minimize exposure to formalin. Food items were identified to species for fish and to the lowest taxonomic level practicable for invertebrates and terrestrial vertebrates. Gizzard shad and alewife were distinguished by presence/absence of a gizzard. All items were blotted dry and weighed to the nearest 0.1 g. For each season and species, piscivore diet composition was described as percent by weight (Bowen 1996);

$$X_i = \frac{\sum_{i=1}^{N} (w_i/w_t)}{N}$$

where X_i = the mean percent composition by weight of item *i* in the diet,

w_i = the weight of food item *i* in an individual fish,

w_t = the total weight of all food items in an individual fish, and

N = the total number of fish with food contents.

Describing the variability around the mean seasonal diet composition was not appropriate in this study. For example, the majority of individual predator fish either contained 0 % or 100 % shad. The range of percent gizzard shad consumption would almost always be 0 – 100 % and standard deviations and/or standard errors would be large.

For each species, percent gizzard shad consumption was calculated on an annual basis;

$$Y_i = \frac{\sum x_{ij}}{\sum w_{ij}} \times 100$$

where Y_i = the mean percent composition by weight of gizzard shad in the diet of species *i* on an annual basis,

x_{ij} = the mean weight of gizzard shad in individual fish within species *i* for season *j*, and

w_{ij} = the mean total weight of all food items in individual fish within species *i* for season *j*.

This method was used to calculate annual gizzard shad consumption, instead of taking the mean of seasonal percentages, in order to account for differential feeding intensities among seasons.

For each season and species, Stomach Fullness Index (SFI) was calculated for amounts (mg food per g predator) of both total food and shad in predator stomachs (Nakashima and Leggett 1979);

$$\mathrm{SFI}_{total} = \frac{\sum_{i=1}^{N} (t/p)}{N}$$

where SFI_{totai} = mean amount of total food items (on a mg shad per g predator basis) collected from piscivore *i*.

t = total weight (mg) of all food items in an individual fish,

p = estimated weight (g) of an individual predator based on length-weight relationship equations (Anderson and Neumann 1996),

N = total number of stomachs examined (including empty stomachs), and

$$\mathrm{SFI}_{shad} = \frac{\sum_{i=1}^{N} (s/p)}{N}$$

where SFI_{shad} = mean amount of gizzard shad (on a mg shad per g predator basis) collected from piscivore *i*.

s = weight (mg) of shad in an individual fish,

p = estimated weight (g) of an individual predator based on length-weight relationship equations (Anderson and Neumann 1996),

N = total number of stomachs examined (including empty stomachs).

Standard (SL) and backbone (BL) lengths of alewife and gizzard shad were converted to total lengths with the use of regression equations developed for each prey species (Moore 1988). Prey total lengths were used in prey TL/piscivore TL comparisons. Differential digestion rates of various prey species were considered insignificant. At constant temperatures, digestion rates of fish, aquatic insect larvae, and crayfish (with highly chitinized exoskeletons) were similar for bluegill (Windell 1966), and I assumed that this equivalence held for my predator species as well.

Age and Growth

Scales were collected for age and growth determination on all six piscivores and gizzard shad. Plastic impressions were made of sportfish and shad scales. Scales were read using a Bausch & Lomb microprojector at 10X magnification. Length of fish at formation of each annulus was calculated using the Fraser-Lee method (DeVries and Frie 1996);

$$L_i = \frac{L_c - a}{S_c} S_i + a$$

Where L_i = back-calculated length of the fish when the *i*th annulus was formed,

L_c = length of fish at capture

S_c = radius of scale measured from the focus to the anterior margin,

S_i = radius of the scale at the *i*th annulus, and

a = intercept value determined by fitting a body-scale linear regression.

Annual growth rates of piscivores were determined during this project and compared to pre-shad data compiled by VPI & SU on Claytor Lake (Kohler 1980) and other reservoirs in Virginia (Banach 1991). Because all pre-shad growth data were obtained using scales, scale ages were used for comparison. Scale impressions were aged and lengths-at-ages were back-calculated using similar methods in the previous study (Kohler 1980).

VDGIF Data Base

Annual sampling on Claytor Lake by VDGIF personnel has produced an extensive data base which was crucial to this study. A variety of sampling methods contributed predator length-weight and abundance data on key species studied in this project.

Lengths and weights for Claytor Lake sportfish were provided by the VDGIF fall gill net (striped bass, hybrid striped bass, and walleye) and spring electrofishing records (black basses) and were used to calculate relative weights (Anderson and Neumann 1996). These data were available for striped bass in years 1981 – 1984, 1988, and 1992 – 1997; walleye in 1981, 1982, 1988, and 1992 – 1997; hybrid striped bass in 1994 – 1997; and black basses in 1988, 1993, 1996, and 1998. For each species (except hybrid striped bass) individual relative weight (Wr) values were pooled among pre-shad (1981 – 1988) and post-shad (1992 – 1998) years. The year 1988 was the last year included in the pre-shad group. In that year, gizzard shad were first collected by the VDGIF in their sampling gears, but still accounted for less than one percent of cove biomass. Mean Wr values for pre and post-shad years were compared to determine if sportfish condition changed after gizzard shad establishment. Only fish 200 mm TL and longer were included in the analysis because weight measurements of small fish tend to be quite variable (Anderson and Neumann 1996). In addition, smaller predators ate few shad, minimizing the direct effect shad consumption placed on Wr values for this size group.

Relative abundance data on pelagic sportfish (moronids and walleye) were gathered from VDGIF's 1981 -1997 fall gill net samples. Gill net catch-per-unit-effort (CPUE = N/9.29 m^2 of net) was used as the index of abundance. The CPUE results from 1989 - 1997 were compared to gill net CPUE from 1981 – 1988. Before 1996, gill nets were 61 m long, 2.4 m deep, and consisted of three 20.3 m panels of 19, 32, and 51 mm bar mesh (hereafter referred to as traditional nets). During the years 1996 – 1998, gill nets were 61 m long, 2.4 m deep, and consisted of five 12.2 m panels of 19, 32, 41, 51, and 64 mm bar mesh (hereafter referred to as experimental nets). To ensure comparability with historic gill net catch rates, CPUEs from experimental nets were calculated for each mesh size, and only the three historic mesh sizes were used for comparative purposes. Sample sites were consistent in years 1981 – 1998 (Figure 1).

Relative abundance of black basses from VDGIF's 1989 -1998 spring electrofishing samples was compared to samples taken from 1986 - 1988. Electrofishing CPUE (N/hour) was used as the index of abundance. Although sample sites were consistent among years 1984 – 1998 (Figure 1), sampling dates were not. The electrofishing survey in 1984 was conducted in October, 1986 was sampled in June, 1988 – 1991 and 1993 - 1995 in May, 1992 in July, 1996 – 1998 in both April and May. Equipment problems prevented the collection of a reliable sample in Spring 1997. Only years in which the VDGIF conducted spring electrofishing (April – June) were used for comparative purposes (1986, 1988 – 1991, 1993 – 1996, and 1998).

The VDGIF conducted cove rotenone samples in the summers of 1996 and 1997 to monitor abundance (N/ha, kg/ha) of littoral fishes. Total fish standing stock and abundance of important fish species in 1996 and 1997 were compared to cove rotenone collections conducted in 1976 – 1978, 1981, 1984, 1988, and 1991. Coves were sampled using techniques developed for this purpose (Bettoli and Maceina 1996). In 1996 and 1997, three coves were sampled instead of the previous four, only 2 pick-up days were used per cove instead of three, and fish biomass was not adjusted for non-recovered fish (unadjusted cove biomass estimates from the 1976 – 1991 period were used for comparison purposes). In previous surveys, species groups were sorted by inch group and each inch group was weighed. In 1996 and 1997, a subsample was taken of the more abundant species which was subsequently weighed, counted, and species biomass was extrapolated based on total number of specimens. Total counts were made of each species.

Angler creel surveys conducted by VDGIF in 1977, 1978, 1981, 1985, 1988, 1992, and 1998 provided angler sport fish harvest and catch data pre vs. post gizzard shad. Creels conducted in 1981 and 1988 did not include night surveys and were omitted from comparisons. Angler effort, catch rates by species, and mean size of individual fish caught were compared. In addition, angler citation award information (VDGIF, unpublished data) was compiled for striped bass. Numbers of citations awarded to anglers catching striped bass > 9 kg and the largest individual weight citation award from each year were compared before and after shad introduction. Angler citation data for striped bass has been collected since 1975. Minimum striped bass citation size was 6.8 kg (15 pounds) from 1975 – 1991, and 9 kg from 1992 – 1998. Until the 1990s, anglers could only receive a citation by submitting weight information. In recent years, anglers could receive citations based on weight or length information. Only citations issued to anglers submitted using weight information and for striped bass catches > 9 kg were used for comparative purposes.

Statistical Procedures

A variety of statistical procedures was used to analyze data sets in this study. Wilcoxon’s rank sum procedure (non-parametric counterpart to the parametric “T” test, two independent samples) was applied to both sportfish diet and VDGIF abundance “before versus after” comparisons because data sets were not normally distributed. Mean percent gizzard shad consumption (% by weight) by each species was analyzed using Wilcoxon’s Rank Sum Test ($\alpha = 0.05$) to elucidate differences among corresponding seasons between the two years of data (Table 2). Stomach Fullness Index (SFI) was used to compare seasonal gizzard shad consumption on a milligram shad per gram piscivore basis by each species within years using a Kruskal-Wallis Test (non-parametric counterpart to the parametric Analysis of Variance) to show seasonal discrepancies in shad utilization. Diet data were analyzed on a mg/g basis to better describe total amounts of gizzard shad in predator stomachs instead of a proportion of the diet listed as a percentage. A Tukey-Kramer's HSD range test was used in the event a statistically significant difference in seasonal gizzard shad consumption was found in order to differentiate seasons. Non-parametric statistical procedures operate under fewer assumptions (e.g. normality) about the populations from which the data were obtained than do parametric tests (Hollander and Wolfe 1973).

No individual fish, back-calculated lengths-at-age data were available from previous studies, only means, precluding any direct statistical comparisons of sportfish growth. To circumvent this problem, I assumed that the variability around back-calculated mean lengths-at-ages for my study would be similar to the variability associated with similar calculations performed previously (Kohler 1980). Substituting my standard deviation values around mean back-calculated lengths-at-ages for the previously unreported values, allowed comparisons to be made between mean back-calculated lengths-at-ages using a Student's "T" test ($\alpha = 0.05$). Weighted mean lengths of combined age classes were compared because samples sizes within each age class were often low.

Pooled Wr values for pre and post-shad were compared for each species (except hybrid striped bass) using a Student's "T" test ($\alpha = 0.05$). All tests were two-sided (I was unable to predict whether compared variables would be higher or lower among years, seasons, and studies) and were considered significant at the $\alpha = 0.05$ level.

RESULTS

Piscivore Diets

A total of 3057 stomachs of the six piscivores was examined from fish collected between October 1996 and September 1998 (Table 1). Seasonal diet composition for each species was calculated using mean percent by weight. Sampling seasons were Spring (April - June), Summer (July - September), and Fall (October - December). No piscivore stomachs were collected from January through March based on the assumption that cold water temperatures limited Claytor Lake piscivore feeding activity (Moore 1988). According to cove rotenone samples, bluegill averaged approximately 90 % of the total *Lepomis* spp. standing stock. All sunfish removed from piscivore stomachs were considered to be bluegill. Diet data are summarized for each piscivore below.

Seasonal Patterns

Striped bass

Gizzard shad and alewives were by far the dominant food items in striped bass stomachs, together comprising over 70 % of food contents throughout the two-year study (Figure 2). Most of the partially digested unidentifiable fish (PDUF) were judged by general clupeid body shape to be either alewife or gizzard shad. This observation also held true for PDUF obtained from hybrid striped bass and walleye. Mayfly nymphs (*Hexagenia* sp.) occurred in stomachs (up to 16 %) during late spring and summer months. Other food items which occurred relatively infrequently included bluegill sunfish, crayfish (*Orconectes* sp.), and insects (Diptera and Odonata).

Striped bass fed most heavily on gizzard shad during late summer and fall (Figure 2). Gizzard shad comprised approximately 50 % of striped bass stomach contents in both fall 1996 and 1997. Shad constituted less than 10 % of striped bass food items in both spring sampling periods. Striped bass, however, consumed proportionately less gizzard shad during summer of 1997 (7 %) than summer of 1998 (63%). In addition, striped bass began feeding on age-0 gizzard shad earlier (mid-July) in 1998 than in 1997 (mid-August). Alewife accounted for over 65 % of striped bass diet composition during both spring periods and summer 1997, and never less than 20 % in the remaining seasons. No sportfish of any species was collected from a striped bass stomach in any season.

Table 1. Number of predator stomachs collected by season and species from Claytor Lake, 1996-1998. The first numeral represents the total number of predator stomachs collected and the second numeral represents those stomachs containing food items.

Species	Fall 1996		Spring 1997		Summer 1997		Fall 1997		Spring 1998		Summer 1998		Total	
	total	w/food	total	w/food	total	w/food	total	w/food	total	w/food	total	w/food	total	w/food
Striped bass	88	35	32	21	36	19	19	6	45	20	34	23	254	124
Hybrd striped bass	109	32	27	17	158	96	106	29	65	33	182	108	647	315
Walleye	146	47	18	12	135	45	155	66	39	21	51	11	544	202
Largemouth bass	33	17	226	101	94	55	25	10	144	71	69	49	591	312
Smallmouth bass	21	17	150	100	158	114	19	14	95	50	143	106	586	401
Spotted bass	22	13	153	72	96	67	28	16	95	47	41	26	435	241
Total	419	161	606	332	677	396	352	141	483	242	520	323	3057	1595

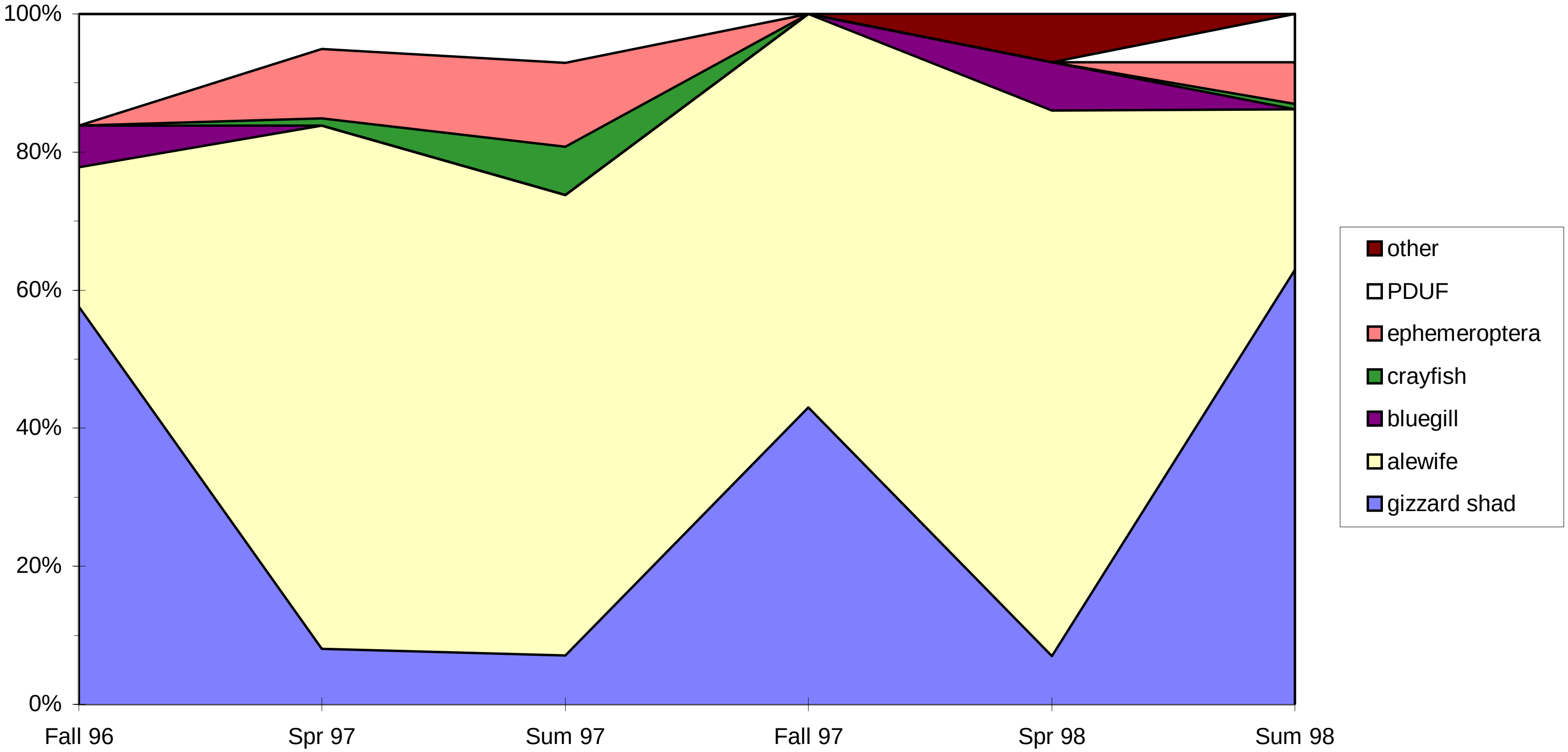

Figure 2. Mean percentage composition by weight of stomach contents of striped bass collected from Claytor Lake, October 1996 - September 1998. "PDUF" = Partially Digested Unidentifiable Fish.

Hybrid striped bass

Similar to striped bass, gizzard shad and alewives comprised the majority of hybrid stomach contents, together constituting greater than 56 % of food items throughout the study (Figure 3). Bluegill sunfish and crayfish each constituted as much as 15 % of hybrid striped bass diet composition on a seasonal basis. During late spring and summer months, hybrid stripers fed opportunistically on abundant mayfly nymphs which comprised as much as 25 % of stomach contents.

Hybrid stripers also fed most heavily on gizzard shad during the late summer and fall months (Figure 3). Gizzard shad comprised approximately 50 % of food items during both fall 1997 and 1998 sampling seasons. Shad constituted 15 % of spring 1997 hybrid striper diets while no shad were obtained from hybrid stomachs the following spring. Discrepancies were manifest in shad consumption between both summers. Only 7 % of summer 1997 hybrid striper diet consisted of gizzard shad compared to a third of all food items the next summer. In agreement with striper food habits, hybrid stripers also began feeding on age-0 shad a month earlier in summer 1998. Alewives were consumed in highest quantities in spring months, comprising greater than 65 % of stomach contents both years and never representing less than 20 % in any season. Out of 647 hybrid striped bass stomachs examined, one contained an age-0 black bass, but no pelagic gamefish was found in a hybrid striped bass stomach.

Walleye

Alewives, followed by gizzard shad, were the dominant food items obtained from walleye stomachs throughout both years of the study (Figure 4). Alewives constituted at least 60 % or greater of walleye diets in spring and summer months and represented a third of the fall diet. No gizzard shad were collected from walleye stomachs in either spring, and only 5 % of the first summer’s diet consisted of shad. However, 20 % of the walleye diet in the summer of 1998 consisted of gizzard shad, and shad comprised approximately a third of the fall diet. Bluegill sunfish and mayfly nymphs each contributed to walleye diets up to 11 % on a seasonal basis. One young-of-year black bass was identified in a walleye stomach collected in the summer of 1997.

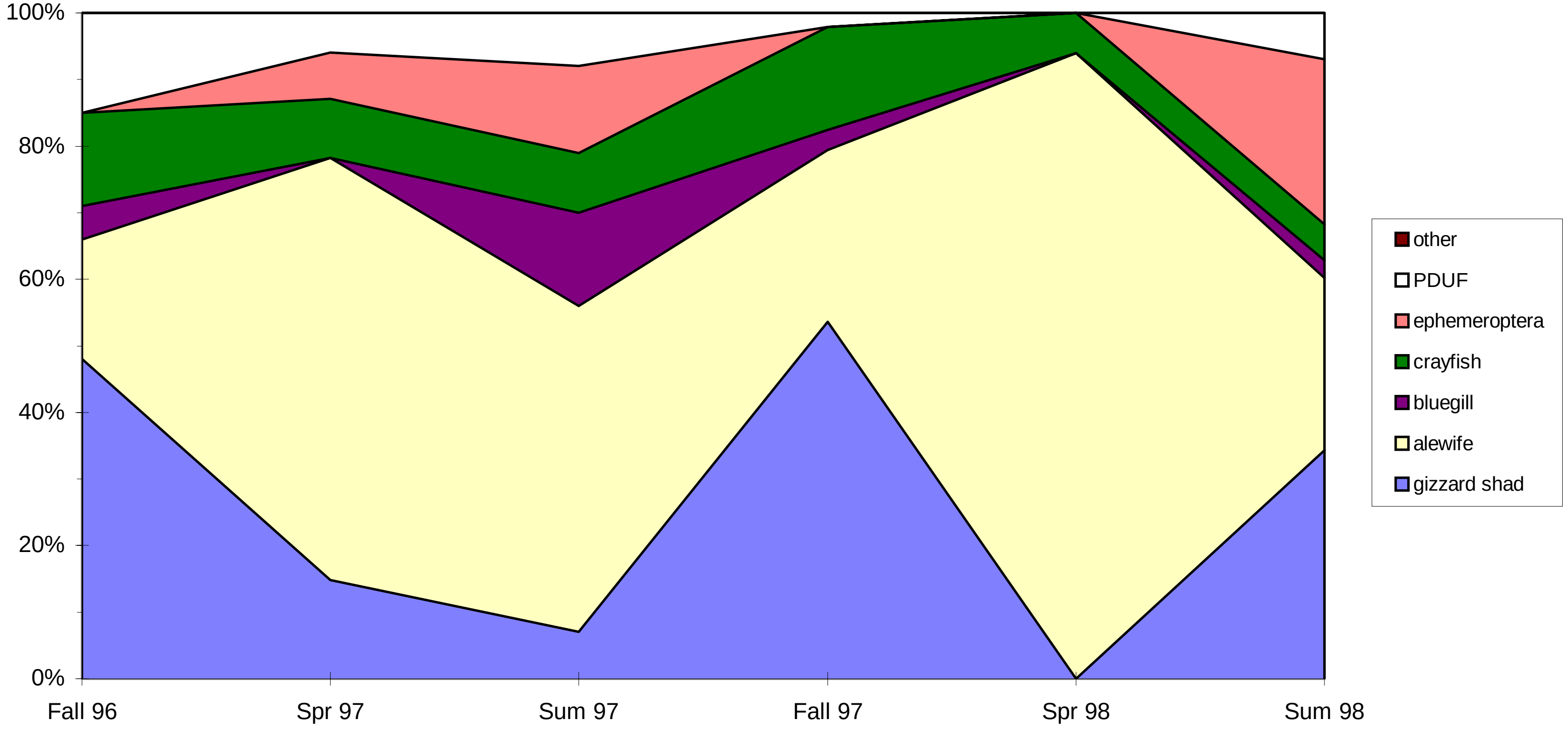

Figure 3. Mean percentage composition by weight of stomach contents of hybrid striped bass collected from Claytor Lake, October 1996 - September 1998. "PDUF" = Partially Digested Unidentifiable Fish.

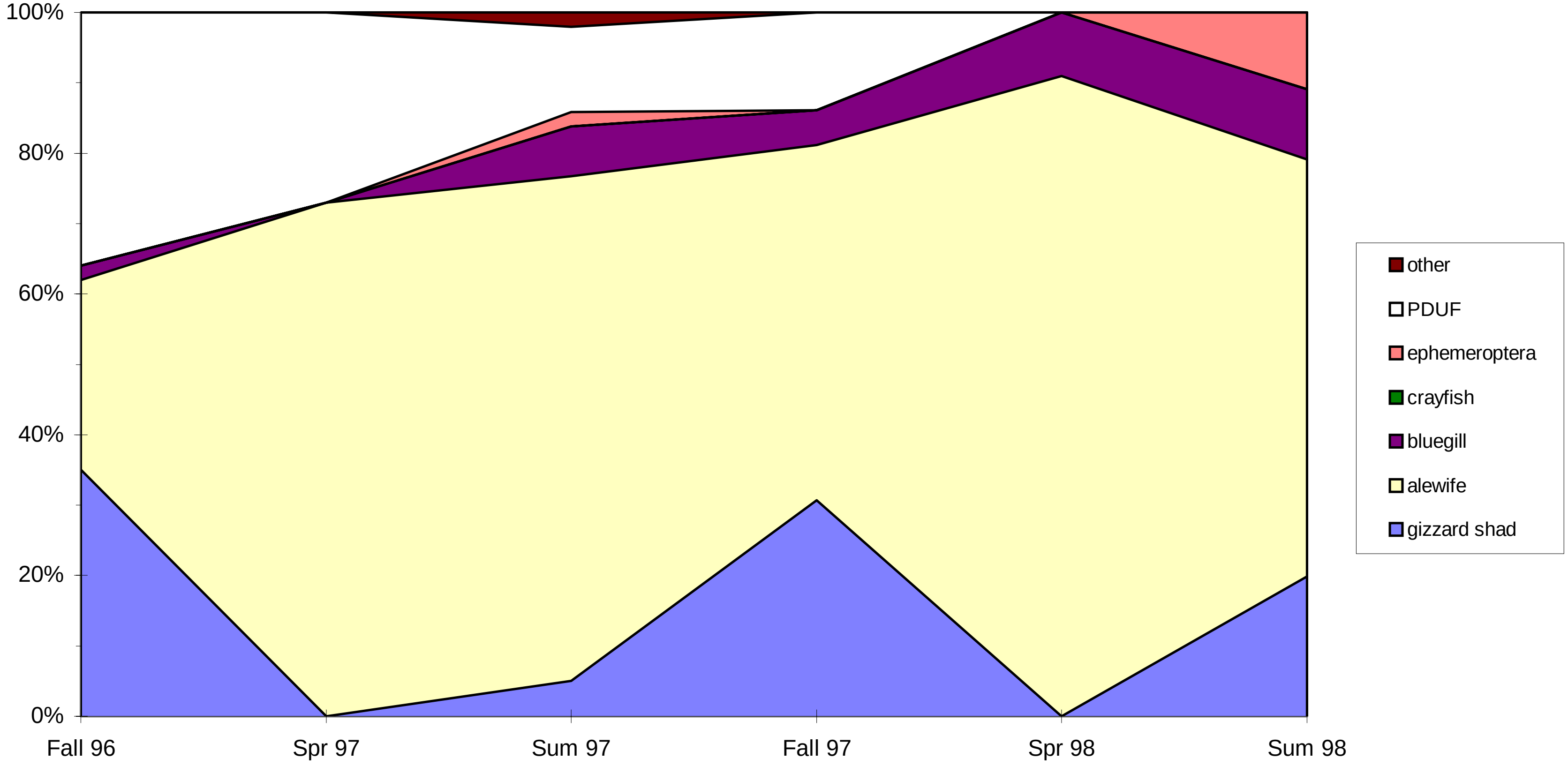

Figure 4. Mean percentage composition by weight of stomach contents of walleye collected from Claytor Lake, October 1996 - September 1998. “PDUF” = Partially Digested Unidentifiable Fish.

Largemouth bass

A variety of prey items comprised the largemouth bass diet (Figure 5). Bluegill sunfish and crayfish together made up the majority of prey items collected in all seasons. Bluegill averaged 13 % of the spring largemouth bass diet, increasing in importance from just below half in summer months to 43 and 88 % for fall 1996 and fall 1997, respectively. Crayfish constituted between 13 % and 48 % of largemouth bass diet throughout the study. Gizzard shad occurred infrequently in largemouth bass stomachs (< 6 % of diet) except for spring and summer 1997 when shad represented 21 % and 14 %, respectively, of stomach contents. Alewives comprised a significant portion of the largemouth bass spring diet, averaging approximately 20 % over both years. Alewife consumption by largemouth bass decreased progressively during each year as only 5 % of the summer diet included this clupeid while no alewives were collected from stomachs in either fall period. Infrequent food items included young-of-year and juvenile black basses (*Micropterus* spp.), crappie (*Pomoxis* spp.), PDUF, rock bass (*Ambloplites rupestris*), minnows (*Notropis* spp.), aquatic insects (*Hexegenia* sp., Odonata), terrestrial insects, and terrestrial vertebrates (Reptilia).

Smallmouth bass

Smallmouth bass diet composition was also diverse, yet more dominated by crayfish than that of largemouth bass (Figure 6). Crayfish constituted between 55 % and 82 % of the smallmouth bass diet throughout the study. Bluegill consistently accounted for around 15 % of smallmouth bass diet during all sampling seasons. Gizzard shad was not prevalent in smallmouth bass stomachs, comprising less than 7 % of the diet during all seasons. Smallmouth bass consumed alewives during spring and summer months, but always in quantities less than 10 % of the seasonal diet. Food items occurring infrequently were PDUF, age-0 and juvenile black basses, minnows (*Notropis* spp.), aquatic insects (*Hexegenia* sp., Trichoptera, Odonata), and terrestrial insects.

Spotted bass

Crayfish were by far the dominant item observed in spotted bass stomachs (Figure 7). Spotted bass diet composition consisted of between 43 % and 86 % crayfish in all sampling seasons. Bluegill accounted for over 40 % of spotted bass diet composition in

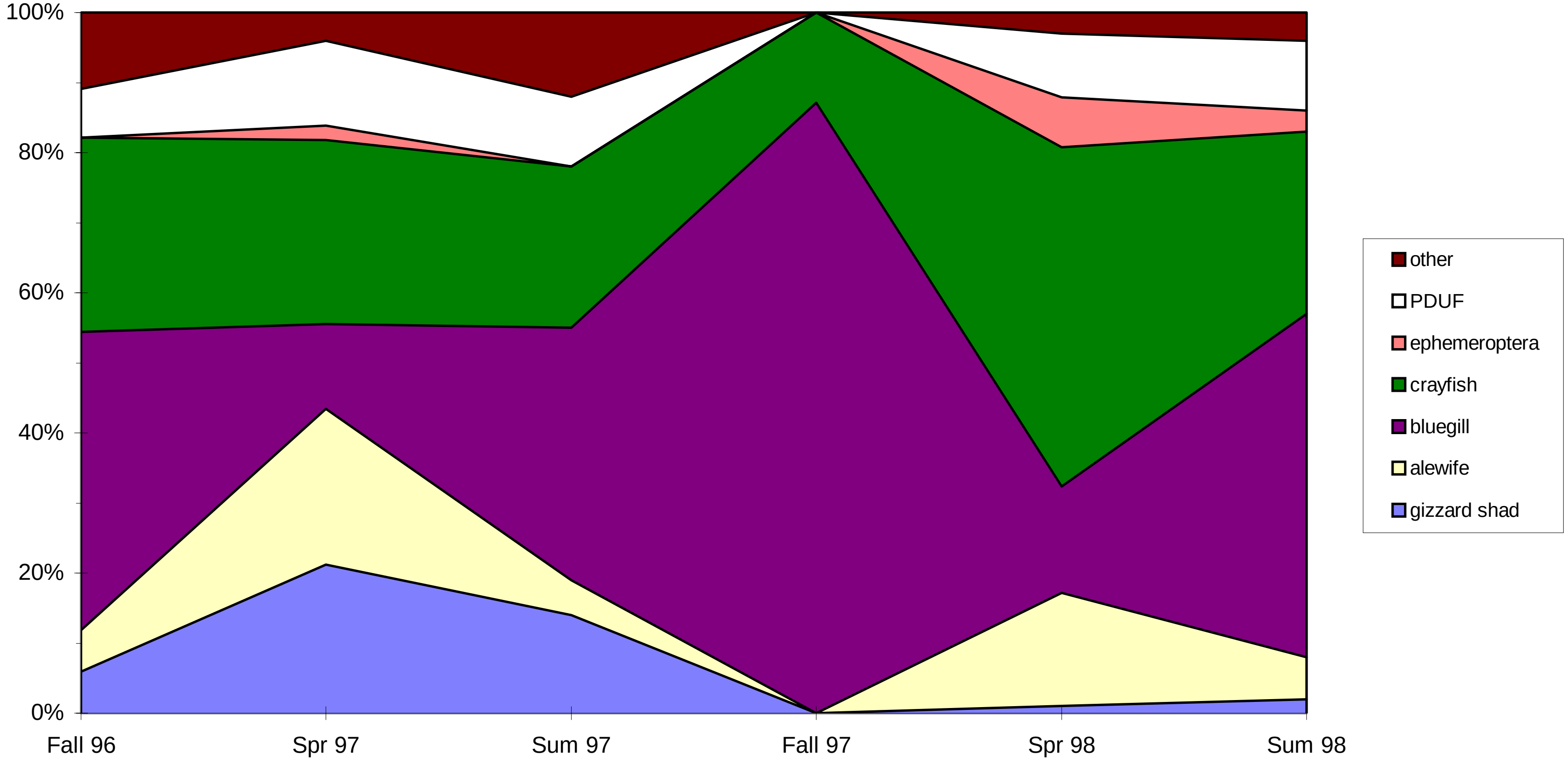

Figure 5. Mean percentage composition by weight of stomach contents of largemouth bass collected from Claytor Lake, October 1996 - September 1998. “PDUF” = Partially Digested Unidentifiable Fish.

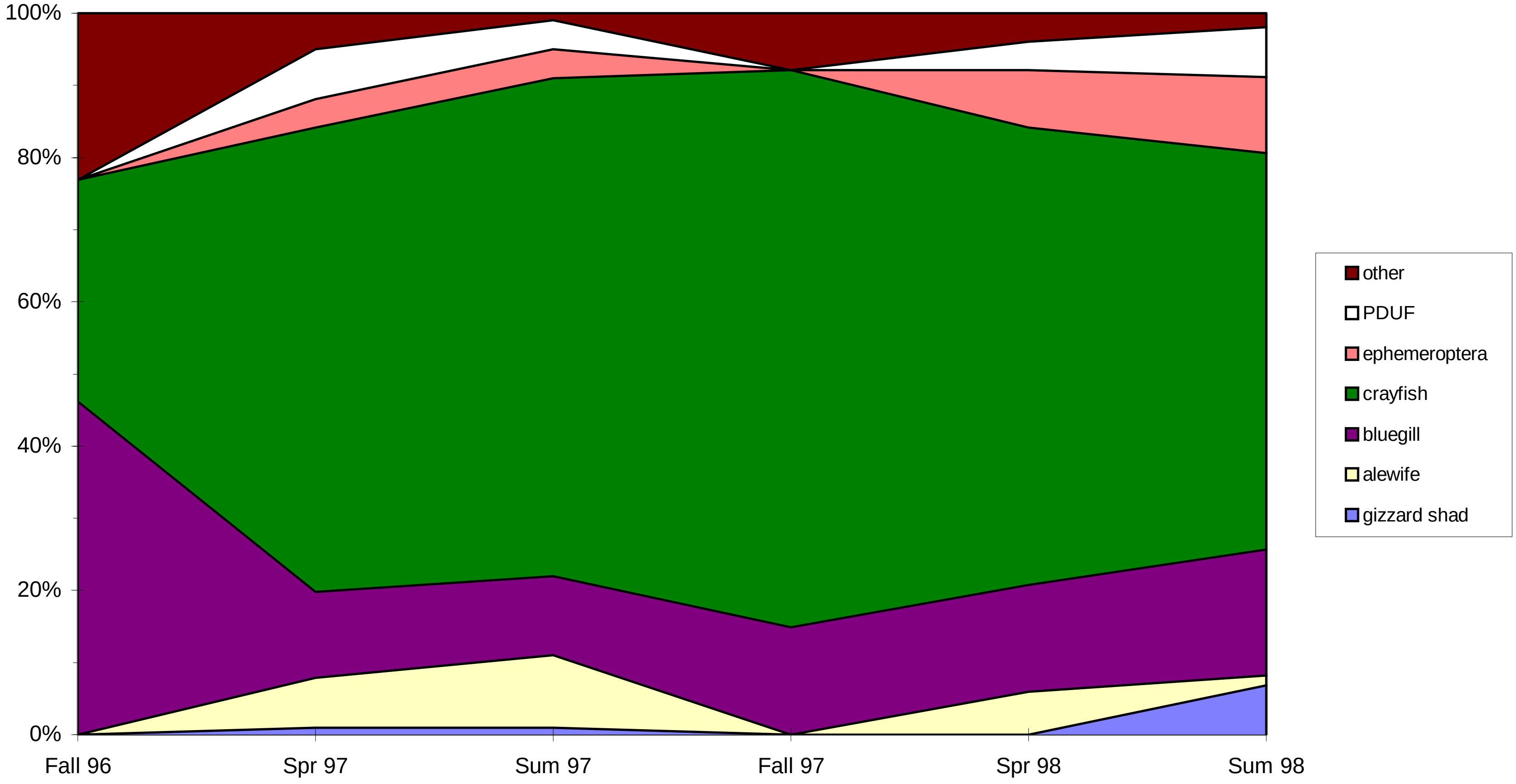

Figure 6. Mean percentage composition by weight of stomach contents of smallmouth bass collected from Claytor Lake, October 1996 - September 1998. “PDUF” = Partially Digested Unidentifiable Fish.

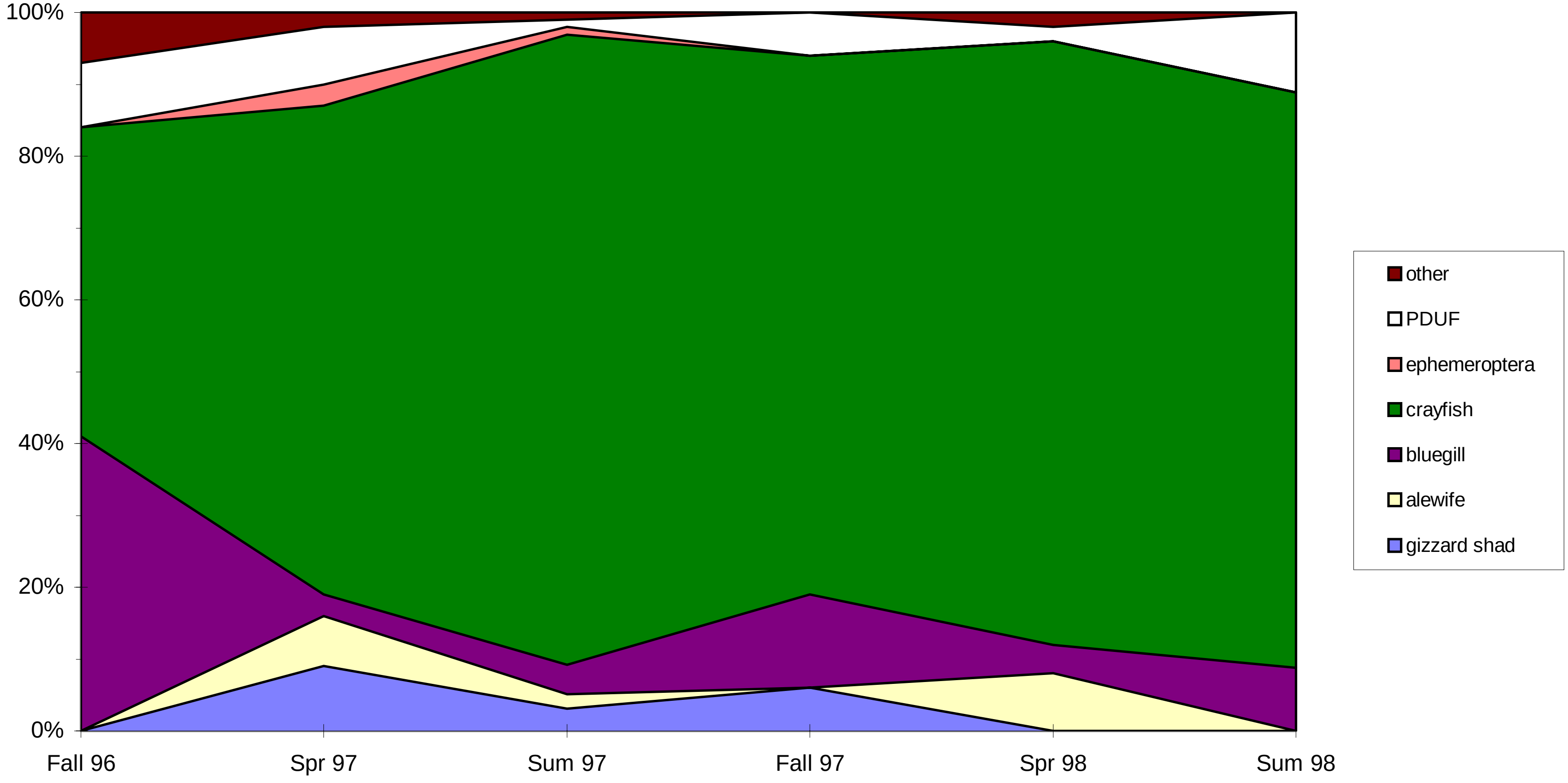

Figure 7. Mean percentage composition by weight of stomach contents of spotted bass collected from Claytor Lake, October 1996 - September 1998. "PDUF" = Partially Digested Unidentifiable Fish.

Fall 1996, but less than 15 % for the remainder of the study. Gizzard shad never comprised more than 10 % of the spotted bass diet. Prey items observed less often were alewives, PDUF, young-of-year and juvenile black basses, rock bass, aquatic insects (*Hexegenia* sp.), and terrestrial vertebrates (Reptilia).

Annual consumption of gizzard shad by Claytor Lake piscivores

Gizzard shad were slightly more important than alewives to the year-round diets of striped bass, comprising approximately half of the striped bass diet on an annual basis (Table 2). Annual consumption of gizzard shad by hybrid striped bass rose from over a quarter of the diet in the first year to nearly 40 % in Year 2, but was second to alewife in importance. Walleye consumed half as much gizzard shad in Year 2 (12 %) than in Year 1 (26 %), averaging nearly 20 % for both years. Alewives were the most important item in the walleye diets, accounting for an average of over two-thirds of the annual walleye diet. Largemouth bass consumed as much mean weight of gizzard shad per individual fish as hybrid striped bass and walleye in Year 1, but only seven percent of the second year's diet consisted of shad. Mean annual consumption of alewives by largemouth bass was slightly higher (18.5 %) than gizzard shad (16.4 %). Both smallmouth and spotted bass diets averaged less than three percent gizzard shad and less than ten percent alewives on an annual basis.

Statistical Comparisons of Diet Composition Data

Between years within species, by season

Within each piscivore species, percent gizzard shad consumption was similar among Fall 1996 and Fall 1997 seasons (Table 3; $P > 0.32$). Both largemouth and spotted bass contained greater amounts of shad in Spring 1997 than Spring 1998 (Table 3; $P < 0.039$). For both species, percent gizzard shad consumption decreased (21 % - 1 % for largemouth; 9 % - 0 % for spotted) from the first to the second spring sampling period. Hybrid striped bass did not contain significantly different amounts of shad among spring seasons, but the marginal P-value ($P = 0.062$) suggests that a reduction in mean gizzard shad consumption from 15 % in Spring 1997 to 0 % in Spring 1998 might reflect a true change. Most worthy of noting were the differences between summer gizzard shad consumption within four of the six sportfish. Moronids and smallmouth bass displayed

Table 2. Mean percentage composition of gizzard shad in the diets of Claytor Lake piscivores on an annual basis, October 1996 – September 1998. Annual consumption of alewives over the same period is included for comparative purposes.

	Oct. 1996 – Sept. 1997		Oct. 1997 – Sept. 1998		Annual Mean	
Piscivore	Gizzard	Alewife	Gizzard	Alewife	Gizzard	Alewife
Striped bass	45.4	45.9	53.8	44.6	50.3	45.3
Hybrid striped bass	25.8	60.2	38.3	54.8	32.1	57.5
Walleye	25.5	66.4	12.1	66.5	18.8	66.5
Largemouth bass	25.8	14.7	6.9	22.2	16.4	18.5
Smallmouth bass	1.8	8.1	3.9	7.8	2.9	8.0
Spotted bass	3.9	5.3	1.3	8.9	2.6	7.1

Table 3. P - values from Wilcoxon's Rank Sum Test of percent by weight gizzard shad consumption within species and between corresponding seasons of alternate years. P - values less than 0.05 were considered significantly different.

Species	Fall 1996 vs. Fall 1997	Spring 1997 vs. Spring 1998	Summer 1997 vs. Summer 1998
Striped bass	0.329	0.831	**0.0003**
Hybrid striped bass	0.518	0.062	**< 0.0001**
Walleye	0.591	1.000	0.113
Largemouth bass	0.493	**0.0002**	**0.020**
Smallmouth bass	1.000	0.450	**0.020**
Spotted bass	0.366	**0.039**	0.383

increases in second summer shad consumption over summer 1997 ($P < 0.020$). Walleye consumed similar amounts of shad among summer seasons ($P = 0.113$), and largemouth bass consumed less gizzard shad in summer 1998 than in summer 1997 ($P = 0.020$).

Within species over three seasons

Stomach Fullness Index (SFI) was used to compare relative amounts (mg shad/g predator) of shad and total prey items eaten by each piscivore among the three seasons (Table 4) because percent composition alone can be misleading. The SFI differentiates between piscivore feeding intensities by including empty predator stomachs in the calculations. For example, striped bass ate approximately 60 % gizzard shad in both Fall 1996 and Summer 1998 but during the former period, striped bass empty stomachs were nearly twice as common (60 % empty) than during the latter time period (32 %). When comparing shad consumption between the same two seasons using SFI, striped bass contained almost four times as much shad during Summer 1998 (23.15 mg/g) than Fall 1996 (6.26 mg/g). Although diet composition was similar on a percentage basis, differences in feeding intensity on gizzard shad were illustrated using SFI. The following statistical comparisons were made between shad and total SFI values for each season within species and years.

No significant differences in shad SFI values over seasons were found for all black bass species in either years (Table 4). Significant differences in total prey contents were found in Year 1 for smallmouth and spotted bass. The low incidence of empty stomachs (19 %) in Fall 1996 resulted in the high total SFI value for that season (18.28 mg/g).

All three pelagic piscivores contained different amounts (mg/g) of gizzard shad among seasons within years of the study (Table 4). Striped bass shad SFI values were higher in the summer and fall of the second ($P = 0.0003$) year. Striped bass contained greater amounts of shad (23.15 mg/g) and total prey items (27.7 mg/g) in the second summer of the study than did any piscivore in any season. Striped bass fed intensively in the fall months of the first year (total SFI = 8.14 mg/g), but fed the least in the fall of the second year (total SFI = 4.30 mg/g).

Hybrid striped bass demonstrated only marginally significant ($P = 0.045$) differences in shad SFI values among seasons of the first year of the study, but inter-

Table 4. Comparison between seasonal Stomach Fullness Index (SFI) values within study years and species (Kruskal - Wallis Test, alpha = 0.05). Kruskal - Wallis Test P - values are given as well as mean SFI values (mg prey/g predator) for both shad and total prey items. Mean SFI values followed by the same letters indicate no statistically significant difference (Tukey - Kramer HSD, alpha = 0.05).

	Year 1			Year 2		
Species	Fall 1996	Spring 1997	Summer 1997	Fall 1997	Spring 1998	Summer 1998
Striped bass						
P – value (shad)		0.055			**< 0.001**	
mean shad SFI	6.26a	0.85a	0.89a	3.69ab	0.15a	23.15b
P – value (total)		0.473			**0.017**	
Total SFI	8.33a	3.78a	6.04a	4.30a	11.84ab	27.70b
Hybrid striped bass						
P – value (shad)		**0.045**			**0.017**	
mean shad SFI	1.62a	0.36a	0.63a	2.79a	0a	7.24a
P – value (total)		0.103			**0.002**	
Total SFI	2.58a	5.18a	5.26a	3.57a	8.0ab	11.17b
Walleye						
P – value (shad)		**0.006**			0.079	
mean shad SFI	2.66a	0b	0.29b	2.25a	0a	0.13a
P – value (total)		0.603			**0.040**	
Total SFI	5.25a	6.77a	6.78a	6.37ab	11.44a	3.70b
Largemouth bass						
P – value (shad)		0.604			0.752	
mean shad SFI	1.0a	2.50a	1.96a	0a	0.75a	0.05a
P – value (total)		0.954			0.843	
Total SFI	8.40a	8.41a	7.90a	8.21a	10.77a	11.12a
Smallmouth bass						
P – value (shad)		0.852			0.075	
mean shad SFI	0a	0.05a	0.10a	0a	0a	0.94a
P – value (total)		**0.008**			0.548	
Total SFI	18.28a	8.98b	8.26b	7.65a	11.51a	12.84a
Spotted bass						
P – value (shad)		0.593			0.091	
mean shad SFI	0a	1.29a	0.80a	1.23a	0a	0a
P – value (total)		**0.012**			0.267	
Total SFI	13.54ab	7.87a	15.57b	8.61a	15.71a	18.92a

seasonal differences in shad consumption were found in the second year ($P = 0.017$). Hybrid stripers contained higher amounts of shad in both summer (7.24 mg/g) and fall (2.79 mg/g) than spring (0 mg/g) of Year 2. Over 70 % of the hybrid stripers collected in fall months contained empty stomachs compared with spring and fall when approximately 40 % were empty. This contributed to the low total SFI values reported for the fall months (Table 4).

Mean walleye shad SFI values were different among seasons within the first year ($P = 0.006$). Walleye contained greater amounts of shad during fall months than in either spring or summer. No differences were found among seasons in shad SFI for walleye in the second year; however, the low P-value (0.079) suggests a difference of biological importance. Walleye in Fall 1997 exhibited a mean shad SFI of 2.25 mg/g compared to 0 mg/g in Spring 1998 and 0.13 mg/g Summer 1998. Feeding intensity on all prey items by walleye was similar between seasons during the first year as indicated by the low variability in total SFI values. In Year 2, high incidences of empty stomachs resulted in a low total SFI in Summer 1998 (3.70 mg/g) which was significantly different from the Spring 1998 total SFI of 11.44 mg/g.

Since SFI may be interpreted as intensity of feeding, a simple comparison of shad SFI values for each piscivore pooled over the entire study reveals that striped bass > hybrid striped bass > walleye > largemouth bass > smallmouth bass = spotted bass for gizzard shad.

Differences Among Species

Schoener's trophic overlap index was used to compare seasonal piscivore diets between each species in each of the three seasons over two years (Table 5). Diet overlap indices over 0.6, which may indicate interactions between predator populations (Zaret and Rand 1971), occurred regularly in comparisons between the pelagic piscivores as well as between smallmouth bass and spotted bass. High diet overlap (≥ 0.7) between striped bass and hybrid striped bass was observed in all seasons. Comparisons of seasonal diets between walleye and both moronid species revealed significant overlap in every season except Summer 1998 when most captured walleye had empty stomachs. Diets of small

Table 5. Schoener's trophic overlap values. Values greater than 0.60 are considered to indicate significant diet overlap.

Species Comparison	Fall 1996	Spring 1997	Summer 1997	Fall 1997	Spring 1998	Summer 1998
largemouth bass x smallmouth bass	0.46	0.55	0.45	0.27	**0.82**	0.56
largemouth bass x spotted bass	**0.83**	0.56	0.35	0.26	**0.64**	0.45
largemouth bass x striped bass	0.25	0.39	0.27	0	0.25	0.19
largemouth bass x hybrid striped bass	0.38	0.54	0.43	0.17	0.23	0.26
largemouth bass x walleye	0.21	0.34	0.30	0.04	0.26	0.21
smallmouth bass x spotted bass	**0.61**	**0.87**	**0.80**	**0.88**	**0.76**	**0.71**
smallmouth bass x striped bass	0.07	0.18	0.27	0	0.13	0.22
smallmouth bass x hybrid striped bass	0.19	0.26	0.39	0.19	0.12	0.34
smallmouth bass x walleye	0.02	0.14	0.26	0.04	0.15	0.29
spotted bass x striped bass	0.16	0.25	0.16	0.06	0.12	0.08
spotted bass x hybrid striped bass	0.28	0.34	0.21	0.28	0.14	0.15
spotted bass x walleye	0.11	0.16	0.13	0.17	0.12	0.09
striped bass x hybrid striped bass	**0.87**	**0.85**	**0.83**	**0.70**	**0.79**	**0.72**
striped bass x walleye	**0.74**	**0.79**	**0.81**	**0.82**	**0.86**	0.49
hybrid striped bass x walleye	**0.70**	**0.70**	**0.72**	**0.62**	**0.91**	0.59

smallmouth bass and spotted bass significantly overlapped in all seasons as crayfish dominated over other prey items. Largemouth bass overlapped significantly (> 0.6) with smallmouth bass in Spring 1998 and spotted bass in Spring 1998 and Fall 1996. In all three cases, crayfish and bluegill dominated the black bass diets. No significant diet overlaps were found in any season between all combinations of black bass versus pelagic piscivores.

Comparison of Historic Piscivore Diets Versus This Study

Claytor Lake sportfish were collected for seasonal diet composition analysis from fall 1977 through summer 1979, when gizzard shad were not present in Claytor Lake, to quantify alewife utilization as a forage fish (Kohler 1980). Percentage contributions of major prey items to the seasonal sportfish diets from Kohler's (1980) research were compared to corresponding food items from this study (Tables 6 – 8). Several factors prevented any statistical comparisons of diet composition data between the two studies. In the previous study, sportfish sample sizes were usually much smaller (often < 10 stomachs containing food items per season), seasonal diet composition data were pooled for both years, and diet composition was determined by percent volume. However, major differences in diet composition between the two projects were apparent. No pre-gizzard shad diet data were available for hybrid striped bass.

Striped bass

Striped bass fed on alewife in every season to the near exclusion of alternative forage in the late 1970s. Alewife still provided a dominant prey source for striped bass after gizzard shad establishment, accounting for approximately three-quarters of striped bass diet in spring months of 1997 and 1998, and greater than 65 % in summer 1997. Gizzard shad, and to a lesser extent mayfly nymphs, supplanted alewife consumption by striped bass during fall periods 1996 - 1997 and summer 1998.

Walleye

Throughout both studies, walleye consumed alewives in similar proportions. Walleye fed upon alewives almost exclusively during the spring months of both studies. Summer alewife consumption by walleye was also consistent between the two studies, accounting for approximately two-thirds of walleye diets. In addition, both studies

Table 6. Comparison of historic piscivore diet composition (percent by volume) versus this study (percent by weight) during spring months. Diet data were pooled between years for each study. "Ale" = alewife, "GS" = gizzard shad, "Y. Perch" = yellow perch, "Ephem" = ephemeroptera larvae, "PDUF" = partially digested unidentified fish. In parentheses, number of fish containing food.

	Food Item								
Piscivore	Ale	GS	Sunfish	Crappie	Crayfish	Y. Perch	Ephem	PDUF	Other
striped bass									
1977-1979 (4)	100								
1996-1998 (41)	77	8	4		1		5	2	3
walleye									
1977-1979 (19)	93			3		4			
1996-1998 (33)	82		4					14	
largemouth bass									
1977-1979 (6)			44		37	19			
1996-1998 (181)	19	11	14		37		4	11	4
smallmouth bass									
1977-1979 (17)	76				24				
1996-1998 (150)	7	1	13		65		6	4	4
spotted bass									
1977-1979 (6)					77	23			
1996-1998 (119)	8	5	3		76		1	5	2

Table 7. Comparison of historic piscivore diet composition (percent by volume) versus this study (percent by weight) during summer months. Diet data were pooled between years for each study. “Ale” = alewife, “GS” = gizzard shad, “Y. Perch” = yellow perch, “Ephem” = ephemeroptera larvae, “PDUF” = partially digested unidentified fish. In parentheses, number of fish containing food.

					Food Item				
Piscivore	Ale	GS	Sunfish	Crappie	Crayfish	Y. Perch	Ephem	PDUF	Other
striped bass									
1977-1979 (3)	95			5					
1996-1998 (42)	45	35			4		9	7	
walleye									
1977-1979 (20)	67		12	5		14			2
1996-1998 (56)	66	13	8				7	6	1
largemouth bass									
1977-1979 (2)					100				
1996-1998 (104)	6	7	43		25		1	10	8
smallmouth bass									
1977-1979 (0)									
1996-1998 (220)	6	4	14		62		7	5	2
spotted bass									
1977-1979 (4)								100	
1996-1998 (93)	1	2	6		83		1	6	1

Table 8. Comparison of historic piscivore diet composition (percent by volume) versus this study (percent by weight) during fall months. Diet data were pooled between years for each study. “Ale” = alewife, “GS” = gizzard shad, “Y. Perch” = yellow perch, “Ephem” = ephemeroptera larvae, “PDUF” = partially digested unidentified fish. In parentheses, number of fish containing food.

					Food Items				
Piscivore	Ale	GS	Sunfish	Crappie	Crayfish	Y. Perch	Ephem	PDUF	Other
striped bass									
1977-1979 (4)	100								
1996-1998 (41)	39	50	3					8	
walleye									
1977-1979 (13)	30		35	26					9
1996-1998 (113)	39	33	3					25	
largemouth bass									
1977-1979 (8)			33	6	2	59			
1996-1998 (27)	3	3	66		20			3	5
smallmouth bass									
1977-1979 (3)				70	30				
1996-1998 (31)			13		80				7
spotted bass									
1977-1979 (1)						100			
1996-1998 (29)		3	27		59			7	4

experienced a decrease in the importance of alewives in the fall diets of walleye. The differences in the seasonal diets of walleye were manifest in the contributions of other prey items. Gizzard shad, which constituted roughly a third of fall and up to 20 % of summer walleye diets, replaced white bass, crappie, and yellow perch (*Perca flavescens*) that were collected from walleye stomachs two decades ago. Bluegill was a minor component of walleye diets in both studies except for fall months 1977 – 1979 when this prey species accounted for 35 % of the walleye diet.

Largemouth bass

Bluegill and crayfish were responsible for 44 and 36 %, respectively, of largemouth bass diets in spring months 1978 and 1979; yellow perch accounted for the remaining 20 %. The mean crayfish component of spring 1997 and 1998 largemouth bass diets was 37 %, remaining unchanged from the previous study. The proportion of spring bluegill consumption has decreased from 44 % to 14 % while alewife and gizzard shad each now comprised 20 % of the diet. No yellow perch were found in largemouth bass sampled during spring of the more recent study.

Only two largemouth bass were sampled during the summer period of the previous study and both contained crayfish. Crayfish accounted for approximately a quarter of the summer largemouth diet in this study while bluegill dominated in importance over the remaining prey items (Figure 5).

Yellow perch dominated the fall 1978 - 1979 largemouth bass diet, accounting for almost 60 % of food items collected, followed by bluegill (33 %), crappie (7 %), and crayfish (2%). In fall 1996 and 1997, no yellow perch or crappie were found in largemouth bass stomachs, bluegill consumption doubled to an average of 66 %, and crayfish consumption increased to an average of nearly 21 percent. Age-0 black bass and clupeid species contributed in small quantities (11 and 12 %, respectively) to the 1996 fall largemouth bass diet.

Smallmouth bass

Alewife constituted three-quarters and crayfish made up one-fourth of the spring 1978 - 1979 smallmouth bass diet. Spring alewife consumption has since decreased to an average of 7 % while crayfish has risen to become the most important prey item, accounting for nearly two-thirds of the spring smallmouth bass diet. My study revealed a spring smallmouth diet consisting of more types of prey species (Figure 6).

No smallmouth bass were sampled during the summer months of the 1970s study, preventing any comparisons of diet composition. Only three smallmouth bass containing food items were collected in the fall period of the previous study. Crappie constituted greater than two-thirds of the fall smallmouth bass diet followed with crayfish accounting for almost a third. No crappie were found in fall smallmouth bass stomachs of this study, and crayfish consumption increased to an average of 80 %. Age-0 black bass also appeared in low quantities (< 10 %) in the fall 1996 - 1997 smallmouth bass diet.

Spotted bass

Spring consumption of crayfish by spotted bass has changed very little as this food item accounted for approximately three-fourths of this predator’s diet in both studies. In the former study, yellow perch were the only other food item collected from spotted bass in the spring period. No yellow perch were found in spotted bass stomachs during spring 1997 - 1998. Figure 7 illustrates the more varied spring diet composition of this study.

All four spotted bass with food items that were sampled during the summer of the previous study contained PDUF. Over 80 percent of the summer spotted bass diet from this study consisted of crayfish. A variety of other food items was also consumed (Figure 7).

Only one spotted bass containing food was sampled during the fall periods of the previous study. That fish had consumed yellow perch. No yellow perch were collected from spotted bass during the fall months of 1996 and 1997. These fish mostly contained crayfish and bluegill (Figure 7).

Predator-Prey Length Relationships

Relationships between sizes of gizzard shad consumed and sizes of predator species were determined for samples of those species whose stomachs contained more than 35 shad in total during the two year study. Both smallmouth bass and spotted bass failed to meet this requirement. Because the three pelagic predators utilized gizzard shad as prey to a greater extent than did the black basses, a breakdown of seasonal diet composition by predator size was calculated for both moronids and walleye. The three size categories of pelagic predator sizes were small (280 - 399 mm TL), intermediate (400 - 499 mm TL), and large ($\geq$ 500 mm TL).

A good relationship ($P < 0.0001$; $r^2 = 0.52$) existed between striped bass TL and consumed shad TL (Figure 8). Consumed gizzard shad total lengths increased with larger striped bass; however, shad sizes tended to be well below maximum lengths predicted by Jenkins and Morais (1978) from an analysis of predator throat diameter versus prey body depth. Smaller striped bass consumed shad that were 25 - 120 mm TL whereas intermediate and larger striped bass ate shad ranging in size from 50 - 200 mm TL.

Seasonal consumption of gizzard shad varied among striped bass size categories (Table 9). In Fall 1996 when age-0 shad were plentiful, the importance of shad to the diets of striped bass increased with predator size. In Fall 1997, when age-0 shad numbers were depressed, alewives made up the bulk of intermediate and large striped bass diets, and bluegill dominated the diet of the small stripers. In spring months, shad were large enough to be invulnerable as prey to all but the large striped bass. Alewives comprised the bulk of the spring striper diets for all size categories. The majority of the striped bass predation on shad in summer months was by striped bass < 400 mm TL when high numbers of small (20 – 70 mm TL) shad were available. The intermediate and large striped bass favored alewives during both summer seasons.

Hybrid stripers also demonstrated a positive linear relationship ($P < 0.0001$; $R^2 = 0.39$) between total lengths and consumed shad total lengths (Figure 9). Small hybrid stripers (250 - 400 mm TL) ate shad 20 - 130 mm TL; six of the 358 shad were greater than maximum sizes predicted by Jenkins and Morais (1978). Intermediate sizes of hybrid stripers consumed shad sizes slightly larger (50 - 140 mm TL) while large hybrid stripers preyed upon even bigger shad (75 - 200 mm TL).

As opposed to striped bass, hybrid stripers consumed shad in similar quantities for each size category during fall months (Table 10). But, like striped bass, most gizzard shad were consumed by large hybrids during the spring months and by small fish in the summer. Bluegill were a major component of the small hybrid diet in the Summer 1997, but were

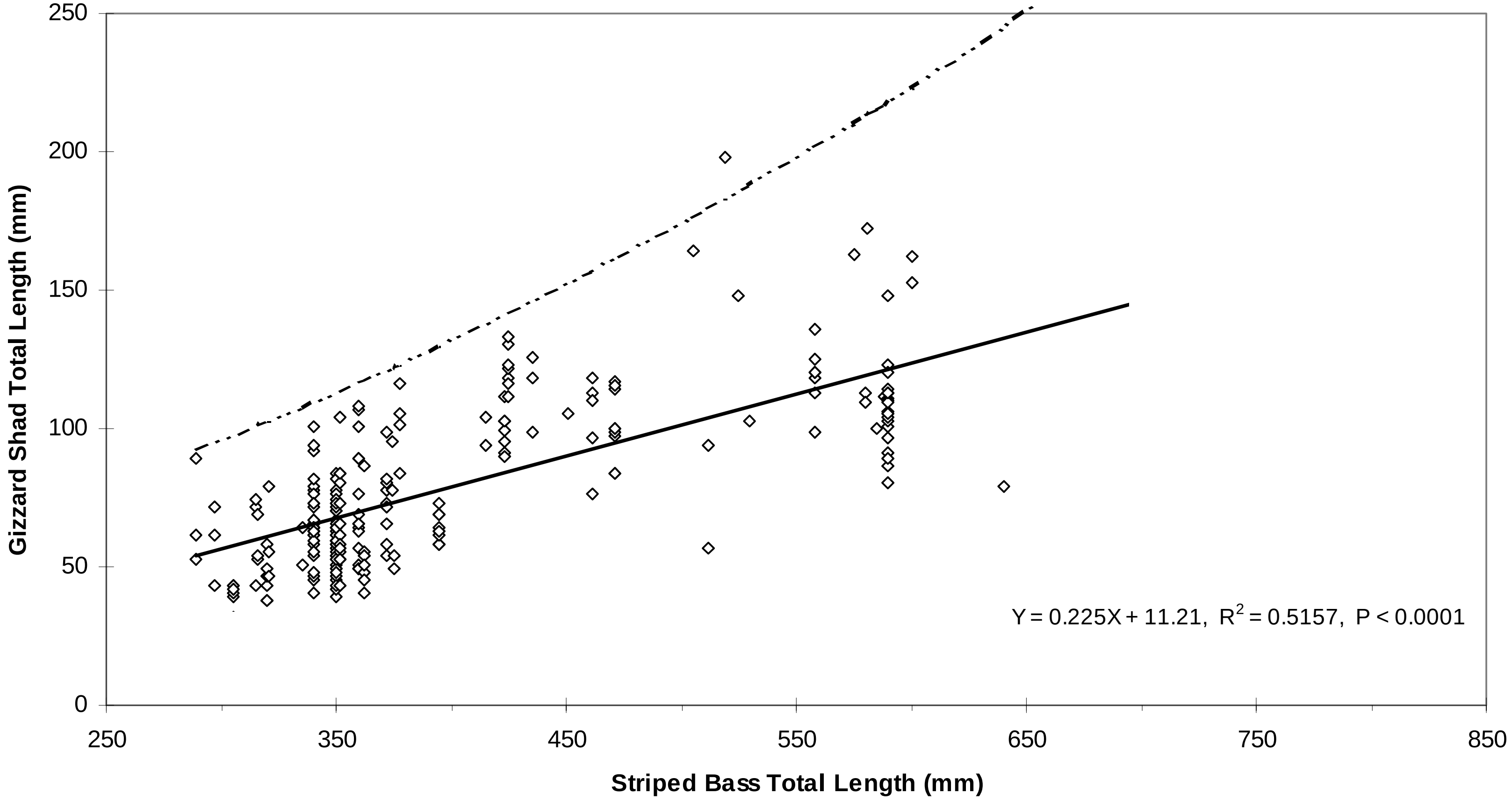

Figure 8. Relationship between sizes of gizzard shad consumed and sizes of striped bass. The dashed line represents the maximum estimated lengths of gizzard shad a striped bass could consume based on the calculations of Jenkins and Morais (1978).

Table 9. Mean percentage by weight of stomach contents of three size categories of striped bass collected from Claytor Lake, October 1996 – September 1998. Size categories are "small" (280 - 399 mm TL), "intermediate" (400 - 499 mm TL), and "large" (≥ 500 mm TL).

		Fall 1996			Spring 1997			Summer 1997	
Prey Item	Small	Intermediate	Large	Small	Intermediate	Large	Small	Intermediate	Large
N =	5	14	10	0	6	14	2	11	5
gizz shad	0	55	80		0	12	63	0	1
alewife	40	25	10		67	72	27	58	99
bluegill	20	7	0		0	0	0	0	0
crayfish	0	0	0		0	2	0	13	0
ephem	0	0	0		33	0	0	20	0
PDUF	40	12	10		0	7	10	9	0
other	0	0	0		0	0	0	0	0

		Fall 1997			Spring 1998			Summer 1998	
Prey Item	Small	Intermediate	Large	Small	Intermediate	Large	Small	Intermediate	Large
N =	15	1	2	6	3	5	20	3	3
gizz shad	13	0	0	0	0	20	76	0	33
alewife	7	100	100	83	67	80	19	25	67
bluegill	80	0	0	17	0	0	0	0	0
crayfish	0	0	0	0	0	0	0	7	0
ephem	0	0	0	0	0	0	5	43	0
PDUF	0	0	0	0	0	0	0	25	0
other	0	0	0	0	33	0	0	0	0

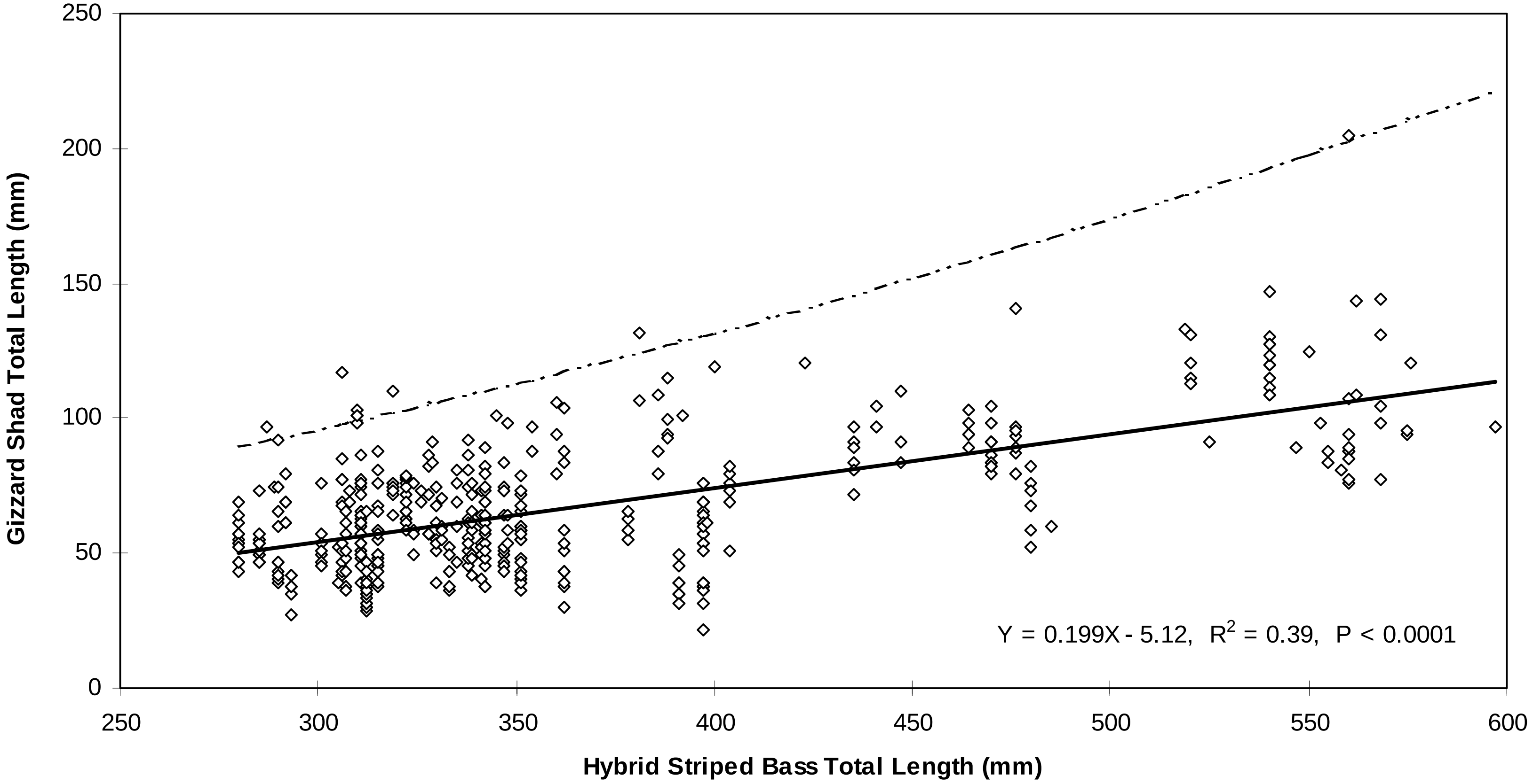

Figure 9. Relationship between sizes of gizzard shad consumed and sizes of hybrid striped bass. The dashed line represents the maximum estimated lengths of gizzard shad a hybrid striped bass could consume based on the calculations of Jenkins and Morais (1978).

Table 10. Mean percentage by weight of stomach contents of three size categories of hybrid striped bass collected from Claytor Lake, October 1996 – September 1998. Size categories are “small” (280 - 399 mm TL), “intermediate” (400 - 499 mm TL), and “large” (≥ 500 mm TL).

	Fall 1996			Spring 1997			Summer 1997		
Prey Item	Small	Intermediate	Large	Small	Intermediate	Large	Small	Intermediate	Large
N =	7	4	16	3	0	12	24	23	43
gizz shad	54	50	46	0		18	16	4	3
alewife	29	0	20	68		64	29	45	61
bluegill	0	0	13	0		0	35	15	5
crayfish	0	50	14	8		9	0	14	11
ephem	0	0	0	0		8	13	13	13
PDUF	17	0	13	24		0	8	9	7
other	0	0	0	0		0	0	0	0

	Fall 1997			Spring 1998			Summer 1998		
Prey Item	Small	Intermediate	Large	Small	Intermediate	Large	Small	Intermediate	Large
N =	16	7	12	7	1	9	56	27	26
gizz shad	50	51	28	0	0	0	61	9	1
alewife	0	34	40	86	100	99	12	37	45
bluegill	38	0	8	0	0	0	4	2	1
crayfish	0	0	5	14	0	0	5	8	3
ephem	0	0	0	0	0	0	10	44	35
PDUF	12	14	11	0	0	1	8	0	15
other	0	0	8	0	0	0	0	0	0

replaced by gizzard shad the next summer when age-0 shad were more abundant. Alewives were an important prey item for all size categories of hybrid stripers in each season.

A very poor relationship ($P = 0.013$; $R^2 = 0.08$) existed between walleye total lengths and ingested gizzard shad total lengths. Small walleye ate similar sizes of shad (70 – 145 mm TL) that intermediate and large walleye preyed upon (Figure 10). Estimated lengths of gizzard shad walleye could consume based on the calculations of Jenkins and Morais (1978) were poor predictors of actual ingested total lengths observed in this study. Over half of the shad consumed by walleye in this study were longer than predicted maximum lengths.

Walleye exhibited less variability in seasonal shad consumption among size categories. All sizes of walleye preyed upon shad in similar amounts (approximately a third of the diet) during fall months (Table 11). No shad were collected from any walleye during spring months when alewife almost completely monopolized the diet composition. A small amount (29 % of the diet) of shad were consumed by intermediate sized walleye in Summer 1998, but alewives were the dominant prey item in each size category for both summer seasons.

Largemouth bass consumed larger shad as their total lengths increased (Figure 11). Most gizzard shad consumed by largemouth bass were 80 - 160 mm TL, although a few shad were eaten as small as 23 mm TL and one as large as 239 mm TL. Out of the 57 gizzard shad consumed by largemouth bass in this study, three were larger than the maximum predicted lengths of Jenkins and Morais (1978).

Predator fish in Claytor Lake began feeding on gizzard shad when shad first grew to 20 mm TL. This occurred as late as mid-August in 1997 and as early as mid-July in 1998. Mean total lengths of consumed shad increased in successive months as age-0 shad grew larger (Figure 12). Claytor Lake piscivores continued to prey on this same cohort of shad throughout Fall and, in lesser quantities, into Spring until June when gizzard shad were almost totally absent from stomachs. Approximately 93 % of the shad collected in predator stomachs were age-0. About seven percent of the ingested shad were age-1 fish, and were almost exclusively from stomachs collected in spring months. The only age-2

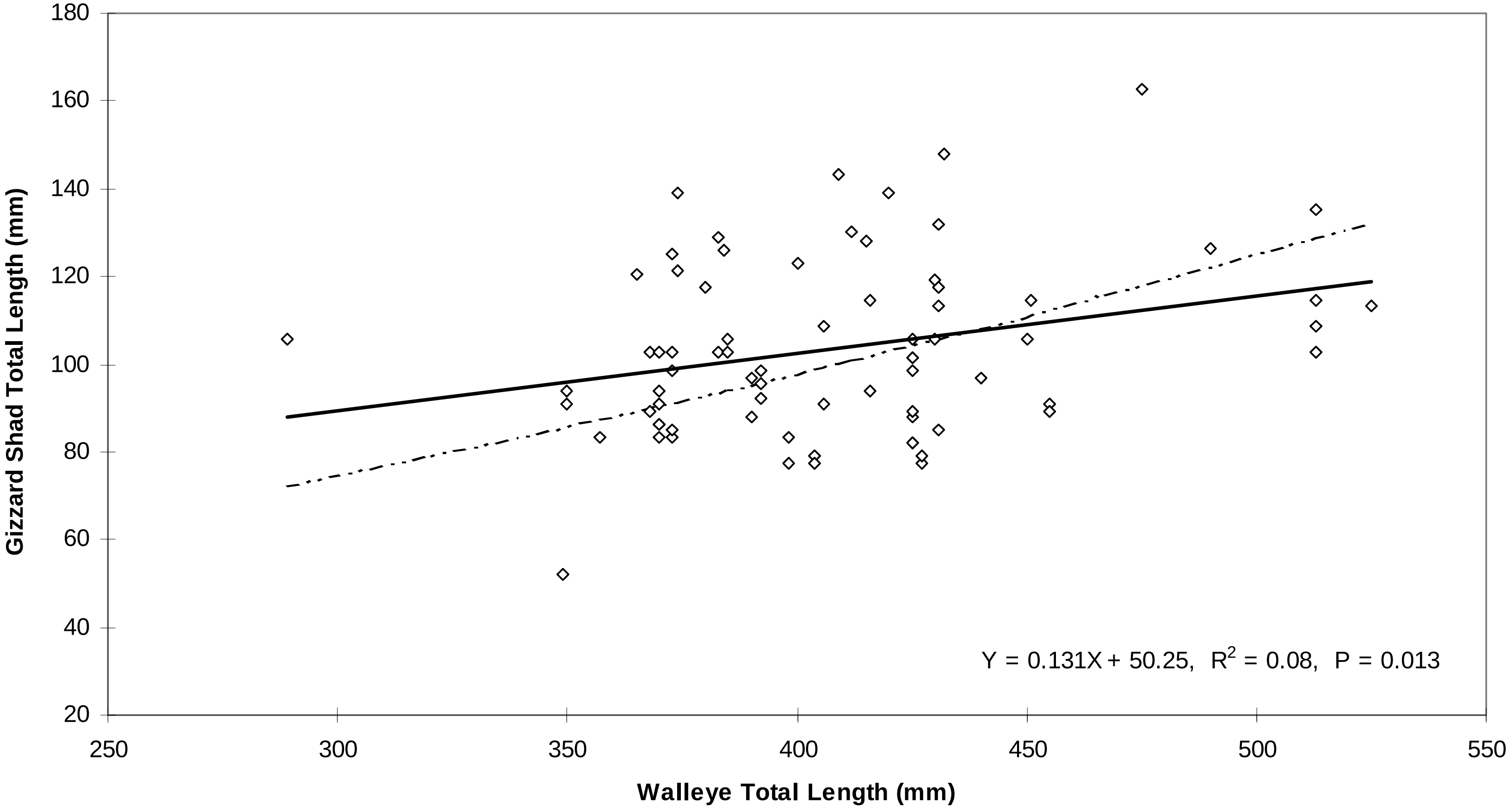

Figure 10. Relationship between sizes of gizzard shad consumed and sizes of walleye. The dashed line represents the maximum estimated lengths of gizzard shad a walleye could consume based on the calculations of Jenkins and Morais (1978).

Table 11. Mean percentage by weight of stomach contents of three size categories of walleye collected from Claytor Lake, October 1996 – September 1998. Size categories are “small” (280 - 399 mm TL), “intermediate” (400 - 499 mm TL), and “large” (≥ 500 mm TL).

	Fall 1996			Spring 1997			Summer 1997		
Prey Item	Small	Intermediate	Large	Small	Intermediate	Large	Small	Intermediate	Large
N =	15	23	6	5	5	1	34	8	0
gizz shad	38	43	0	0	0	0	6	0	
alewife	29	23	33	80	80	0	71	75	
bluegill	7	0	0	0	0	0	9	0	
crayfish	0	0	0	0	0	0	0	0	
ephem	0	0	0	0	0	0	3	0	
PDUF	27	34	67	20	20	100	9	25	
other	0	0	0	0	0	0	3	0	

	Fall 1997			Spring 1998			Summer 1998		
Prey Item	Small	Intermediate	Large	Small	Intermediate	Large	Small	Intermediate	Large
N =	43	18	5	3	6	2	2	7	1
gizz shad	26	39	38	0	0	0	0	29	0
alewife	60	28	60	100	100	50	100	43	95
bluegill	4	6	2	0	0	50	0	14	0
crayfish	0	0	0	0	0	0	0	0	0
ephem	0	0	0	0	0	0	0	14	5
PDUF	9	28	0	0	0	0	0	0	0
other	0	0	0	0	0	0	0	0	0

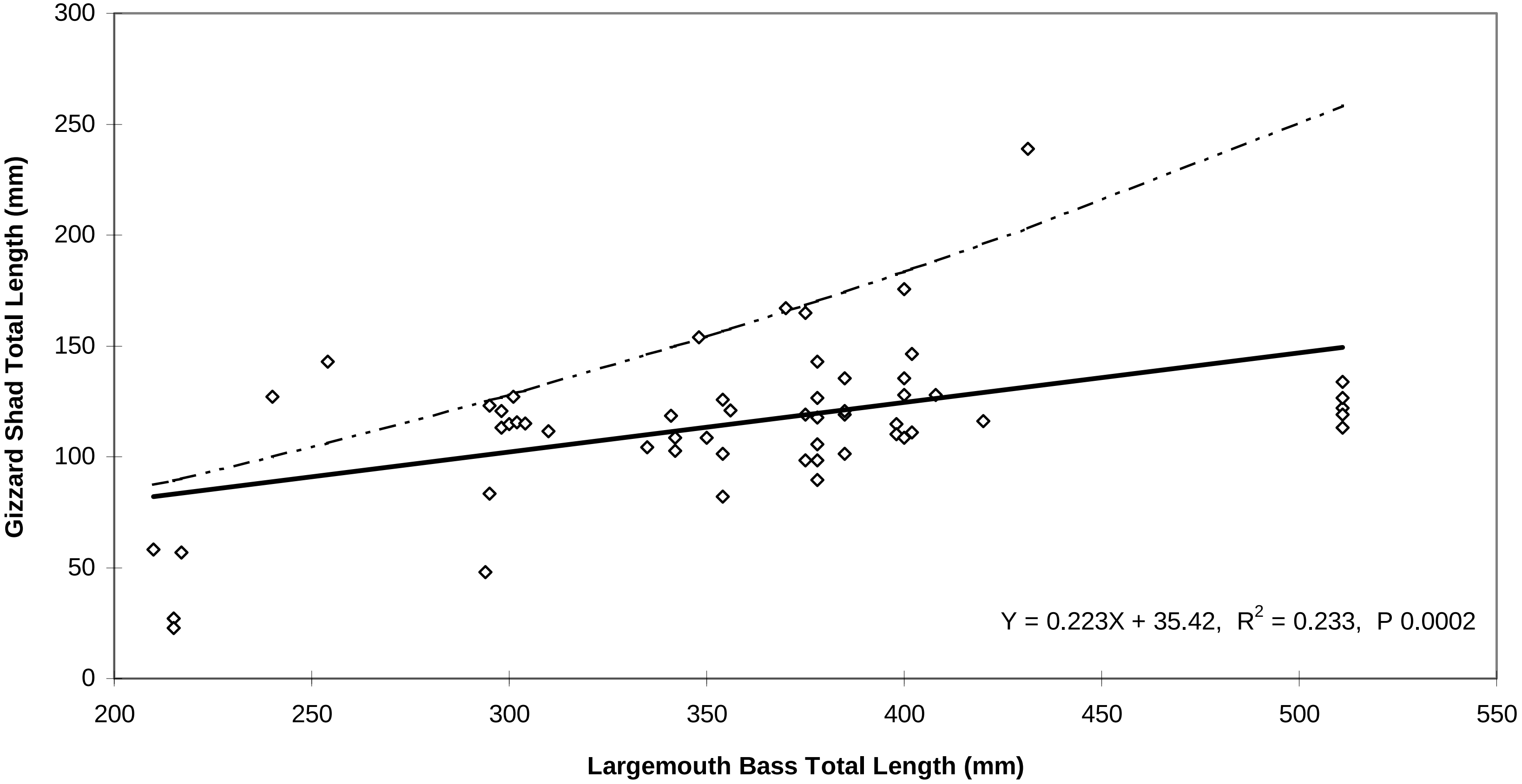

Figure 11. Relationship between sizes of gizzard shad consumed and sizes of largemouth bass. The dashed line represents the maximum estimated lengths of gizzard shad a largemouth bass could consume based on the calculations of Jenkins and Morais (1978).

shad found in stomach contents measured 239 mm TL and was collected from a 431 mm TL largemouth bass.

Gizzard Shad Population Characteristics

A sample (N = 1,218) of gizzard shad ranging in size from 89 - 400 mm TL was collected from Claytor Lake during both years using the horizontal experimental gill nets. Back-calculating mean lengths-at-ages from shad scale samples provided growth information. Claytor Lake gizzard shad reached an average total length of 155 mm (± 17.3 mm SD) by the end of their first growing season and 235 mm (± 20.5 mm SD) by age-2 (Table 12). Annual growth rates of gizzard shad were fast when compared with other reservoirs (Table 13). Shad were aged with otoliths up to age-7 (Figure 15). Ingested shad lengths differed greatly from lengths of shad removed from gill nets (Figure 14). The Index of Vulnerability (IOV) for shad collected with the clupeid gill nets was only 4.2. The IOV calculates the percentage of shad ≤ 203 mm TL in the sample (DiCenzo et al. 1996).

Experimental clupeid gill nets collected age-1 and older gizzard shad during both sampling seasons (Figure 13). No age-0 gizzard shad were collected during the first sampling season, and only twelve age-0 shad were collected in year two. Also worth noting is the decrease in CPUE of age-1 shad from 1997 (6.5 per net-night) to 1998 (0.1 per net-night). Percent annual mortality estimates calculated using catch-at-age regressions (Ricker 1975) averaged 66 % for adult (age 3 and older) gizzard shad in Claytor Lake between 1997 and 1998 compared to a mean of 62 % (range = 34 – 86 %) for adult gizzard shad in 15 Missouri reservoirs (Michaletz 1998).

Comparison of Predator Growth Rates Pre vs. Post Gizzard Shad

Previous to gizzard shad establishment in Claytor Lake, Kohler (1980) determined growth rates of striped bass, walleye, and all three black bass species, among others, collected from Claytor Lake in 1976 - 1978. Pre-gizzard shad growth data on hybrid striped bass were nonexistent because this sportfish was first introduced into Claytor Lake in 1992, after shad establishment. No individual fish, back-calculated lengths-at-age data were available from previous studies, only means, precluding any statistical comparisons of sportfish growth. Percent change in mean back-calculated lengths-at-age

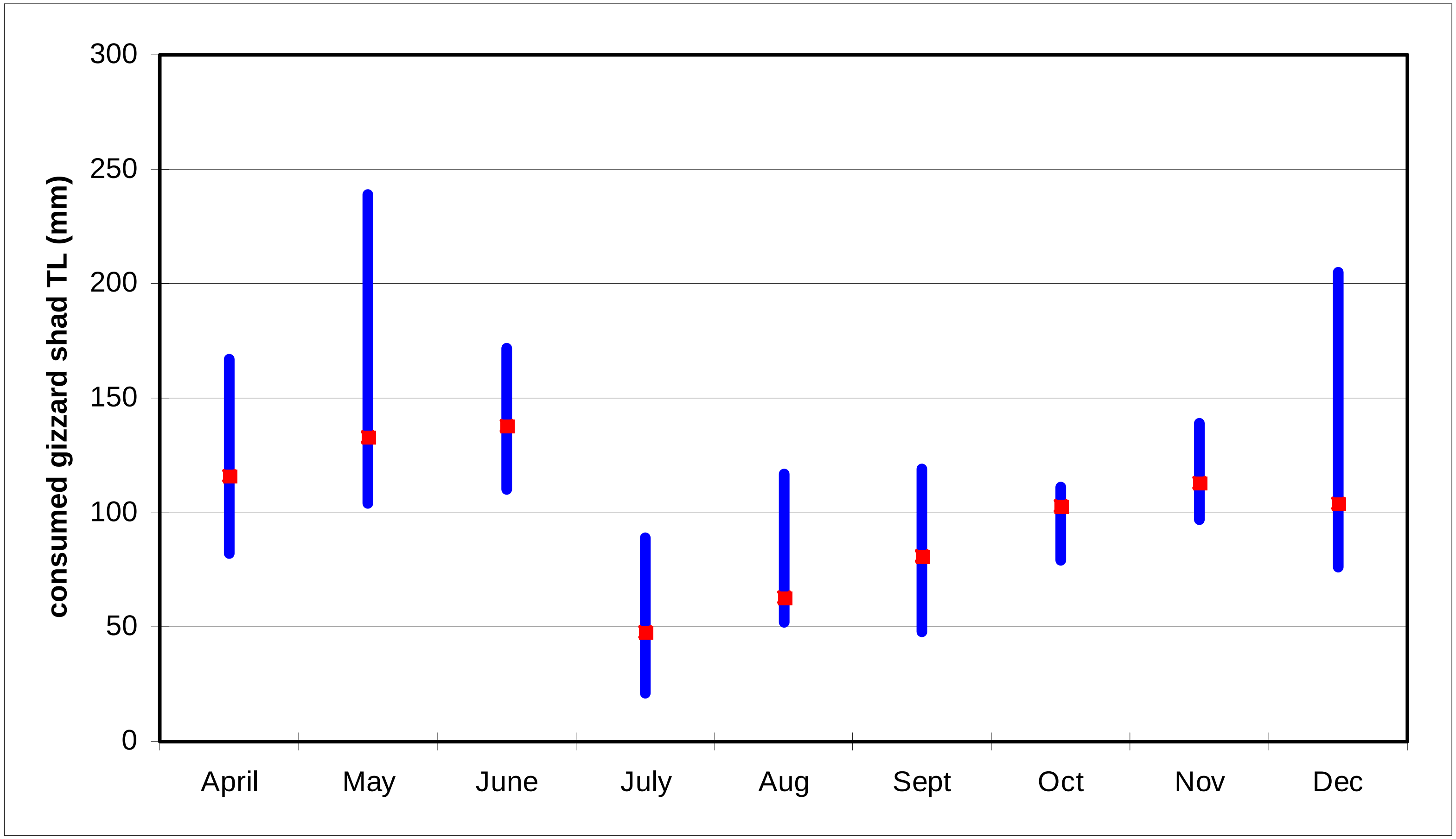

Figure 12. Sizes (TL mm) of gizzard shad consumed by Claytor Lake piscivores by month (both years combined). Blue bars represent the range of shad sizes consumed and the red squares represent the mean ingested shad length.

Table 12. Mean back-calculated total length (mm) at successive ages by age group of gizzard shad from Claytor Lake, 1997.

Age Class	N	I	II	III	IV	V	VI	VII
1	18	158						
2	38	158	244					
3	30	154	241	285				
4	42	152	224	270	301			
5	26	154	229	273	302	317		
6	2	148	250	285	320	337	348	
7	1	173	278	319	341	350	353	356
Weighted Mean TL		155	235	276	302	320	349	356
Standard deviation of mean TL		17.3	20.5	21.9	18.8	24.5	43.6	-
Mean Annual Increment of TL		155	80	41	26	18	29	7

Table 13. Back-calculated length-at-ages of gizzard shad in various waters.
* = mean back-calculated lengths-at-ages, pooled, for four oligo-mesotrophic ($\leq$ 7 mg/m^3 chlorophyll-*a*) Alabama reservoirs: Harding, Harris, Lewis Smith, and Tuscaloosa.
** = mean back-calculated lengths-at-ages, pooled, for six eutrophic ($\geq$ 8 mg/m^3 chlorophyll-*a*) Alabama reservoirs: Aliceville, Demopolis, Gainseville, Jones Bluff, Lay, and Weiss.

					Age			
Lake or Reservoir	Source	I	II	III	IV	V	VI	VII
Bull Shoals, MO	Michaletz 1998a	83	175	225				
Claytor, VA	**This study**	**155**	**235**	**276**	**302**	**320**	**349**	**356**
Clearwater, MO	Michaletz 1998a	120	193	210				
Elephant Butte, NM	Jester and Jensen 1972	94	151	183	219	254	273	291
** Eutrophic, AL	DiCenzo et al. 1996	123	183	189	208	279	285	
Harry S. Truman, MO	Michaletz 1998a	111	187	213				
Kerr, VA	Banach 1991	104	160	201	234	255	264	264
Erie, OH	Bodola 1965	140	279	324	354	368		
Lake of the Ozarks, MO	Michaletz 1998a	118	156	198				
Long Branch, MO	Michaletz 1998a	126	172	186				
Mark Twain, MO	Michaletz 1998a	114	170	202				
Montrose, MO	Michaletz 1998a	118	152	192				
Norfolk, MO	Michaletz 1998a	95	204	229				
* Oligo-mesotrophic, AL	DiCenzo et al. 1996	120	200	252	283	311	315	
Pomme de Terre, MO	Michaletz 1998a	86	151	191				
Smith Mountain, VA	Banach 1991	122	210	253	254	278	301	328

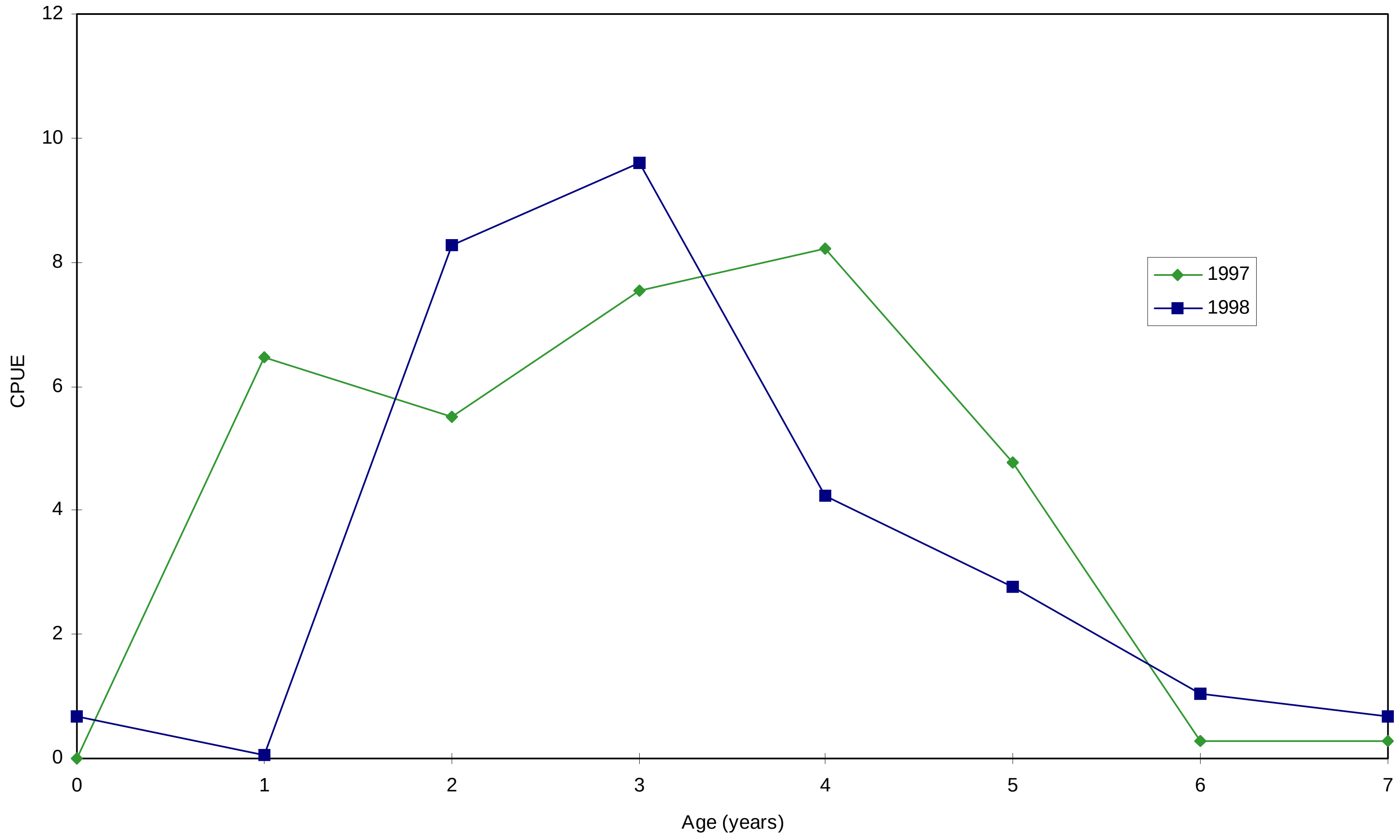

Figure 13. Mean CPUE (number/net night) of gizzard shad collected from shad nets set on Claytor Lake, Virginia, 1997 and 1998.

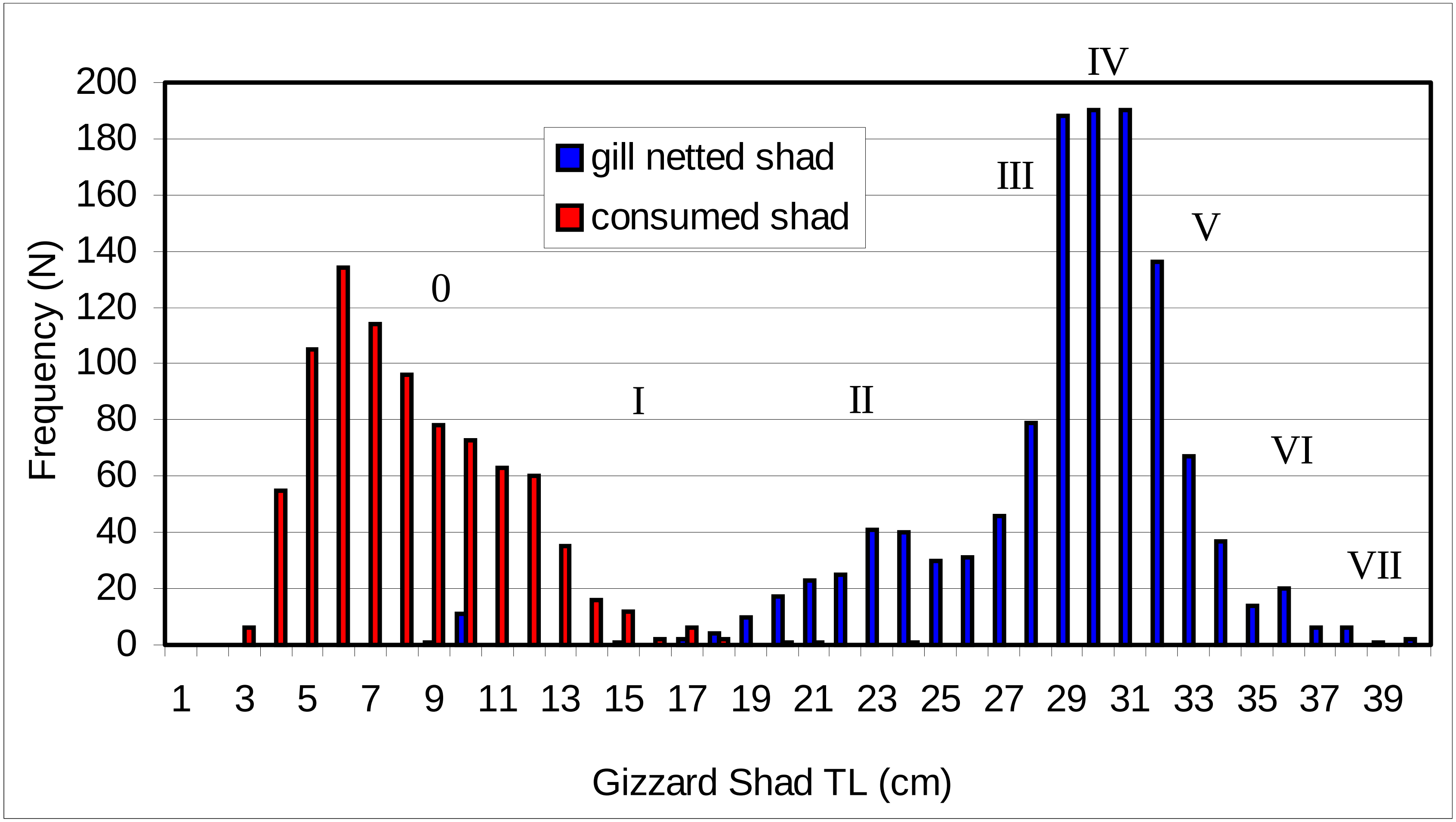

Figure 14. Length frequency distributions of sizes of gizzard shad collected with clupeid gill nets (May 1997 – October 1998) and from predator stomachs (October 1996 – September 1998) from Claytor Lake. Roman numerals represent age classes.

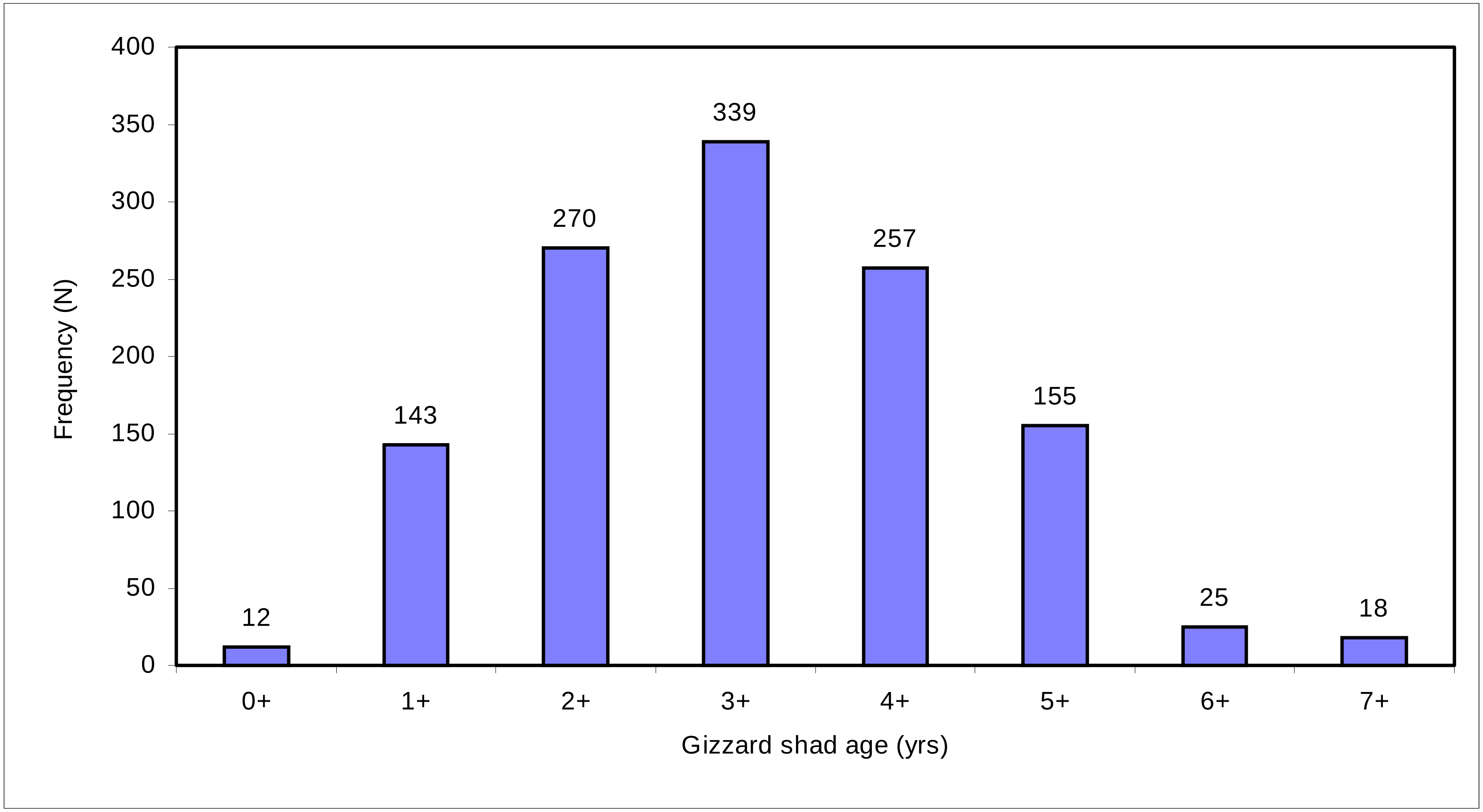

Figure 15. Numbers of gizzard shad caught at successive ages with clupeid gill nets from Claytor Lake, May – October, 1997 – 1998.

for fish collected in this study from those determined in the late 1970s (Kohler 1980) was used for comparisons of sportfish growth (Figure 16). Weighted mean lengths of combined age classes were compared instead of mean lengths at terminal annuli, at the risk of biases associated with “Lee’s Phenomenon” (Ricker 1975), because sample sizes of individual age classes were often not sufficient. The bias associated with “Lee’s Phenomenon” results from differential size-related mortality rates and could lead to underestimating lengths at older (> age-3) ages. Age-and-growth tables for each sportfish species are included in the appendix (Appendix Tables A1 - A6). In addition, incremental growth between back-calculated lengths-at-ages were compared to those calculated by Kohler (1980), previous to gizzard shad introduction (Figure 17). Incremental growth comparisons eliminate the possibility of one year’s growth characteristic carrying over and affecting the lengths at successive years. With incremental growth comparisons, each year is independent of the previous year’s growth.

Striped bass lengths-at-age have increased ($P < 0.05$) an average of 14.5 % for the first two years of growth (Figure 16; Appendix Table A1). Low sample sizes for ages 3 and older prevented the ability to statistically differentiate growth rates for those ages among the two studies. Claytor Lake striped bass appear to be growing at least as fast as striped bass in nearby Smith Mountain Lake, Virginia, as back-calculated lengths at ages 1-3, and 5 averaged 6 % longer for Claytor Lake fish.

Growth rates for walleye have improved ($P < 0.01$) 25.3 and 8.3 % for ages one and two, respectively (Figure 16; Appendix Table A3). Three-year old walleye exhibited similar growth rates ($P > 0.50$), but low sample sizes prevented an age-4 comparison.

All three species of black bass have experienced decreases in their growth rates since the late 1970s (Figure 16). Largemouth bass showed an average decrease ($P < 0.05$) of nearly 7 % in growth for the first four age classes (Appendix Table A4). Smallmouth bass growth for ages one and two have both declined ($P < 0.001$) nearly 18 %. Age-3 smallmouth bass growth has declined ($P < 0.001$) by 25 % while age 4 has decreased ($P < 0.001$) 29 %. Spotted bass growth has declined ($P < 0.001$) an average of 23.6 % for ages 1 - 5.

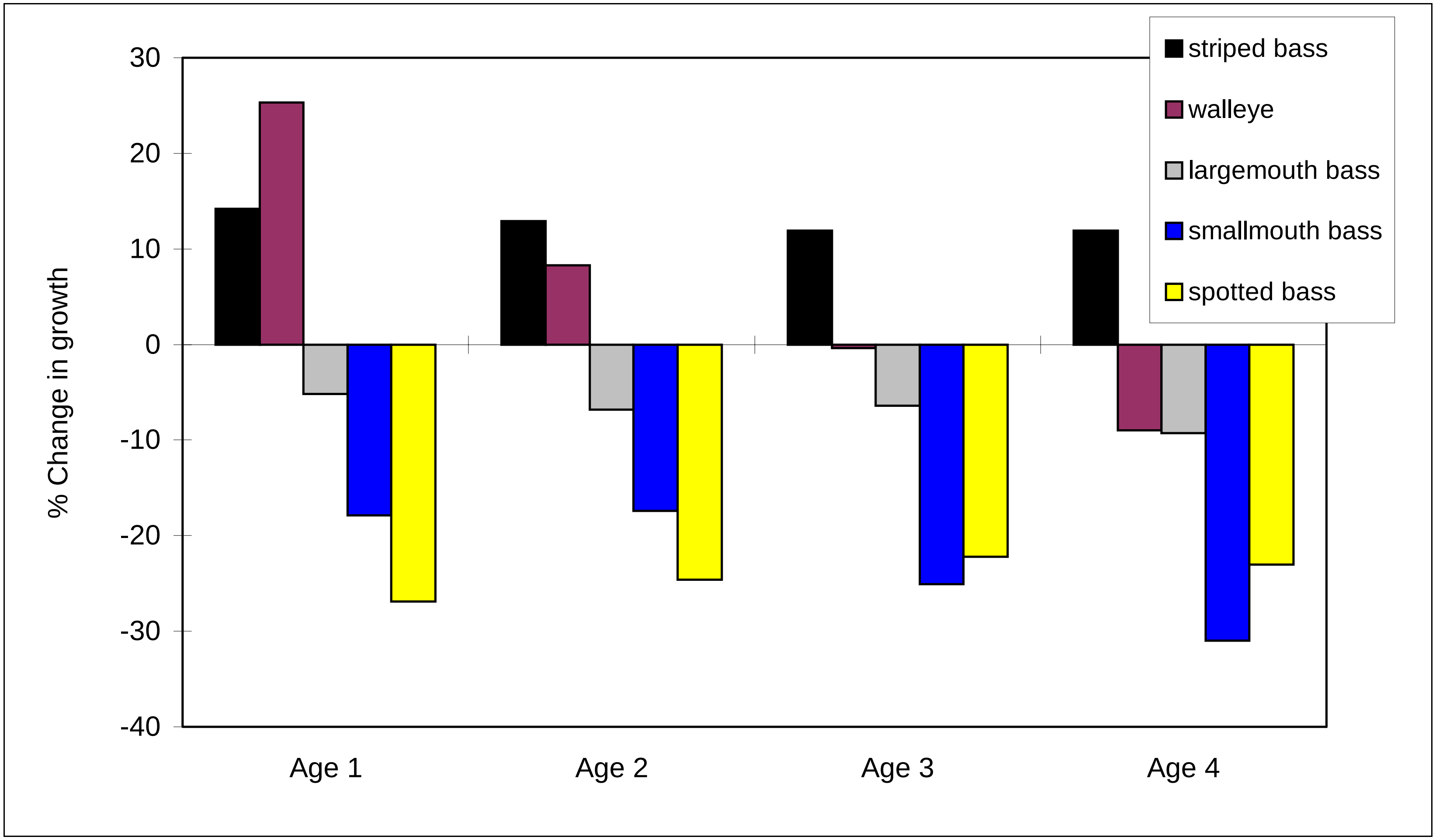

Figure 16. Percent changes in Claytor Lake piscivore mean back-calculated lengths-at-age in 1996 - 1998 versus 1979 - 1980 (Kohler 1980).

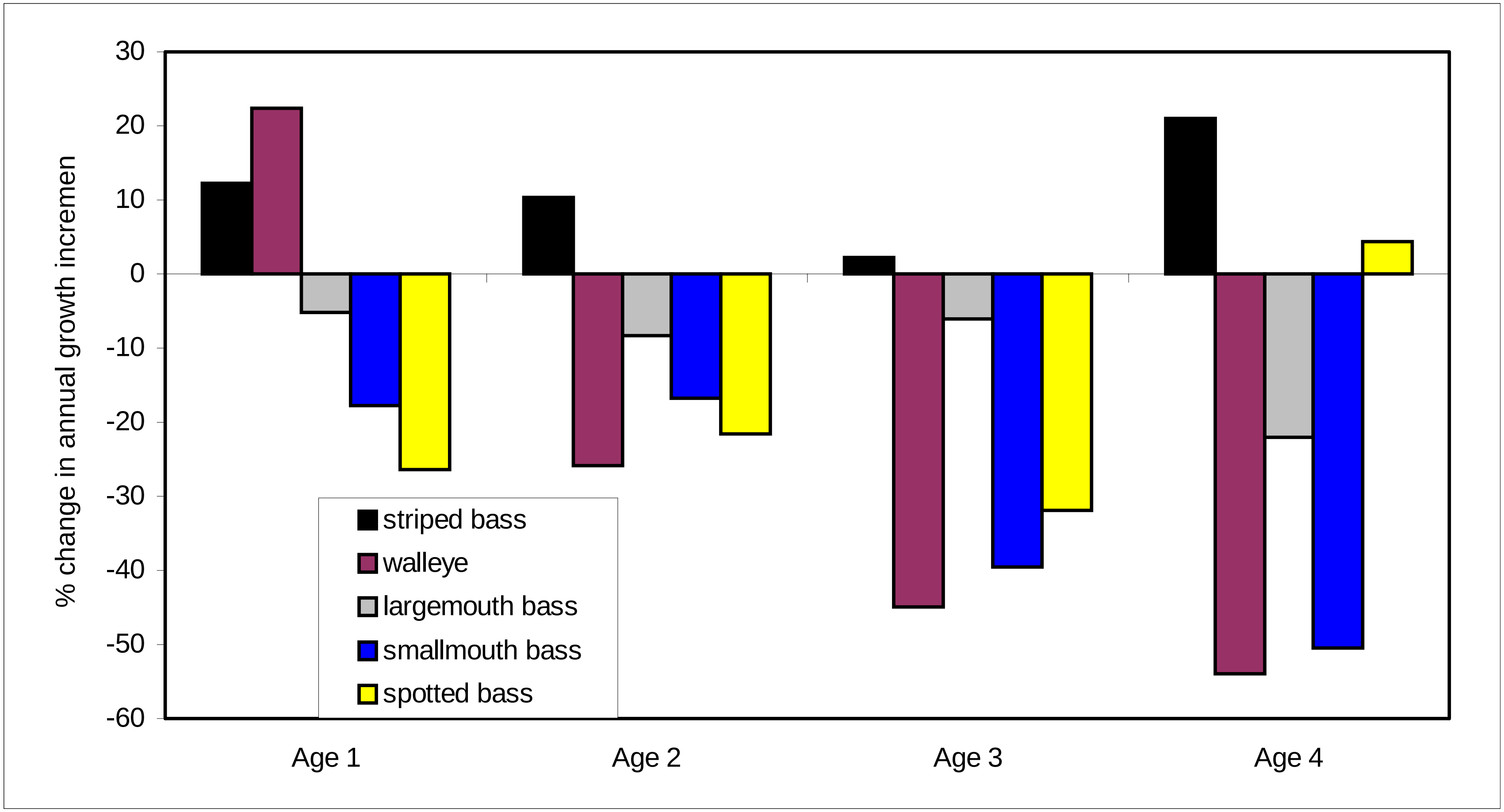

Figure 17. Percent changes in mean annual growth increment in back-calculated lengths-at-age 1996 - 1998 versus 1979 - 1980 Kohler 1980).

Striped bass incremental growth improved by at least ten percent for ages 1, 2, and 4, and two percent for age-3. Walleye were longer at age-1 (22 %), but incremental growth was progressively less than the late 1970s (up to 54 % at age-4) for ages 2 - 4. All three black basses experienced declines in incremental growth rates for ages 1 - 3, especially smallmouth and spotted bass (Figure 17).

Condition of Piscivores Pre versus Post Gizzard Shad

Mean striped bass Wr values (Figure 18) pooled over years pre and post shad improved ($P < 0.0001$) from 87.7 (SD = 8.3; N = 130) to 93.5 (SD = 8.8; N = 213). No pre-shad Wr data exist for hybrid striped bass, but weighted mean Wr for years 1994 – 1997 was 90.2 (SD = 7.5). Walleye were thinner (P = 0.011) on average after gizzard shad (mean Wr = 96.3; SD = 9.8; N = 440) than in years before shad (mean Wr = 99.8; SD = 10.8; N = 58).

Largemouth bass condition did not change after shad were established (P = 0.244). Mean largemouth bass Wr in 1988 was 91.1 (SD = 12.4; N = 75) compared to a mean of 92.8 (SD = 9.0; N = 282) after shad were established. Mean smallmouth bass Wr in 1988 (mean Wr = 86.0; SD = 9.9; N = 52) was similar (P = 0.615) to post-shad years (mean Wr = 85.3; SD = 7.8; N = 147). Spotted bass were heavier ($P < 0.0001$) on average in 1988 (mean Wr = 104.0; SD = 7.9; N = 70) compared to post-shad years (mean Wr = 97.3; SD = 10.6; N = 303).

Abundance of Piscivores Pre versus Post Gizzard Shad

Abundance data on Claytor Lake piscivores has been compiled by the VDGIF from sampling surveys conducted on the lake. Comparisons of relative abundance and biomass estimates of various Claytor Lake fish species before and after gizzard shad are made below.

VDGIF Gill Net Data

The VDGIF has been collecting Claytor Lake relative abundance data on striped bass and walleye since 1981 and 1974, respectively (Figure 19). Mean yearly gill net CPUEs for pre-shad years (before 1989) were compared to post-shad years (1989 - 1997) using Wilcoxon’s Rank Sum Procedure (alpha = 0.05). Striped bass were collected with similar (P = 0.894) frequency pre (mean annual CPUE = 0.162, N = 5)

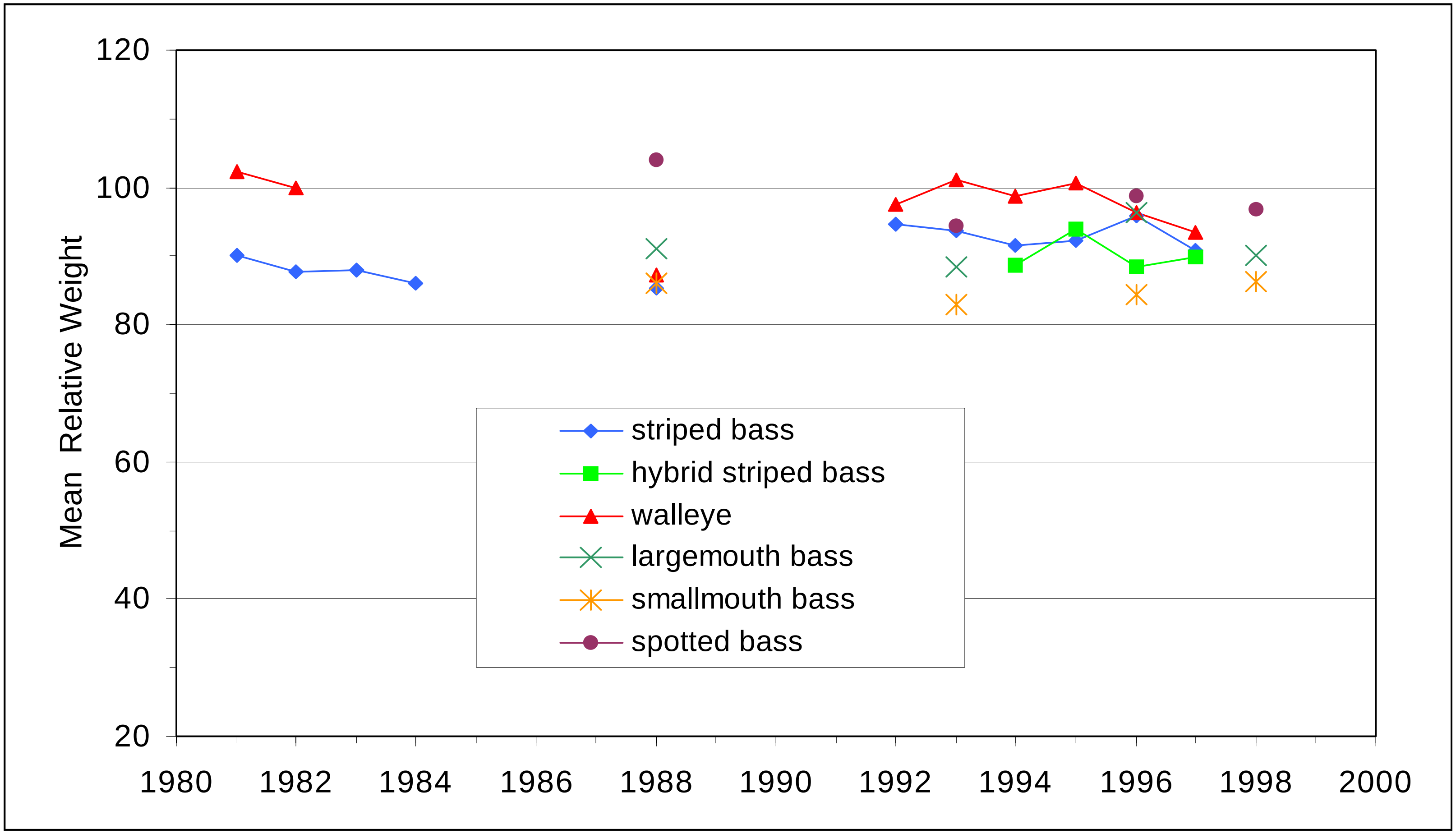

Figure 18. Mean relative weight (Wr) values calculated in various years for each piscivore. Mean Wr was calculated during fall for striped bass, hybrid striped bass, and walleye, and during spring for the black basses.

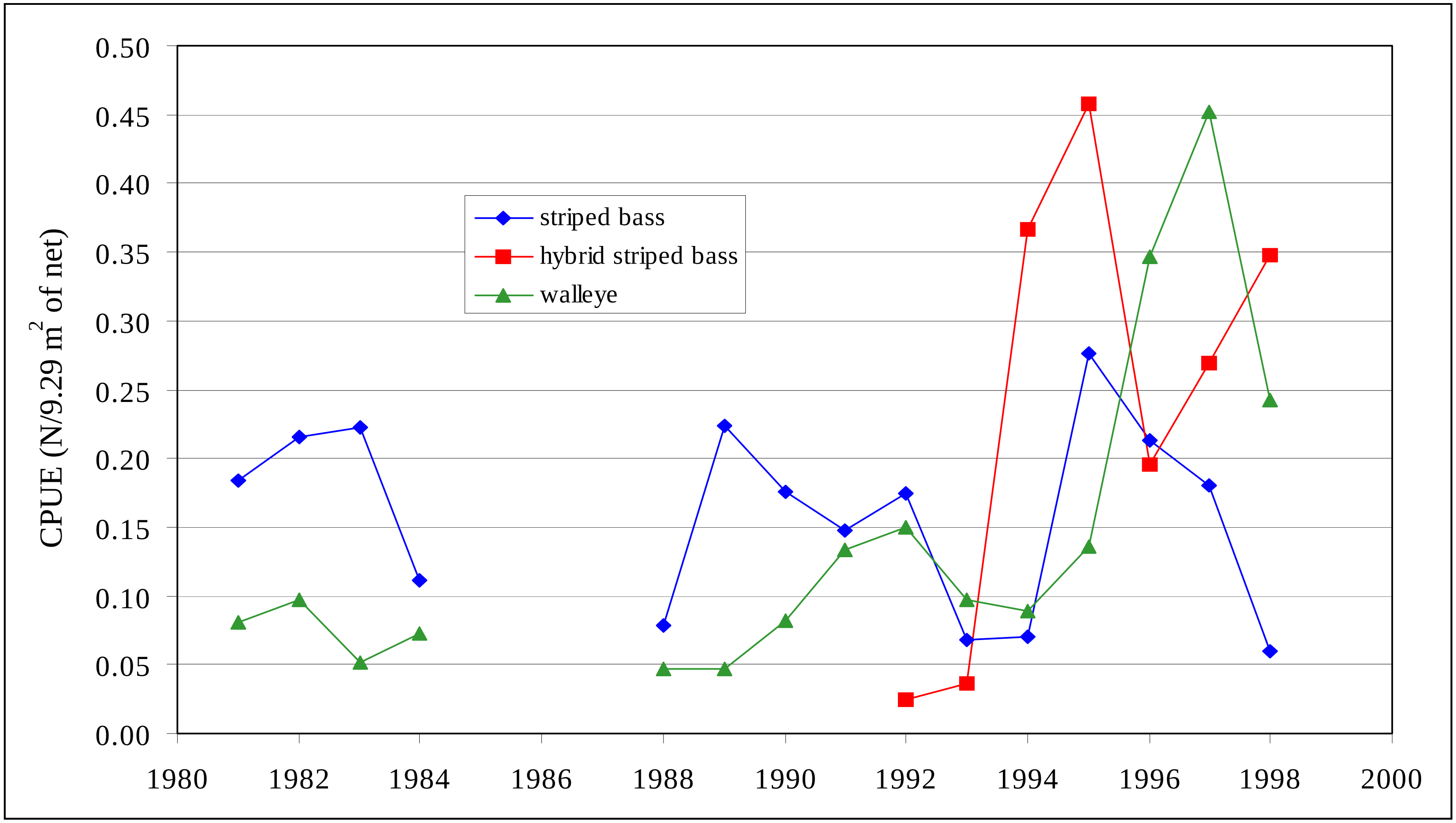

Figure 19. Relative abundance (CPUE in N/9.29 m^2 of net) of striped bass, hybrid striped bass, and walleye collected from Claytor Lake by VDGIF personnel, 1981 - 1998.

Table 14. Stocking history of striped bass, hybrid striped bass, and walleye in Claytor Lake, Virginia, from 1975 – 1998, in fingerlings per hectare. * = fry stockings.

Year	Striped Bass	Hybrid Striped Bass	Walleye
1975	35.8	0	35.8
1976	74.0	0	0
1977	38.6	0	66.6
1978	37.3	0	0
1979	39.0	0	30.2
1980	60.0	0	37.1
1981	73.8	0	41.3
1982	46.1	0	0
1983	37.1	0	41.2
1984	46.9	0	196.7*
1985	37.1	0	13.3
1986	37.1	0	28.6
1987	38.7	0	13.4
1988	39.0	0	49.5
1989	36.8	0	0
1990	27.5	0	37.4
1991	36.8	0	36.8
1992	36.8	0.5	36.8
1993	18.5	19.2	38.8
1994	18.6	0	26.2
1995	18.5	13.5	24.7
1996	19.9	19.1	49.1
1997	18.7	18.5	0
1998	37.7	18.5	0

versus post (mean annual CPUE = 0.170, N = 9) gizzard shad establishment. However, post-shad annual CPUEs for walleye (mean annual CPUE = 0.170, N = 9) were higher (P = 0.003) than pre-shad (mean annual CPUE = 0.053, N = 11) years. No pre-shad relative abundance data for hybrid striped bass were available for comparison purposes.

Claytor Lake stocking history revealed considerable variance in numbers of fingerling fish stocked per year for striped bass, hybrid stripers, and walleye (Table 14). Fingerling striped bass stockings averaged over 46 fish per hectare (sd = 13.9) and ranged from 35.8 – 74.0 fish per hectare during 1975 – 1987. After gizzard shad were first collected from Claytor Lake, striped bass stockings averaged nearly 40 per hectare until 1993 when the first major stocking of hybrid stripers was conducted. At this time, striped bass stockings were cut in half so that the combined numbers of stocked moronids would be similar to recent striped bass stockings. In 1998, numbers of striped bass fingerlings stocked were increased to former levels (approximately 37 fish per hectare).

Walleye fingerling stockings in the late 1970s and 1980s were highly variable, ranging from zero in several years to over 65 fish per hectare in 1977. In 1984, walleye fry were stocked at a rate of nearly 197 fish per hectare. In the 1990s, walleye fingerling stockings ranged from 24.7 – 49.1 fish per hectare. Walleye stocking was postponed in 1997 and 1998 while research was being conducted on this species in Claytor Lake and the upper New River (Palmer 1999).

VDGIF Electrofishing Data

Claytor Lake black bass have been electrofished by VDGIF personnel during spring months (April – June) to obtain relative abundance estimates (N/hr) since 1986 (Figure 20). Samples were collected in only two years before gizzard shad establishment, preventing any statistical comparisons of black bass relative abundance. Total black bass CPUE was fairly consistent, averaging 55 fish per hour (SD = 7.8) from 1986 – 1998. However, Figure 19 illustrates trends in individual species CPUE. Largemouth bass have steadily increased in relative abundance since 1990. Mean annual CPUE for largemouth bass was higher (P = 0.021) from 1993 – 1998 than for years 1986 – 1991. Smallmouth bass were the most abundant of the three Claytor Lake black basses previous to gizzard shad introduction, but since the early 1990s, have decreased to the least abundant. Mean

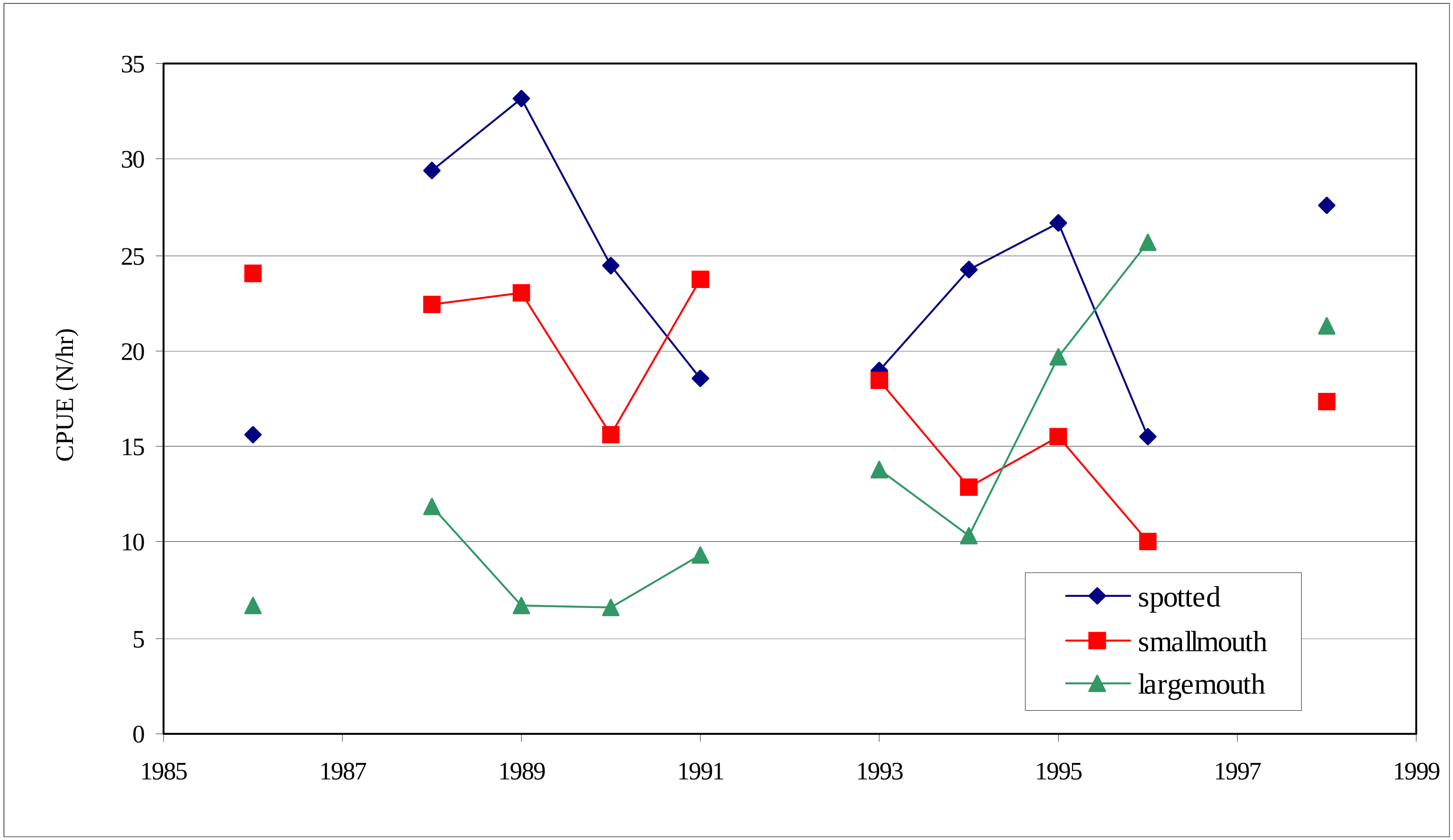

Figure 20. Relative abundance (CPUE in N/hr) of black bass collected from Claytor Lake by VDGIF personnel, 1986 - 1998.

annual CPUE for smallmouth bass was lower (P = 0.043) for years 1994 – 1998 than in 1986 – 1993. Spotted bass CPUE has varied and no pre versus post gizzard shad trend in relative abundance was apparent.

VDGIF Cove Rotenone Temporal Changes

Cove rotenone sampling was conducted by the VDGIF on Claytor Lake in years pre and post gizzard shad establishment (Table 15). Only three cove rotenone samples were taken post gizzard shad establishment, precluding any statistical comparison to samples taken previous to shad introduction. Abundance estimates within species varied often greatly between years. However, total standing stock varied little from 1975 – 1997, averaging approximately 267 kg/ha (range = 245 – 317 kg/ha). The gizzard shad population has expanded to account for up to 88 kg/ha (Table 15), or greater than a third of the 1997 cove biomass (Figure 21). Age-0 shad, however, accounted for less than 1 % of the total fish standing stock in cove rotenone samples conducted in 1996 and 1997.

This addition to the Claytor Lake fish assemblage could possibly be at the expense of other species. Bluegill biomass remained fairly stable after gizzard shad introduction, averaging 88 kg/ha (sd = 11.6 kg/ha) from the 1970s through 1996. However, bluegill biomass decreased to 47.2 kg/ha in 1997. Carp also experienced declines in abundance, falling from a mean of 86 kg/ha (sd = 42 kg/ha) before gizzard shad to 48 kg/ha in 1991 to a mean of 25 kg/ha (sd = 3 kg/ha) in 1996 and 1997. High variability in biomass estimates was common for the pelagic alewife. However, alewife cove abundance was the lowest in 1996 and 1997, averaging only 2.5 kg/ha compared with estimates from the 1970s through the early 1990s which averaged almost 15 kg/ha (sd = 10 kg/ha). Littoral prey fishes such as yellow perch, crappie, and sunfish (other than bluegill) differed little in their total (Table 15) or percent contribution to total biomass (Figure 21) over the three decades. Except for the low catfish collection in the 1991 cove sample, this species also differed little in percent species composition and total biomass.

Total black bass biomass changed little in percent by weight of the total cove estimates since pre-shad years, but black bass abundance increased to a peak of 28 kg/ha in 1991 before falling to previous levels in 1996 and 1997.

Table 15. Biomass (kg/ha) represented by various Claytor Lake fish species collected from cove rotenone samples conducted by the VDGIF, 1975 – 1997.

Species	1975-1978 Pooled	1981	1984	1988	1991	1996	1997
Largemouth bass	3.1	2.3	7.7	6.2	20.8	14.1	7.6
Smallmouth bass	3.3	2.0	1.8	3.0	1.6	1.3	1.4
Spotted bass	6.1	5.9	7.0	8.1	5.3	4.3	4.4
Bluegill	70.1	84.2	95.6	89.0	104.1	83.0	47.2
Other sunfish	11.9	7.6	10.0	8.2	13.0	8.9	5.6
Gizzard shad	0	0	0	0.5	29.9	51.9	87.9
Alewife	4.1	7.7	20.2	13.0	20.0	2.8	2.1
Catfishes	37.6	49.5	38.9	34.3	5.9	46.0	37.7
Carp	90.4	77.1	36.7	138.7	48.0	27.3	23.4
Crappie	12.6	4.4	10.5	2.7	0.9	5.3	5.9
Yellow perch	11.6	4.6	9.2	11.5	16.0	14.5	7.8
Misc. minnows	3.7	0.4	8.2	0.6	3.7	5.6	8.1
Suckers	1.1	0.1	0.5	0.2	1.2	3.2	5.5
Total	269.3	246.5	247.1	316.5	270.4	271.2	245.4

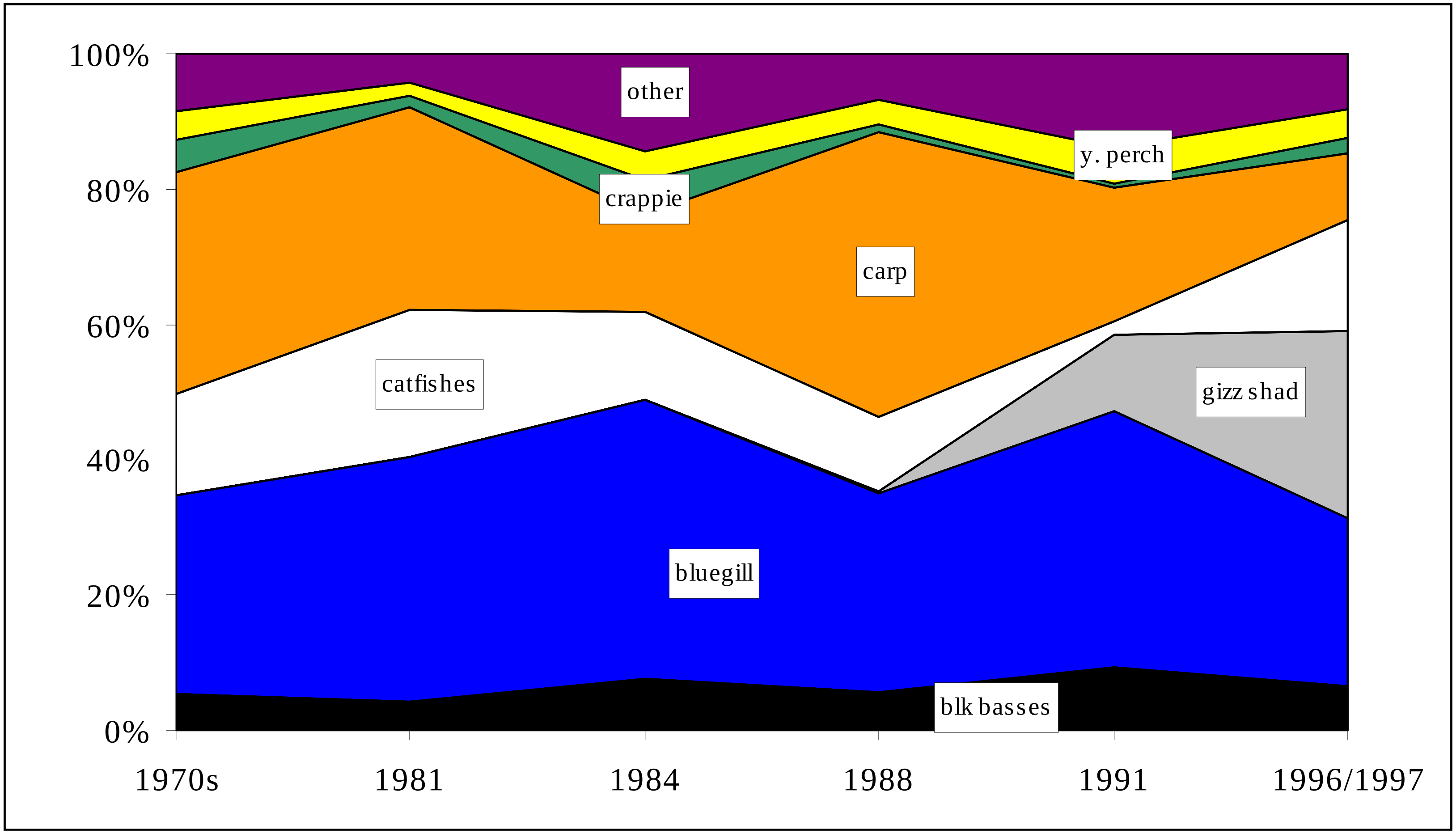

Figure 21. Percent weight of major fish species collected in cove rotenone samples at Claytor Lake, Virginia. "1970s" represents 1975 – 1978 data pooled and "1996/1997" represents 1996 and 1997 data pooled. "Other" includes *Lepomis* spp. other than bluegill, alewife, miscellaneous minnows, and suckers.

VDGIF Creel Survey Data

Total fishing effort has increased from an average of 104 hrs/ha (1977-1992) to more than 182 hrs/ha in 1998. However, proportions of directed angler effort for each species was similar between the two creel surveys. Over 50 % of the directed angler effort was intended for black bass, approximately 10 % for striped bass (1998 included hybrid striped bass with striped bass), and less than 1 % for walleye in each year. Mean weight (kg) of striped bass harvested from Claytor Lake has varied little since the 1970s, but the numbers of striped bass $\geq$ 9 kg (20 pounds) caught on rod-and-reel from Claytor Lake and submitted for citation awards have risen sharply since 1991 (Figure 22). In addition, the largest striped bass submitted for an angler citation award has generally increased each year since the early 1990s (Figure 23). The heaviest striped bass recorded being caught using conventional angling tackle was a 15.9 kg specimen in December 1996. The proportion of total fishing pressure targeted for striped bass has remained around ten percent since the late 1970s.

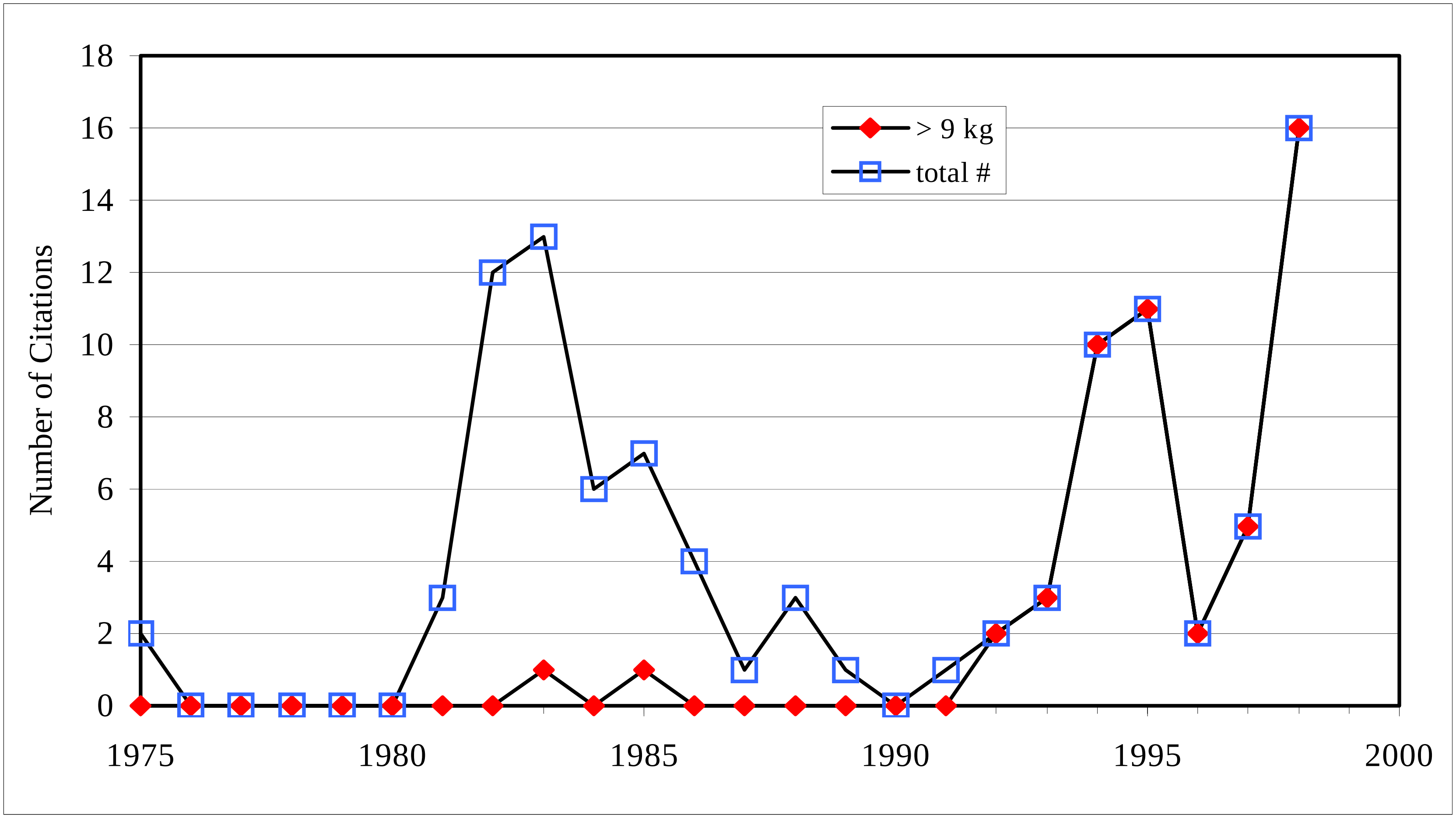

Figure 22. Number of citations awarded to anglers for catching a striped bass ≥ 9 kg (20 pounds) compared to the total citations for striped bass from Claytor Lake, Virginia, 1975 – 1998 (VDGIF, unpublished data). Minimum striped bass citation size was 6.8 kg (15 pounds) from 1975 – 1991, and 9 kg from 1992 – 1998.

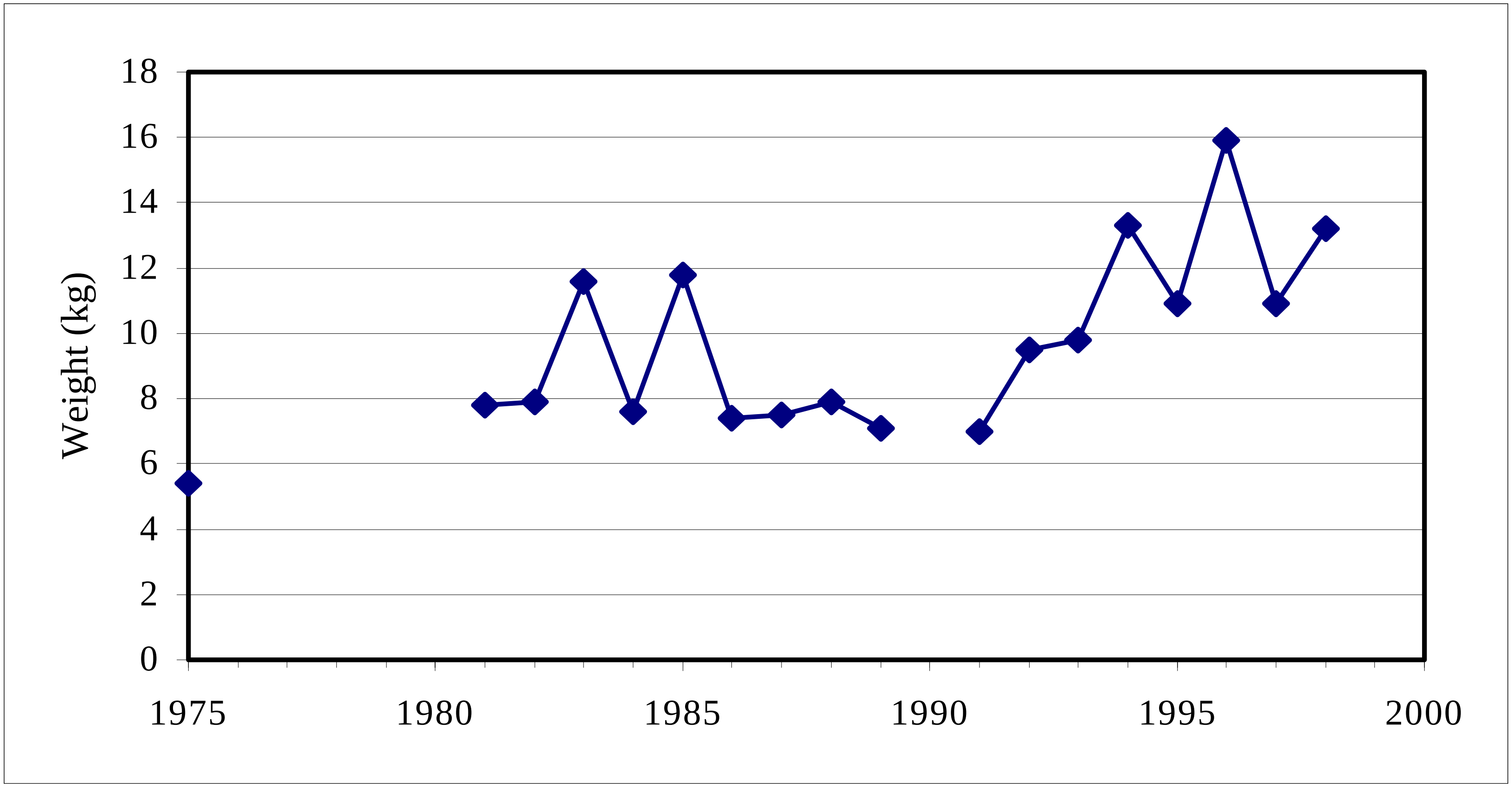

Figure 23. Largest individual fish weight (kg) of all striped bass citations from Claytor Lake issued by the VDGIF for each year, 1975 – 1998.

DISCUSSION

The potential benefits of the introduced gizzard shad population to Claytor Lake piscivores would include providing forage during all seasons and for all sizes of piscivorous sportfish, improving piscivore growth rates, and increasing piscivore survival, hence increasing relative abundance. Analysis of Claytor Lake piscivore food habits, growth rates, and relative abundance has helped reveal some benefits to various sportfish. These findings are discussed subsequently, and then synthesized in the conclusion as an evaluation of the benefits this introduced gizzard shad population has provided to Claytor Lake piscivores.

Piscivore Utilization of Gizzard Shad

An analysis of the trophic overlap between Claytor Lake piscivore diets revealed that the potential exists for competition for prey resources among pelagic sportfish and between black bass species. Pelagic piscivore diets overlapped significantly in almost every season in both years of the study as these fish were heavily dependent on the clupeid forage base. Summer 1998 was the only season in which no significant overlap was found between a moronid piscivore and walleye. Even with a stronger gizzard shad spawn in 1998, walleye still preferred alewife over age-0 shad. Smallmouth bass and spotted bass diets significantly overlapped in all seasons as crayfish dominated over other prey items. Significant trophic overlap between smallmouth and spotted bass was also documented in both impounded and riverine sections of the New River, above Claytor Lake (Scott and Angermeier 1998). On occasion, the largemouth bass diet significantly overlapped with both smallmouth and spotted bass, but no black bass diet ever significantly overlapped with that of a pelagic piscivore. This suggests spatial partitioning of the prey resources in Claytor Lake into littoral and pelagic zones. Moore (1988) found that the greater use of nonclupeid fish and crayfish by black basses minimized diet overlap between pelagic predators and black basses in Smith Mountain Lake, Virginia.

Diets of Claytor Lake piscivores varied by species, season, and year. Gizzard shad was the single most important prey item for striped bass on an annual basis, comprising 50 % of the diet by weight. Alewives were a close second to shad in the diets of striped bass comprising 45 % on an annual basis. Shad were significant components of the hybrid striped bass (32 %) and walleye diets (19 %) annually, but were not as important as alewife (Table 2). In Smith Mountain Lake, Virginia, where gizzard shad and alewives have coexisted for a much longer duration than in Claytor Lake, these two prey species appeared to be spatially segregated (gizzard shad inhabiting the upper end while alewives resided in the lower section of the reservoir) and were both utilized heavily by resident piscivores within their respective habitat locations (Moore 1988; Ney et al. 1990). However, Smith Mountain Lake is a storage reservoir with a much longer retention time (3.2 years) when compared to Claytor Lake (2 months), a mainstream, run-of-the-river reservoir. A trophic gradient exists on Smith Mountain Lake from a relatively shallow, eutrophic upper end preferred by shad to a deep, oligotrophic lower end inhabited by alewife. Claytor Lake does not exhibit a dramatic trophic gradient and Small (unpublished) found larval gizzard shad and alewife to overlap in their spatial distributions. Further, I did not observe any spatial differences in Claytor Lake piscivore diets in this study although I only sampled the first 10 river-kilometers above the dam, covering < ½ the length but > ½ of the lake's surface acreage. Because the distributions of both clupeids spatially overlap in Claytor Lake, the potential exists for gizzard shad and alewives to compete for food resources, especially at the larval stage. Diet composition data have been collected on alewives and larval gizzard shad in an effort to compare food habits (Small, unpublished).

Consumed gizzard shad ranged in size from 21 to 239 mm TL. However, 99 % of shad collected from predator stomachs were less than 150 mm TL. Growth calculations indicated that gizzard shad collected from 1997-1998 averaged approximately 155 mm TL at age-1. Piscivore predation on Claytor Lake gizzard shad appears limited to age-0 shad beginning in mid-summer through the Fall and, to a lessor extent, age-1 shad the following spring. Gizzard shad were not eaten until they reached 25 mm TL in two Missouri reservoirs (Michaletz 1997b) which is similar to sizes of shad initially consumed in Claytor Lake.

Extent and duration of piscivore predation on gizzard shad depended on the timing and strength of the shad spawn. Consumption of age-0 shad did not begin until mid-August in 1997. In addition, age-0 shad comprised much less of piscivore summer diets in 1997 compared to Summer 1998 when young-of-year shad were more abundant. Not only were shad more utilized in Summer 1998, but consumption of age-0 shad began a month earlier, in mid-July. In the presence of fewer young-of-year shad in 1997, piscivores exerted heavier predation on young bluegill and alewives. Although age-0 gizzard shad have been shown to compete with young-of-year bluegill for zooplankton resources (Dettmers and Stein 1992), shad may, conversely, buffer predation on young bluegill, increasing sunfish survival.

An unseasonably cool spring in 1997 probably played a role in the apparently poor shad spawn the subsequent summer. Claytor Lake water temperatures during the first two weeks of June averaged over 4° C warmer in 1998 than the previous year (Small unpublished). The spring of 1998 was characterized by warm and wet climatic conditions locally, which was followed by a stronger shad spawn the subsequent summer. Michaletz (1997a) reported that the distribution and initial abundances of larval gizzard shad were influenced by water temperature and reservoir water levels in two Missouri reservoirs. The author reported that cohorts of larval gizzard shad were more abundant in warm springs and/or those with water level rises. This discrepancy in shad year class strength was reflected in both Claytor Lake piscivore diets and gill net catch rates of shad ages 0 and 1. Changes in age-0 gizzard shad abundance and size can significantly influence predator diets (Michaletz 1997b).

Seasonal diets of striped bass and hybrid striped bass were very similar in both prey compositions and proportions during the entire study. These two piscivores appeared to be trophic equivalents and thus potential for competition is high. The importance of gizzard shad to the diets of striped bass and hybrid striped bass in other reservoirs has previously been documented (Stevens 1958, Williams 1970, Ware 1974, Morris and Follis 1978, Combs 1978, Matthews and Hill 1982, Germann 1982, Lewis 1983, Filepek and Tommey 1984, Harper and Namminga 1986, Moore 1988). Striped bass consumption of alewives has previously been reported for Claytor Lake (Kohler 1980). Infrequent consumption of crayfish by striped bass has also been documented (Hepworth et al. 1977, Combs 1978, Moore 1988).

Walleye were almost exclusively piscivorous, relying greatly on the clupeid forage base. This piscivore fed more heavily on alewife than gizzard shad in every season, but utilized shad when they were abundant at small sizes (e.g., Fall 1996/1997 and Summer 1998). Clupeids also comprised most of the diets of walleyes in other southern reservoirs (Dendy 1946; Jester 1971; Momot et al. 1977; Fitz and Holbrook 1978; Moore 1988).

The largemouth bass diet was characterized by a diverse forage composition with a single prey species rarely dominating in importance. Bluegill and crayfish, together, represented the majority of largemouth bass seasonal diets. Gizzard shad made up a fifth of the Spring 1997 largemouth bass diet, but were consumed in much lower quantities the following spring when fewer age-1 shad were available. Gizzard shad was not a significant portion of the largemouth bass diets in any other season. Alewives were also utilized in spring months by largemouth bass, possibly as a result of increased spatial availability as a result of alewife spawning behaviors. Alewives are pelagic and tend to inhabit deeper, offshore waters (Ney et al. 1982) except in the spring when spawning behaviors bring them within nearshore areas (Wagner 1972; Nigro 1980). Elevated consumption of alewives during spring months by black bass has been previously documented (Kohler 1980; Moore 1988). Generally, gizzard shad were less important to the Claytor Lake largemouth bass diet than previously reported in other reservoirs (Aggus 1973; Lewis et al. 1974; Pasch 1975; Timmons et al. 1981; Adams et al. 1982; Storck 1986; Moore 1988; Michaletz 1997b).

A low incidence of cannibalism was documented in all three black bass diets, but was not found in any pelagic piscivore. In addition, no pelagic piscivore was ever collected from the stomach of a black bass, and only two black basses were collected from pelagic piscivore stomachs. Black bass cannibalism is well documented (Applegate et al. 1966; Mullan and Applegate 1970; Miller and Kramer 1971; Hubert 1977; Timmons et al. 1981; Moore 1988), but interspecific predation between black basses and moronids as well as walleye has not been frequently reported (Moore 1988; Cyterski 1999; Miranda et al. 1998).

Percent gizzard shad consumption was similar between fall seasons for all predator species. Oddly, despite lower apparent age-0 shad abundance in Fall 1997 than

Fall 1996, percent gizzard shad consumption and percent empty stomachs of piscivores was very similar between fall seasons.

A probable reduction in Spring 1998 versus Spring 1997 age-1 gizzard shad abundance was, however, manifest in spring-time piscivore shad consumption percentages. Largemouth bass, spotted bass, and hybrid stripers all consumed proportionately less gizzard shad in Spring 1998 than Spring 1997, although the difference was not statistically significant for hybrid stripers.

The most conspicuous differences in the seasonal utilization of shad between years occurred in summer. The diets of both moronid species included significantly greater percentages of gizzard shad in Summer 1998 than Summer 1997. Summer smallmouth bass shad consumption increased from one percent in 1997 to seven percent in 1998, but large sample sizes of this sportfish made detecting the difference possible. Walleye also consumed a greater proportion of shad in Summer 1998, but only eleven second summer walleye were collected with food items, thus hindering a statistically significant result. These differences in summer piscivore diets all appeared to be a function of the greater number of young shad available during the second summer. Unexplainably, largemouth bass consumed significantly fewer gizzard shad in Summer 1998 than in Summer 1997 but they never ate many during the summer months, anyway.

No significant differences in the intensity of black bass predation on gizzard shad over seasons were found using shad SFI. Significant differences in seasonal gizzard shad consumption did, however, occur for all three pelagic piscivores. In each case, pelagic piscivores contained greater amounts of shad during fall months and in the second summer when age-0 shad were at peak abundance and least in the spring.

Several possibilities exist to explain the lower shad SFI values during spring months. One reason is that by spring, most shad that were age-0 the previous year had already grown too large (> 150 mm TL) to be consumed except by the larger piscivores (moronid species > 450 mm TL and walleye > 550 mm TL). By spring months, pelagic piscivores switched to alewife because this prey species was still abundant in sizes smaller (< 110 mm TL) that age-1 shad. Pelagic piscivore feeding intensity was not reduced during spring months because total SFI values were not significantly lower than any other season.

There was evidence from predator diets that a spatial shift in shad ages 0 - 1 from open water areas in the fall into littoral areas within creeks and coves occurred during the following spring months. Black basses, especially largemouth and spotted bass, exibited greater shad SFI values during spring months rather than summer and fall, when greater amounts of shad were eaten by the three pelagic sportfish.

Comparison of Piscivore Diets Pre vs. Post Gizzard Shad Establishment

Information on Claytor Lake piscivore diet composition was collected previous to gizzard shad introduction to assess alewife utilization as a forage fish (Kohler 1980). The study design of the previous work prevented any statistical comparisons of diet data between research projects. However, major differences in piscivore diet composition between the two studies were evident.

Gizzard shad have supplanted a variety of prey species in the pelagic piscivore diets. Striped bass relied almost exclusively on an alewife forage base two decades ago. Although alewife remained a dominant prey source for striped bass after gizzard shad establishment, shad were heavily utilized seasonally during this study. Gizzard shad have replaced white bass, crappie, and yellow perch in the Summer and especially the Fall diets of walleye. In both investigations, black bass relied most heavily on crayfish (smallmouth and spotted) and sunfish (largemouth). Although present in black bass stomach contents previously, no yellow perch were collected from black bass stomachs in this study. Crappie have also decreased in importance in black bass diets. Mean 1996 and 1997 cove biomass estimates of crappie decreased by 68 %, but yellow perch abundance remained stable since the 1970s. This reduction in crappie abundance maybe the reason for less predation on crappie, but the absence of yellow perch in predator stomachs remains an enigma. Interestingly, except for the smallmouth bass spring diet, alewives were found in black bass stomachs more frequently in this study than in the 1970s when no gizzard shad were present. The spring smallmouth sample (N = 17) collected in the previous study was the only black bass sample that contained over eight individuals. The small sample sizes of black bass from the previous study failed to adequately capture the extent of the black bass predation on alewife.

Predator-Prey Length Relationships

The maximum sizes of gizzard shad available to selected piscivores as determined by Jenkins and Morais (1978) were generally poor predictors of actual shad sizes collected from predator fish stomachs. Each piscivore species consumed some shad greater in length than the maximum lengths predicted, especially walleye. Over half of the shad that walleye consumed were greater than predicted maximum lengths. Walleye regularly consumed shad that were greater than the maximum estimated lengths in Smith Mountain Reservoir, Virginia (Moore 1988). Michaletz (1997b) lends evidence to disprove the equations of Jenkins and Morais (1978). He found that predicted maximum gizzard shad lengths based on gape measurements (external mouth width and cleithrum width) seriously underestimated the observed maximum length of shad ingested by predators. However, both moronids and largemouth bass usually consumed shad much smaller than maximum predicted sizes. This was a result of many ages of piscivores preying on only one or two ages of shad.

Striped bass displayed a better linear relationship between TL of gizzard shad consumed and piscivore TL than other Claytor Lake sportfish. However, predation on gizzard shad by even the largest sizes of Claytor Lake piscivores was limited to shad ages 0 and 1.

Juanes (1994) reviewed literature concerning piscivore prey size selection, and found that many other studies have demonstrated that piscivorous fishes tend to ingest prey much smaller than the possible maximum. The author also suggested that as fish grow, successively larger prey are eaten because of their increased vulnerability, but smaller prey are never excluded from the diet because their relative vulnerability stays high (i.e., capture success). Further, as food energy benefits to predators increase with prey size, energy costs related from poor capture success also increase, making larger prey bioenergetically unprofitable. Data from my study supports the observations made by Juanes (1994).

Similar information on striped bass and hybrid striped bass prey size selectivity was compiled by Dennerline (1990). Lewis (1983) found that even though striped bass (> 400 mm TL) and adult gizzard shad distributions overlapped, striped bass did not consume these large shad in Lake Norman, North Carolina, although the shad were morphologically vulnerable to predation. Age-0 gizzard shad in Lake Erie outgrew their vulnerability to walleye predation by spring the following year (Knight et al. 1984) and Moore (1988) found virtually all shad eaten in Smith Mountain Lake, Virginia, were age-0 and age-1.

Dettmers et al. (1998) found that hybrid stripers (190 - 250 mm TL) preferred gizzard shad 40 mm TL over both 60 and 80 mm TL size groups, but larger hybrid stripers (310 - 360 mm TL) did not show any size selective predation on shad ranging in size from 40 to 120 mm TL. However, selective predation on larger gizzard shad (> 130 mm TL) by hybrid stripers was not determined (Dettmers et al. 1998). Ott and Malvestuto (1981) reported that hybrid striped bass, in a Georgia reservoir, did not utilize gizzard shad much greater than 65 mm TL even though larger sizes were available. These authors found no significant relationship between prey size and hybrid striped bass gape width or between prey size and hybrid length.

Consumption of gizzard shad in Claytor Lake is size-limited, and rapid shad growth means that almost all shad eaten are age-0. This produces an annual pattern of gizzard shad consumption: low in spring, increasing in summer, and high in fall. Reliance on one edible age class makes gizzard shad an unstable food supply (which was demonstrated by mean shad SFI values among summer seasons). Small piscivores are especially disadvantaged because they must find alternate prey by the end of fall when age-0 shad outgrow their vulnerability or during years of poor age-0 shad production. Both scenarios were documented in Claytor Lake during this study.

Spatial and temporal variation in age-0 gizzard shad availability within reservoirs between years has been linked to changes in piscivore growth rates (Michaletz 1997b and Michaletz 1998). He found that faster growth rates of age-0 predators were correlated with higher age-0 gizzard shad biomass estimates and smaller mean fall TL of age-0 shad in several Missouri reservoirs. Claytor Lake's age-0 shad population is relatively low even in good years according to shad gill net and electrofishing samples and growth rates are high, which should result in age-0 predator growth rates that are slower than their potential. However, pelagic predators in Claytor Lake grew faster to age-1 in this study than before gizzard shad were introduced (Kohler 1980). But, increases in age-1 growth can not be attributed to gizzard shad because the diets of young-of-year sportfish were not examined.

Gizzard Shad Population Characteristics

Although effectively used in Lake Texoma, a more eutrophic reservoir supporting a greater abundance of shad (Van Den Avyle et al. 1995), horizontal gillnets were ineffective at capturing age-0 shad in the more mesotrophic Claytor Lake where young-of-year shad densities were lower. Net avoidance was not believed to have been a problem because the smallest mesh size (12 mm bar mesh) was successful at capturing alewife (80 – 120 mm TL). Age-0 gizzard shad were rarely seen during summer and fall electrofishing when black bass were being collected for the diet study. If age-0 gizzard shad were in low densities and aggregated in schools, the possibility exists that few schools encountered the nets. Highly mobile predators such as the moronids might be able to follow these schools of shad and, consequently, supplement their diet composition. However, gillnet CPUE of gizzard shad year classes was sufficient to illustrate a poor shad spawn in 1997. This variation in gizzard shad year class strength was reflected in piscivore stomach contents.

Although abundance of age-0 gizzard shad was higher in 1998 based on gill net catch rates and predator diets, gill net CPUE of age-0 shad was still low. A variety of habitat types was sampled with the horizontal gill nets in an attempt to catch age-0 shad, but none were very successful. Claytor Lake's gizzard shad population resembles those described by DiCenzo et al. (1996) in mesotrophic Alabama reservoirs. At chlorophyll-*a* concentrations similar to values reported for Claytor Lake (Thomas and Johnson 1998), gizzard shad exhibited relatively low abundance, fast growth, increased longevity, and were dominated by larger individuals compared to more eutrophic systems (DiCenzo et al. 1996). These authors believed that first year growth was density-dependent as eutrophic systems produced high numbers of slower growing individuals compared to low abundance, fast growing cohorts in mesotrophic lakes. Michaletz (1998a) reported that gizzard shad in 15 Missouri reservoirs exhibited increased abundance, adult mortality, and recruitment stability as reservoir productivity increased and mean depth decreased. Claytor Lake is deep (mean depth = 29 m) and is meso- to moderately eutrophic. My data supported these observations (Table 9 and Figures 13 – 15) because Claytor Lake gizzard shad are low in abundance (age-0), grow rapidly, exhibit erratic recruitment, skewed toward older ages, and are relatively long lived (up to age 7; adult mortality averages 66 %).

The Index of Vulnerability (IOV) calculates the percentage of gizzard shad within a sample that is < 203 mm TL. Research has shown that gizzard shad > 203 mm TL were rarely consumed by predators (Ott and Malvestuto 1981; Lewis 1983; Knight et al. 1984; Moore 1988), thus the utility of this segment of the shad population as forage is minimal. DiCenzo et al. (1996) did not calculate IOV values for shad samples collected with gill nets because the IOV was biased for larger fish. However, their smallest gill net bar mesh size was 25 mm, twice as large as my smallest mesh. Gizzard shad IOV values calculated from electrofishing samples averaged 19.8 (range = 0 – 45) and 68.2 (range 39 – 78) for oligo-mesotrophic and eutrophic Alabama reservoirs, respectively (DiCenzo et al. 1996). Although not directly comparable to IOV values collected with electrofishing gear, Claytor Lake's IOV value of 4.2 fell within the range (0 – 45) for oligo-mesotrophic reservoirs. Claytor Lake's gizzard shad population appears to be dominated by large (> 203 mm TL) individuals, outside the range of vulnerability to predation. Further, 99 % of the shad collected from Claytor Lake piscivore stomachs were < 150 mm TL. My data suggest that the IOV should use a shorter (150 mm TL) delineation length than 203 mm TL.

Small (unpublished) reported larval gizzard shad densities in Claytor Lake (1997 - 1998) that were much lower than typical values published in the scientific literature. Although adult gizzard shad represented up to a third of the total cove fish biomass (1996 – 1997), age-0 shad accounted for an average of 0.07 kg/ha, or less than 1 % of total standing stock. In comparison, age-0 shad constituted 30 % of total gizzard shad biomass in the 1996 cove rotenone survey at Smith Mountain Lake, Virginia (Cyterski 1999).

Thus, even during years coinciding with stronger shad spawns, Claytor Lake age-0 shad densities may be much lower than other reservoirs.

Growth Rates of Piscivores

Of the five piscivore species aged by Kohler (1980), only striped bass have experienced enhanced growth since gizzard shad were established. In fact, Claytor Lake striped bass in the late 1990s grew at least as fast as striped bass in Smith Mountain Lake (Banach 1991). With the addition of hybrid striped bass, stocking densities for striped bass were reduced by half (1993 - 1997), bringing the total numbers of stocked moronids to similar densities previously used for stripers alone (approximately 50/ha). My diet composition data showed Claytor Lake stripers and their hybrids function practically as trophic equivalents. Interestingly, striped bass growth rates have improved in spite of trophic resource sharing with hybrid stripers, but their relative abundance decreased. Since introduction, gizzard shad have provided an important additional forage source seasonally for striped bass, and more recently for hybrid stripers. However, improvements in first year growth of striped bass can not be attributed to gizzard shad because I did not analyze diet composition for age-0 striped bass.

First-year walleye growth rates have improved from values reported twenty years previously, but they have declined after age-1. Larger back-calculated TL at age-1 for walleye could be a function of changes in stocking strategies (e.g., larger sizes at time of stocking, date of stocking, and lower density), walleye reproductive success, or an overestimation of the intercept value (length at time of scale formation) in the Fraser - Lee method of back-calculating TL at ages. The 125 walleye used for back-calculating lengths at age-1 in 1978 (Kohler 1980) were part of a 1977 cohort that was stocked into Claytor Lake at a rate of 67 fingerlings per hectare (Table 15). The 77 age-1 walleye sacrificed in 1996 for growth information were part of the 1995 cohort that was stocked at a rate of 24.7 fingerlings per hectare, a 63 % decrease from the previous study. Walleye stocked in 1995 could have grown faster to age-1 than their counterparts in 1977 as a result of less intra-specific competition for food resources.

All three black basses displayed decreased growth rates from those reported two decades ago (Kohler 1980), with lower incremental growth in length at all ages (except age-4 spotted bass). Interestingly, largemouth bass growth rates have decreased much less than either spotted bass or smallmouth bass even though largemouth bass were the only *Micropterus* species to have shown increasing relative abundance since gizzard shad introduction (Figure 17). Spotted bass and smallmouth bass utilized shad in lower (< 3 % annually) amounts than did largemouth bass (16 % annually). Whether the 13 % discrepancy in shad utilization was enough to explain lesser reductions in growth rates and increased relative abundance of largemouth bass compared with other black basses would only be speculation. Claytor Lake spotted and smallmouth bass relied heavily on crayfish for prey, but largemouth bass were more piscivorous. Crayfish are omnivorous, feeding on periphyton among other items (R. J. Neves, Virginia Tech personal communication). Periphyton constitutes much of the adult gizzard shad diet (Scott and Crossman 1973). Gizzard shad could have reduced crayfish numbers through trophic competition. A reduction in crayfish biomass would have negatively impacted (through reductions in growth) smallmouth and spotted bass to a greater extent than the more picivorous largemouth bass. Admittedly, there is no proof of this mechanism. At this time, competition among crayfish and adult gizzard shad for trophic resources has not been studied.

Stripers seem to be growing faster as a result of gizzard shad introduction as evidenced by increases in back-calculated lengths-at-ages. However, the other species are not growing as fast. Reasons for decreases in growth could be explained by higher piscivore abundance, hence greater competition for food resources, lower abundance of preferred foods, lower lake fertility, or some unknown factor(s). Total standing stock of littoral prey species (except crappie) remained stable from pre-shad years based on cove rotenone sampling. Fish production in Claytor Lake is phosphorus limited, like most U.S. reservoirs, and 1997/1998 phosphorus concentrations were similar to levels reported in 1973. However, the clupeid populations in Claytor Lake have not been assessed using current hydroacoustic techniques. The following section addresses piscivore abundance.

Piscivore Abundance

The VDGIF has been collecting relative abundance data on Claytor Lake sportfish since 1974, 1981, 1984, and 1992 for walleye, striped bass, black basses, and hybrid striped bass, respectively. Mean annual gill net CPUE of striped bass has been variable, and no increase in relative abundance of this sportfish was evident after gizzard shad were added to the Claytor Lake fish assemblage. However, striped bass relative abundance has steadily decreased since the first major stocking of hybrid stripers in 1993. Annual stockings of striped bass fingerlings were cut in half after the development of the hybrid striped bass fishery (1993), making it difficult to determine whether the 79 % decrease in striped bass relative abundance (1995 – 1998) was a function of inter-specific competition for food resources, reduced stocking rates, or unknown factors. In spite of the potential masking effects of the inconsistent annual stocking rates for walleye, a significant increase in walleye relative abundance after gizzard shad establishment was evident, possibly accounting for the reduced growth rates observed for this species.

Only one year (1986) of pre-shad VDGIF electrofishing data was available, preventing any statistical comparisons of black bass relative abundance. No trends in total black bass CPUE were evident, as mean annual electrofishing catch rates were consistent (approximately 55 bass per hour) among pre-shad and post-shad years. However, shifts in the proportions of the three black bass species were obvious. Largemouth bass relative abundance began increasing coincident with the illegal stocking of gizzard shad, and has steadily increased since. Smallmouth bass relative abundance has declined since the early 1990s, and mean annual spotted bass electrofishing catch rates have exhibited high variability and no trends. This does not seem to be a new phenomenon. Patterns of high variability in abundance among the three black basses have been previously documented for Claytor Lake (Roseberry 1950, Kohler et al. 1986). Gizzard shad comprised up to a fifth of spring largemouth bass diets, but were not a major dietary constituent for largemouth bass in most seasons. Other influencing factors (e.g., reduced harvest through catch-and-release, or unknown factors) could have been responsible for the increase in largemouth bass numbers.

Cove rotenone sampling was conducted by the VDGIF on Claytor Lake in years both previous to and post gizzard shad introduction. Mean annual black bass abundance (N/ha and kg/ha) estimates derived from this sampling technique were extremely variable. According to these data, largemouth bass abundance has increased since gizzard shad introduction while both smallmouth bass and spotted bass have declined. However, due to the large variation in yearly abundance estimates and the small number of samples, caution should be used in the interpretation of the comparisons between pre and post gizzard shad mean abundance values.

Total fishing effort has more than doubled from 1992 to 1998, but directed angler effort has increased proportionally for each species. Although walleye were sampled with greater frequency in recent (1996 – 1998) VDGIF fall gill net samples than striped bass, less than 1 % of the directed angling effort is targeted for this species. However, there is evidence of a seasonal fishery for walleye in the headwaters of Claytor Lake each spring (Palmer 1999).

Piscivore Condition Before and After Gizzard Shad

A relative weight (Wr) of 100 can be considered a benchmark for comparison of samples and populations (Murphy et al. 1990). Wr values well below 100 for a population could indicate limited food availability. Conversely, Wr values well above 100 could result from the availability of surplus forage (Anderson and Neumann 1996). Striped bass condition during fall months improved after gizzard shad were introduced as evidenced by increases in mean fall Wr values, but were still below 100, even with the addition of shad. The observed increases in striped bass Wr values add credibility in defense of the improved growth rates over pre-shad years. No pre-shad Wr information exists for hybrid striped bass, but their mean fall Wr values averaged 90 in years after shad introduction. Morinids utilized shad in greater amounts than other sportfish, but food resources still appear to be limiting even during fall months when age-0 gizzard shad were most plentiful.

Walleye condition decreased slightly after shad introduction, but their condition during fall months remained good. Walleye relied heavily on the alewife forage base even after shad introduction. Lower post-shad Wr values could be an indication of reduced availability of alewives, but no data exists to substantiate this theory.

Mean spring spotted bass Wr values decreased after gizzard shad, supporting observations of reduced growth for this species. However, post-shad spotted bass Wr values remained near 100, possibly an indication of adequate prey availability.

Smallmouth bass (which function as trophic equivalents to spotted bass) exhibited lower mean spring Wr values than spotted bass. These two black bass experienced similar diet compositions and declines in growth rates, but the mechanisms behind the discrepancies in Wr values are unknown. Mean spring largemouth bass Wr values varied among years and no indication exists to prove any change in largemouth condition after gizzard shad.

Care should be made in interpreting pre-shad Wr values for the black basses. Pre-shad Wr data was only available in 1988 and may not adequately reflect black bass condition in previous years. Information on length and weights of black basses could not be obtained for years corresponding to the previous study (Kohler 1980). As a result, observed decreases in black bass growth rates from the 1970s can not be fully supported with Wr information.

Fish Assemblage Composition Before and After Gizzard Shad

Total Claytor Lake littoral fish biomass (kg/ha) as measured in cove rotenone surveys varied little from the 1970s through 1997. Third day pick-ups (part of cove sampling methodology, 1975 – 1991) only accounted for an average of 5.4 % of the total fish biomass estimates. If 1996 and 1997 total standing stock values (did not include 3rd day pick-ups) are adjusted up by 5.4 %, they still fall well within the range of previous sampling years. In 1973, total phosphorus (TP) in Claytor Lake averaged 31 ug/L, similar to values reported for 1996 (33 ug/L) and 1997 (28 ug/L) (Thomas and Johnson 1998). Because phosphorus is the limiting nutrient in Claytor Lake, like most U.S. reservoirs, one would not expect to see drastic changes in total fish standing stock over similar TP levels. However, shifts in the proportions of individual fish species and groups were evident. The expansion of the gizzard shad population seems to have had a detrimental effect on crappie and carp because these fish species have decreased in biomass since gizzard shad were introduced. The decline of crappie in piscivore diets from this study maybe a result of this reduction in abundance. Although standing stock of bluegill was at or above pre-shad levels (mean bluegill biomass 1975 – 1988 = 85 kg/ha) in cove surveys conducted in 1991 (104 kg/ha) and 1996 (83 kg/ha), bluegill biomass dropped to 47 kg/ha in 1997. This recent reduction in abundance may be a result of a sampling anomaly and not because of any deleterious effects from gizzard shad. Future cove rotenone samples could provide additional insight into this recent reduction in bluegill biomass.

SUMMARY AND CONCLUSIONS

1. Data on the seasonal diets, growth, and abundance of six Claytor Lake piscivores were collected to assess the contribution of the gizzard shad as a forage fish resource. Predators included three pelagic species (walleye, striped bass, and hybrid striped bass) maintained by put-grow-take stocking and three black bass species (largemouth, smallmouth, and spotted) that are self-sustaining. Pelagic piscivores and shad were sampled by gill netting while black basses were captured by electrofishing. Comparisons of diet, growth, condition, and abundance of piscivore species were made before and after (1988) gizzard shad establishment.

2. Gizzard shad in Claytor Lake accounted for half of the striped bass diet and a third of the hybrid striper diet on an annual basis. The walleye and largemouth bass diets both consisted of between 15 and 20 % shad annually. Gizzard shad provided additional prey for pelagic piscivores on a seasonal basis, but were not heavily utilized by black basses. Pelagic piscivores, especially moronid species, consumed most gizzard shad (e.g., up to 63 % of the seasonal striped bass diet) during fall months and Summer 1998 when age-0 shad > 20 mm TL were most available. Alewives were nearly as important to striped bass, and more important to hybrid striped bass, walleye, and the black bass annual diets than gizzard shad were.

3. Black basses, especially largemouth bass, consumed more shad during spring months (up to 21 % of the Spring 1997 largemouth bass diet). This suggests possible spatial segregation of young (< 200 mm TL) shad between littoral and pelagic zones during different times of the year.

4. All three pelagic predators were highly dependent on the clupeid forage base in Claytor Lake. Only during Summer 1997, when low numbers of age-0 shad were available, did the diets of any pelagic piscivore consist of less than 80 % clupeid (alewife and gizzard shad combined). The diets of black basses were dominated by bluegill and crayfish.

5. Schoener’s (1970) Trophic Overlap Index revealed that Claytor Lake food resources were effectively partitioned between pelagic and littoral piscivores from Fall 1996 through Summer 1998. The diets of all three pelagic piscivores (striped bass, hybrid

striped bass, and walleye) significantly overlapped in almost every season, but the overlap was most severe between striped bass and their hybrids. These two moronids appeared to be trophic equivalents, and the potential for competition for food resources is high. The diets of smallmouth bass and spotted bass displayed high overlap in every season. Largemouth bass diets were similar to the other black basses, but overlap was high in only a few seasons.

6. Claytor Lake piscivore diet compositon has changed somewhat since the 1970s. Gizzard shad have partially supplanted alewives in the diets of pelagic predators in the fall and summer months. Alewife constitute greater amounts of the black bass spring diets than previously documented (Kohler 1980). Crappie and yellow perch were more important components of the 1970s diets of walleye and black basses.

7. Catch rates of age-0 and age-1 shad collected from clupeid gill nets indicated a poor 1997 gizzard shad year class compared to those in 1996 and 1998. Disparities observed in clupeid gill net catch rates of age-0 and age-1 shad corresponded with the differences seen in seasonal gizzard shad consumption by sportfish. Claytor Lake shad grew fast, attaining average sizes of 155 mm TL (± 17.3 SD) and 235 mm TL (± 20.5 SD) for ages 1 and 2, respectively. The estimated annual mortality rate for gizzard shad ages 3 - 7 was 66 %.

8. Consumption of gizzard shad by Claytor Lake piscivores was almost completely limited to a single cohort of shad. In this study, 99 % of the shad collected from fish stomachs measured less than 150 mm TL. Consequently, consumption of gizzard shad was size-limited and rapid growth means almost all shad eaten were age-0, or just age-1 (spring of second year). Rapid shad growth results in a seasonal pattern of gizzard shad consumption: low in spring, increasing (and sometimes intense) in summer, and high in the fall. Reliance on one edible age class, especially by small piscivores, makes gizzard shad an unstable food supply.

9. Striped bass annual growth rates for ages 1 – 2 have improved (length-at-ages averaging > 14 % longer and incremental growth rates exhibiting increases > 10 % for ages 1 and 3) while growth rates for walleye (except age-1) and the black basses have declined since the 1970s (Kohler 1980). Increases in striped bass growth were reflected

sizes of striped bass submitted for angler citation awards. The decreases in annual growth rates of walleye and black basses were more pronounced as age increased. The decline in largemouth bass annual growth rates was less severe than either smallmouth or spotted bass, perhaps because this species took greater advantage of gizzard shad as a prey source than the other two black basses. Hybrid striped bass were not stocked proir to gizzard shad establishment.

10. Striped bass condition (Wr) improved after the addition of shad while walleye and spotted bass were thinner post shad introduction. Largemouth and smallmouth bass exhibited no change in condition after shad establishment. All six piscivores, including hybrid striped bass, displayed mean Wr values below 100, indicating that food remains limiting even with the addition of shad.

11. Relative abundance for striped bass collected from the VDGIF's annual fall gill net sampling has exhibited a cyclic pattern and has varied over five-fold since 1981. Striped bass do not appear to be any more or less abundant after gizzard shad establishment (late 1980s) than before. A more recent trend indicated that striped bass numbers have been decreasing since reduced stocking rates were initiated in 1993 with the introduction of hybrid striped bass. Walleye do appear to be more abundant after gizzard shad establishment as VDGIF fall gill net catch rates increased dramatically in 1996 over pre-shad levels. This is most likely the result of doubling the stocking rate for walleye in 1996 and not a result of gizzard shad.

12. Electrofishing CPUE (N/hr) from VDGIF spring samples has indicated that the relative abundance of black basses (combination of all species) has remained stable. However, shifts in the proportions of each species were evident.

13. Total standing stock of littoral fishes has remained stable as evidenced by cove rotenone data. The gizzard shad expansion has supplanted carp in the littoral fish assemblage as carp biomass has declined sharply since 1991. The advent of shad has been accomplished without declines in centrarchids, perch, or catfishes.

14. Creel surveys conducted by the VDGIF on Claytor Lake have shown that total fishing effort has more than doubled from 1992 to 1998, though proportions of directed angling effort has remained similar. Stripers over 9 kg (20 lbs.) were harvested regularly in 1998,

but stripers this large were rare previous to gizzard shad establishment (VDGIF, unpublished data).

Gizzard shad were illegally introduced to Claytor Lake presumably by anglers with good intentions, but most likely without much thought toward the ecological ramifications such an introduction could materialize. After investigating the potential benefits of this newly established shad population on six Claytor Lake piscivores, a few positive results became apparent. Gizzard shad provided forage for pelagic piscivores as age-0 during late summer and fall and to a lesser extent as age-1 in spring months. The timing and extent of piscivore predation on young-of-the-year shad depends on the relative strength of the shad spawn. But, if there are fewer alewives than previous to shad introduction, then the total forage supply is not greater.

The addition of this new prey base apparently has increased striped bass growth rates and performance over pre-shad years. Although walleye participated in preying on shad, their growth rates and condition actually declined. Black basses do not seem to have benefited from the gizzard shad introduction. They did not readily consume shad on a regular basis, all three species experienced declines in growth rates, and condition for each black bass either remained consistent or declined. The observed declines in growth rates were not attributed directly to gizzard shad because competition for food resources would only be during the first year’s growth, when both black bass and shad were zooplanktivorous. Evidence of reduced sunfish forage, as a result of trophic competition with shad, was not found based on cove rotenone surveys. However, changes in the availability of crayfish (dominant prey for spotted and smallmouth bass) was not researched, although evidence supports trophic resource sharing with adult gizzard shad (Scott and Crossman 1973; R. J. Neves, Virginia Tech personal communication).

Relative abundance information compiled by the VDGIF has been highly variable, although both largemouth bass and walleye appear to have increased in abundance. Hybrid striped bass relative abundance averaged almost twice as much as striped bass (1995 – 1998), and their growth rates were similar to hybrid striped bass from Kerr Reservoir, Virginia.

Gizzard shad benefits seem most limited to the moronids in Claytor Lake, but the potential negative impacts (e.g., competition at age-0 with young of the year sportfish for zooplankton resources causing reduced growth and survival, and reducing abundance of alternative prey due to trophic overlap between age-0 shad and alewives) to these species as well as other game and non-game fishes remain to be fully understood. The negative impacts of gizzard shad to the fish assemblage of Claytor Lake were investigated concurrent with this research (Small unpublished), and they must be weighed against the results from this study. In addition, further positive or negative impacts to the Claytor Lake fisheries and other systems will continue to manifest as time advances and the shad continue to emigrate from Claytor Lake into the New River and downstream reservoirs.

MANAGEMENT RECOMENDATIONS

1. Quantitative assessment of the available supply of clupeid forage fishes in Claytor Lake is lacking. Hydroacoustic technology should be used to quantify prey supply relative to predator demand and to describe interannual variability in shad and alewife populations.
2. Although data supplied by the VDGIF were crucial to this research, inconsistencies in sampling regimes and strategies sometimes made comparison of pre versus post shad establishment data difficult. A trade-off exists between using consistent sampling techniques to evaluate trends within the data and increasing the effectiveness and efficiency of sampling gears and strategies. Assessment data, collected by the VDGIF for use in temporal comparisons, should be collected with high consideration for consistency.
3. Striped bass have taken advantage of gizzard shad as additional forage and have subsequently experienced improved growth and performance. However, striped bass CPUE from the VDGIF fall gill net sampling has declined since hybrid striper introduction. Continued monitoring of striped bass and hybrid striped bass relative abundance with routine fall gill net sampling is recommended in order to assist in evaluating competition between these two species. This information is pertinent if consideration is made to adjust moronid stocking rates.
4. Total standing stock of gizzard shad as estimated by cove rotenone sampling has risen sharply since 1988. Whether the shad population will stabilize or continue to expand is difficult to predict. Because of the unchecked increase in shad biomass, 1988 – 1997, and the reduction in bluegill standing stock in 1997, a follow-up cove rotenone survey is warranted.
5. The introduction of gizzard shad into Claytor Lake did not positively benefit the black bass species. Introducing gizzard shad into mesotrophic, highland reservoirs to augment the black bass forage base is not recommended.
6. Walleye were captured more frequently by the VDGIF fall gill net surveys than striped bass from 1996 – 1998, but account for < 1 % of the total fishing effort compared to > 10 % for striped bass and > 50 % for black bass. Walleye have historically been

underutilized in Claytor Lake and this put-grow-take fishery should be either promoted to anglers or discontinued.

7. Benefits (and/or non benefits) of the gizzard shad introduction to Claytor Lake piscivores should be included in a synthesis assessment with the negative impacts, and this educational information should be made available to the angling public. A directed effort should be made to discourage future illegal stockings of fish into other public waterbodies.

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APPENDIX TABLES

Table A1. Mean calculated total length (mm) at successive ages by age group of striped bass, Claytor Lake, Virginia, 1996-1998. Comparative data from Kohler (1980) in parentheses and Banach (1991) in brackets. Weighted mean lengths-at-ages from this study above weighted mean lengths-at-ages from previous study (Kohler 1980) followed by the same letter indicate no significant difference (α = 0.05).

		Mean calculated total length (mm) at annulus				
Age Class	N	I	II	III	IV	V
I	56 (4)	219 (192)				
II	20 (5)	236	425 (353)			
III	1 (20)	222	424	567 (523)		
IV	2 (6)	221	398	530	619 (577)	
V	3 (6)	253	425	556	641	716 (647)
Weighted Mean Total Length		230a	418a	551a	630a	716
Standard Deviation of mean		38.8	39.3	55.8	52.6	63.4
Kohler (1980)		(214)b	(387)b	(519)a	(583)a	(647)
Smith Mountain Lake, VA. (Banach 1991)		[200]	[399]	[536]	[627]	[706]
Mean Annual Increment of Total Length		230	188	133	79	86
Kohler (1980)		(214)	(173)	(132)	(64)	(64)
Smith Mountain Lake, VA. (Banach 1991)		[200]	[199]	[137]	[91]	[79]

Table A2. Mean calculated total length (mm) at successive ages by age group of hybrid striped bass, Claytor Lake, Virginia, 1996-1998. Comparative data from Banach (1991) in brackets. Weighted mean lengths-at-ages from this study above weighted mean lengths-at-ages from Kerr Reservoir (Banach 1991) followed by the same letter indicate no significant difference ($\alpha = 0.05$).

		Mean calculated total length (mm) at annulus				
Age Class	N	I	II	III	IV	V
I	23	183				
II	2	242	390			
III	79	221	386	495		
IV	7	222	394	504	554	
V	2	228	409	512	559	581
Weighted Mean Total Length		219a	395a	504a	557	581
Standard Deviation of mean		39.3	31.5	22.5	14.4	14.3
Kerr Reservoir, VA (Banach 1991)		[162]b	[379]a	[498]a		
Mean Annual Increment of Total Length		219	176	109	53	24
Kerr Reservoir, VA (Banach 1991)		[162]	[217]	[119]		

Table A3. Mean calculated total length (mm) at successive ages by age group of walleye, Claytor Lake, Virginia, 1996-1998. Comparative data from Kohler (1980) in parentheses and Banach (1991) in brackets. Weighted mean lengths-at-ages from this study above weighted mean lengths-at-ages from previous study (Kohler 1980) followed by the same letter indicate no significant difference (α = 0.05).

		Mean calculated total length (mm) at annulus				
Age Class	N	I	II	III	IV	V
I	77 (125)	311 (245)				
II	44 (66)	325	439 (405)			
III	2 (6)	310	435	471 (466)		
IV	1 (2)	332	445	496	542 (573)	
V	3 (0)	351	431	473	501	521 (-)
Weighted Mean Total Length		326a	437a	480a	522	521
Standard deviation of mean		21.5	18.5	19.1	21.5	8.4
Kohler (1980)		(253)b	(404)b	(482)a	(573)	(-)
Smith Mountain Lake, VA (Banach		[235]	[413]	[487]	[522]	[595]
Mean Annual Increment of Total Length		326	112	43	42	-1
Kohler (1980)		(253)	(151)	(78)	(91)	(-)
Smith Mountain Lake, VA (Banach		[253]	[178]	[74]	[35]	[73]

Table A4. Mean calculated total length (mm) at successive ages by age group of largemouth bass, Claytor Lake, Virginia, 1996-1998. Comparative data from Kohler (1980) in parentheses and Banach (1991) in brackets. Weighted mean lengths-at-ages from this study above weighted mean lengths-at-ages from previous study (Kohler 1980) followed by the same letter indicate no significant difference ($\alpha = 0.05$).

		Mean calculated total length (mm) at annulus					
Age Class	N	I	II	III	IV	V	VI
I	25 (20)	134 (137)					
II	15 (25)	106	229 (244)				
III	15 (12)	103	213	293 (321)			
IV	13 (10)	115	216	285	332 (398)		
V	14 (0)	97	214	294	353	386 (-)	
VI	4 (0)	116	215	281	340	386	424 (-)
Weighted Mean Total Length		112a	217a	288a	342a	386	424
Standard deviation of mean		27.9	30.1	41.6	46.3	41.0	31.2
Kohler (1980)		(134)b	(243)b	(325)b	(398)b	(-)	(-)
Smith Mountain Lake, VA (Banach		[112]	[234]	[332]	[387]	[429]	[456]
Mean Annual Increment of Total Length		112	106	71	53	44	38
Kohler (1980)		(134)	(109)	(82)	(73)	(-)	(-)
Smith Mountain Lake, VA (Banach		[112]	[122]	[98]	[55]	[42]	[27]

Table A5. Mean calculated total length (mm) at successive ages by age group of smallmouth bass, Claytor Lake, Virginia, 1996-1998. Comparative data from Kohler (1980) in parentheses and Banach (1991) in brackets. Weighted mean lengths-at-ages from this study above weighted mean lengths-at-ages from previous study (Kohler 1980) followed by the same letter indicate no significant difference (α = 0.05).

		Mean calculated total length (mm) at annulus					
Age Class	N	I	II	III	IV	V	VI
I	13 (9)	97 (104)					
II	19 (29)	91	171 (189)				
III	21 (22)	103	174	239 (300)			
IV	9 (4)	95	163	239	303 (386)		
V	4 (2)	77	174	239	300	341 (474)	
VI	3 (0)	76	136	200	245	293	326 (-)
Weighted Mean Total Length		90a	164a	229a	283a	317	326
Standard deviation of mean		28.3	25.5	29.6	36.6	36.0	23.0
Kohler (1980)		(113)b	(197)b	(303)b	(396)b	(467)	(-)
Smith Mountain Lake, VA (Banach		[109]	[210]	[306]	[380]	[454]	[-]
Mean Annual Increment of Total Length		90	74	66	53	34	9
Kohler (1980)		(113)	(84)	(106)	(93)	(71)	(-)
Smith Mountain Lake, VA (Banach		[109]	[101]	[96]	[74]	[74]	[-]

Table A6. Mean calculated total length (mm) at successive ages by age group of spotted bass, Claytor Lake, Virginia, 1996-1998. Comparative data from Kohler (1980) in parentheses. No comparative data were available from Virginia reservoirs (Banach 1991). Weighted mean lengths-at-ages from this study above weighted mean lengths-at-ages from previous study (Kohler 1980) followed by the same letter indicate no significant difference (α = 0.05).

		Mean calculated total length (mm) at annulus					
Age Class	N	I	II	III	IV	V	VI
I	5 (12)	86 (106)					
II	10 (19)	87	158 (182)				
III	14 (5)	82	150	206 (258)			
IV	8 (6)	89	164	215	259 (295)		
V	11 (6)	90	154	204	241	266 (350)	
VI	15 (2)	73	134	194	244	280	304 (364)
Weighted Mean TL this study		85a	152a	205a	248a	273a	304
Standard deviation of mean		21.1	26.7	30.7	32.9	32.4	30.8
Weighted Mean TL Kohler (1980)		(106)b	(180)b	(249)b	(295)b	(340)b	(413)
Mean Annual Increment of Total Length		85	68	53	43	25	31
Kohler (1980)		(106)	(74)	(69)	(44)	(45)	(24)

VITA

Charles Craig Bonds was born on January 8, 1974, in Houston, Texas. After the relocation of his family to rural Central Texas in 1980, he nurtured his interest in aquatic life by running trotlines in local creeks for catfish and fishing for largemouth bass and sunfish in his grandmother's stock tanks while watching the cattle come to drink. Following graduation from Holland High School in 1992, he began his collegiate studies at Tarleton State University in Stephenville, Texas, where he was offered a Presidential Honor's Scholarship. After receiving his Bachelor's degree in Fisheries Science from Texas A&M University in May 1996, he entered the graduate program in the Department of Fisheries and Wildlife Sciences in August 1996 at Virginia Polytechnic Institute and State University to pursue a Master of Science degree in Fisheries Science. During his tenure at VPI&SU, he served as both a Teaching Assistant and Research Assistant, studying the effects of an illegally introduced gizzard shad population on the piscivorous sportfishes of Claytor Lake, Virginia. Prior to completing his master's thesis in February 2000, he accepted an offer to return to his home state to work as a fisheries biologist for the Texas Parks & Wildlife Department.

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