EFFECTS OF STRIPED BASS STOCKING ON LARGEMOUTH BASS, AND SPOTTED BASS IN LEWIS SMITH LAKE, ALABAMA

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EFFECTS OF STRIPED BASS STOCKING ON LARGEMOUTH BASS, AND SPOTTED BASS IN LEWIS SMITH LAKE, ALABAMA

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EFFECTS OF STRIPED BASS STOCKING ON LARGEMOUTH BASS, AND SPOTTED BASS IN LEWIS SMITH LAKE, ALABAMA

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Michael David Shepherd, son of Sammy Shepherd and Ann (Richardson) Shepherd, was born February 15, 1982 in Salisbury, North Carolina. He graduated from East Rowan High School in Salisbury, North Carolina in 2000. He received his Bachelor of Science degree in Fisheries and Wildlife Sciences from North Carolina State University in December 2005. In January 2006, he entered the Graduate School at Auburn University in the Department of Fisheries.

THESIS ABSTRACT

EFFECTS OF STRIPED BASS STOCKING ON LARGEMOUTH BASS, AND SPOTTED BASS IN LEWIS SMITH LAKE, ALABAMA

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Striped bass *Morone saxatilis* have been introduced into over 100 USA reservoirs over the last several decades to provide additional sport fishing opportunities and to control abundant shad, *Dorosoma* spp. populations. Stocking of striped bass has been controversial and-non striped bass anglers have expressed two primary concerns; 1) striped bass consume sport fish including black bass and therefore reduce the abundance of catchable size fish; and 2) striped bass compete for limited prey with other piscivorous fish, which could reduce the growth rates and ultimately the abundance of black bass.

The objectives of this study were to 1) compare food habits among striped bass, largemouth bass, and spotted bass; 2) estimate biomass and relative weights of all three species; and 3) predict consumptive food demand of all three species. Striped bass, largemouth bass *Micropterus salmoides* and spotted bass *M. punctulatus* were sampled every other month in Lewis Smith Lake, Alabama (8,583 ha) between October 2006 and August 2007. In addition, striped bass were sampled in November 2005, and April and June 2006. Striped bass and black bass stomachs were examined to describe food habits and striped bass were aged using otoliths to describe striped bass growth and survival. Growth and survival were estimated for largemouth bass and spotted bass from historically collected age data. Density and biomass of striped bass, largemouth bass, and spotted bass were estimated using striped bass stocking densities, black bass age-0 densities, and mortality rates and weight:length relations for each species. Fish bioenergetics models were used to estimate striped bass and black bass consumptive food demands.

Striped bass diets (by weight) were dominated by shad (64%), while black bass and sunfish/crappie comprised 5% and 6% of the diet, respectively. Largemouth bass and spotted bass diets were dominated by crayfish 72% and 75%, respectively and sunfish 21% and 9%, respectively, while shad comprised 6 and 14% of the diets, respectively. Diet overlap values varied seasonally among species with highest overlap in June between striped bass and black bass, but relative weights of black bass did not decline. Black bass diets shifted from shad to crayfish in December when striped bass consumption of shad was the highest. Black bass relative weights were slightly depressed in December and indicated the potential for a competitive interaction between striped bass and black bass. Partitioning of prey resources between black bass and striped bass was evident throughout the rest of the year and diet overlap was minimal.

Striped bass and black bass biomass estimates were nearly equal between species groups and ranged from 0.7 to 9.4 kg/ha, and 1.4 to 8.3 kg/ha, respectively. Overall, consumptive prey demand was similar between striped bass and black bass. Bioenergetics modeling indicated striped bass consume between 3 to 28 kg/ha a year of shad and 0.2 and 2.3 kg/ha a year of black bass, while annually black bass consume between 1 to 3 kg/ha of shad, 7 to 25 kg/ha of crayfish, and 2 to 6 kg/ha of sunfish. All black bass consumed by striped bass were less than the 330-381 mm slot limit on Lewis Smith Lake, and striped bass consumption of these black bass provided an additional mechanism to reduce small black bass. Although striped bass did consume some black bass, impact on the black bass population was low, striped bass and black bass partitioned prey resources, and impact of striped bass stocking on the black bass population was low.

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INTRODUCTION

Striped bass *Morone saxatilis* have been introduced into over 100 USA reservoirs over the last several decades (Axon and Whitehurst 1985) to provide additional sport fishing opportunities and to control abundant shad, *Dorosoma* spp. populations. Self-sustaining populations in land-locked reservoirs have rarely been established resulting in striped bass populations maintained through stocking. Most of these reservoirs also contain viable black bass *Micropterus* spp fisheries. Lewis Smith Lake, Alabama has a popular recreational sport fishery for striped bass, and black bass which includes largemouth bass *M. salmoides* and spotted bass *M. punctulatus*. Stocking of striped bass has been controversial and anglers have expressed two primary concerns; 1) striped bass consume sport fish including black bass reducing the abundance of catchable size fish; and 2) striped bass and other sport fish including black bass are competing for limited prey which could reduce the growth rates and ultimately the abundance of black bass.

Piscivorous black bass have been shown to consume mostly shad and sunfish *Lepomis* spp in reservoirs (Timmons and Pawaputanon 1980; Storck 1986; Bettoli et al. 1992; Janssen 1992; Alicea et al. 1997; Miranda and Pugh 1997). Timmons and Pawaputanon (1980) showed diets of largemouth bass on West Point Lake, Alabama-Georgia, were dominated by bluegill, threadfin shad *D. petenense*, and gizzard shad *D.*

cepedianum. Largemouth bass greater than 120 mm in Lake Conroe, Texas, consumed mostly shad, sunfish *Lepomis* spp., and silversides *Menidia* spp. (Bettoli et al. 1992). Alicea (1997) showed that diets from juvenile largemouth bass in Lucchetti Reservoir, Puerto Rico were primary threadfin shad and bluegills, while Miranda and Pugh (1997) also indicated juvenile largemouth bass diets were dominated by shad and bluegills in Aliceville Lake, Alabama-Mississippi. Janssen (1992) indicated that smallmouth bass *M. dolomieu*, spotted bass and largemouth bass in Pickwick Reservoir, Alabama mainly consumed threadfin and gizzard shad. Finally, Storck (1986) indicated that gizzard shad was the most important prey species of largemouth bass in Lake Shelbyville, Illinois.

Studies have shown that adult striped bass consume mostly pelagic dwelling clupeids including gizzard shad, threadfin shad, and alewives *Alosa pseudoharengus* (Combs 1978; Slipke et al. 2001; Raborn et al. 2002; Sutton and Ney 2002; Thompson et al. 2005). Striped bass rarely consume other young or adult sport fish such as crappie *Pomoxis* spp., sunfish, and black bass. Van Den Avyle et al. (1983) found diets of young-of-the-year striped bass in Watts Bar Reservoir, Tennessee contained nearly all larval shad. Striped bass and largemouth bass greater than 50 mm showed low diet overlap in Smith Mountain Lake, Virginia (Sutton and Ney 2002). In Lake Texoma, Texas diet overlap between juvenile striped bass and largemouth bass occurred and suggested potential trophic competition although the two species occupied substantially different habitats as juveniles (Matthew et al. 1992). Slipke et al. (2001) indicated that the diet of striped bass in Weiss Lake, Alabama consisted numerically of 93% shad and only 0.2% crappie and natural reproduction of striped bass showed no negative impacts on the crappie population. Raborn et al. (2002) found clupeids and sunfish accounted for 94 and 2% of striped bass diet, respectively, in Norris Reservoir, Tennessee. Raborn et al. (2002) also simulated the removal of all striped bass in Norris Reservoir to predict the possible increase in biomass of other sport fish. As a result of this modeling, the potential increase in other sport fish biomass was 3% with a 75% probability that this increase in biomass would be less than 12% if striped bass were not stocked and eliminated. Finally, Thompson et al. (2005) indicated that striped bass diets consisted of 92 and 97% clupeids in two North Carolina reservoirs.

Consumptive prey demand of striped bass and black bass populations in reservoirs varied and was dependent on reservoir trophic state, morphology, available prey sources, and predator population sizes. Miranda et al. (1998) indicated that striped bass in Norris Reservoir, Tennessee consumed 65 kg/ha of prey items, while largemouth bass and spotted bass consumed 64 and 31 kg/ha of prey items, respectively. Thompson et al. (2005) found striped bass consumed 117 and 100 kg/ha of prey items in two North Carolina reservoirs. Finally, Cyterski (1999) showed striped bass in Smith Mountain Lake, Virginia consumed 84 kg/ha of prey items, while largemouth bass consumed 48 kg/ha of prey items.

As water temperatures increase during the summer months, striped bass tend to migrate downstream in reservoirs to inhabit cooler water temperatures (Cheek et al. 1985; Moss 1985; Lamprecht and Shelton 1988; Hampton et al. 1988; Matthews et al. 1989; Bjorgo et al. 2000; Bettoli 2005; Thompson et al. 2005). However, most reservoirs seasonally exhibit low concentrations of dissolved oxygen and prevent striped bass from using cooler water which they prefer. Zale et al. (1990) found that striped bass tolerated exposures to 27-28°C temperatures for about one month, but died from malnutrition if water temperatures were any higher for any prolonged period of time. Thompson et al. (2005) found that striped bass in Lake Norman and Badin Lake, North Carolina occupied either water just above the oxycline or the coolest water available with at least 2 mg/L dissolved oxygen when water temperatures exceeded 20°C. Moss et al. (2003) found during the summer months when water temperatures increased, striped bass migrate downstream and inhabit the lower more oligotrophic portions of Lewis Smith Lake.

In oligo-mesotrophic reservoirs, shad were less abundant than in more productive reservoirs, which was related to lower growth and body condition of black bass (Bayne et al 1994; DiCenzo et al. 1995; DiCenzo et al 1996; Maceina et al 1996; Allen et al. 1999). With striped bass migrating to these more prey limited oligo-mesotrophic waters during summer months and potential competitive interactions between introduced striped bass and black bass, this investigation was warranted.

In this study, I quantified and compared food habits of striped bass, largemouth bass, and spotted bass in Lewis Smith Lake, Alabama. I estimated the density and biomass, relative weight, growth, and survival of striped bass, largemouth bass, and spotted bass. The abundance of gizzard shad and threadfin shad, which I assumed would be important items in the diets of all three species, was estimated throughout the reservoir. Based on temperature, growth, food consumed, and body condition, I predicted the consumptive demands of striped bass, largemouth bass and spotted bass, and the potential for deleterious effects of striped bass stocking on the black bass population in Lewis Smith Lake.

STUDY SITE

Lewis Smith Lake, Alabama is a 8,583 ha reservoir (Figure 1) with a mean depth of 20 m and an annual retention time of 435 days (DiCenzo et al. 1996). Since 1983, a total of 1.1 million advanced striped bass fry (25-50 mm) were stocked into Lewis Smith Lake. Annual stocking rates ranged from 3.7 to 8.9 fish/ha. From data collected by Alabama Department of Environmental Management (ADEM), Lewis Smith Lake is oligotrophic (Forsberg and Ryding 1980) reservoir, with an average chlorophyll *a* concentrations in 2007 of 2.5 mg/m^3 (range 0.1 to 9.1 mg/m^3). I colleted fish from the dam forebay, Sipsey River, and Ryan Creek in 2007 (Figure 1), and chlorophyll *a* concentrations averaged 1.0, 1.4, and 2.5 mg/m^3, respectively, in 2007 (ADEM, unpublished chlorophyll *a* data). Ryan Creek historically has had higher chlorophyll *a* concentrations than other regions in Lewis Smith Lake due to nutrient additions from poultry operations in this watershed (ADEM, unpublished data).

METHODS

Collection and Processing

Striped bass were collected using five monofilament gill nets, 60 m long and 2.3 m deep with panels containing 76, 102, 127 mm bar mesh, and 4 baited longlines containing 19 circle hooks in November 2005, April and July 2006. Longlines were baited with gold fish *Carassius auratus* obtained from the Alabama Department of Wildlife and Freshwater Fisheries (ADWFF) Carbon Hill fish hatchery. Based on low catch rates of striped bass with longlines, striped bass were only collected with gill nets after September 2006. Five additional monofilament gill nets, 60 m long and 3.6 m deep with panels containing 76, and 102 mm bar mesh were included when sampling for a total of 10 gill nets of effort and striped bass were sampled every other month between October 2006 and August 2007. Gill nets and longlines were set approximately 5-10 m below the water surface during each sampling period in the late afternoon and checked every six hours over a 12-hour period.

Striped bass were collected from three different tributary locations conductive to seasonal aggregations including Ryan Creek, the Sipsey River, and the dam forebay (Figure 1). Additional striped bass were collected with DC electrofishing while sampling for black bass and used for diet analysis and age assignment. Upon collection, striped bass were placed in a solution of MS-222 until they expired. Once sacrificed, total length (TL) was measured to the nearest mm, fish were weighed to the nearest 10 g, stomach contents removed and frozen, and sagittal otoliths removed for aging.

From the same regions that striped bass were collected, largemouth bass and spotted bass over 200 mm were collected every other month between October 2006 and August 2007 at night with DC electrofishing in littoral zone (Smith Root 7.5 GPP). Black bass were measured (TL mm), fish were weighed to the nearest 1 g, food items removed using clear acrylic tubes, and then released. For each collection period (N=6), about 80 individuals of each black bass species were collected for food habit analysis from each sampling region (N=3).

Daily water temperature was determined from July 2006 to July 2007 at a single station located in Ryan Creek at 8 depths ranging from 1 m to 20 m using HOBO water temperature pro data loggers. Loggers were programmed to record temperature (C) every four hours and temperatures were then averaged to provide mean daily temperatures at each depth. These data were used in the bioenergetics model simulations (see section in methods).

On 20 and 21 of August 2007, an hydroacoustic survey to estimate the abundance of gizzard shad and threadfin shad was conducted starting an hour after dark (21:00) till dawn (5:00) from the three study regions in the reservoir. Hydroacoustic echogram transects were conducted along a series of cross channel transects using a Biosonics DT-X digital ecosounder with an elliptical transducer oriented for down-looking data while a circular transducer collected side-scanning data simultaneously. The side-scanning transducer collected data from water surface to 2 m depth and down-looking transducer collected data from 2 m to bottom of water column. Echograms were read and data generated by Aquacoustics Inc. (D. Degan, Sterling, Alaska). Data for gizzard shad and threadfin shad abundance were pooled to estimate clupeid abundance and biomass for fish less than 190 mm TL. Estimates of shad abundance were examined in relation to food habits and relative weights of each species.

Gizzard shad, threadfin shad, bluegill, and brook silverside *Labidesthes sicculus,* were collected in June 2007 and twenty five individuals of each species were dried to a constant weight at a temperature of 60 - 70^{C} for caloric density analysis. Each dried fish was ground to a powder form and analyzed using a Parr 6725 Semimicro Bomb Calorimeter following procedures of Rand (1994). Caloric density values were compared to values reported by Eggleton and Schramm (2002) to confirm consistency of reported values. A reduced caloric value for crayfish (923 cal/g) was used to account of the percent undigestibility of crayfish. These data were used in the bioenergetics model simulations (see section in methods).

Diet analysis

Food items were identified and counted to the nearest practical taxon. Prey items were placed into 7 different categories including; (1) shad (gizzard shad, threadfin shad and unidentified clupeids), (2) sunfish, (3) black bass, (4) crayfish (*Oronectes* spp.), (5) insects, (6) silversides, and (7) other. For consumed prey fish, total length (mm), standard length (mm) or backbone length (mm) were measured based on amount of digestion and otolith radius was taken if an otolith was found. For consumed crayfish, carapace length if present was measured. Measurements of prey were converted to total length and wet weight using regression equations (Table 1, and 2; Raborn et al 2002; Thompson et al 2005; D. Glover unpublished data, Auburn University; S. Sammons unpublished data, Auburn University). When carapace length or backbone length was not available, crayfish and clupeids were assigned the mean total length for specimens collected.

Total numeric and percentage of prey consumed by all three species were compared using the Percent Resource Overlap Index (PROI) developed by Schoener (1970) to assess diet overlap and extent of shared food resources; PROI values over 60 were considered as high diet overlap (0 = no overlap; 100 = complete overlap). Diet overlap was calculated and compared for each sampling month to examine possible temporal shifts in diet overlap.

For fish that contained food, differences in the number of food items consumed was examined with two-way analysis-of-variance (ANOVA) among species, months, and the month-by-species interaction. If a significant interaction was detected, a Bonferroni correction ($P = 0.05/N$) was applied to correct for the type I error rate to assess species differences in monthly number of prey items consumed, where N was equal to the number of comparisons. Differences in percent empty stomachs among species and over seasonal collection periods were examined using Chi-squared analysis. Relation between lengths of consumed shad and striped bass, largemouth bass, and spotted bass lengths were described by regression analysis and tested for significant differences among species by analysis of covariance. In addition, the differences in the ratios of prey length-to-predator length were tested with one-way ANOVA and means were compared with the Student-Neuman-Keuls (SNK) multiple range test.

Age and Growth

Striped bass otoliths were sectioned and aged following the procedures of Maceina (1988). Partial year ages were assigned to striped bass based on the month collected. If striped bass were collected in July, 0.17 years were added to age, if collected in August, 0.25 years were added to age, and if collected between October and December, 0.5 years were added to age. Ages of unaged striped bass were assigned to fish using a length:age key. Ages for largemouth bass (N = 364) and spotted bass (N = 297) were obtained for data collected from 2002 to 2007 by the ADWFF and Auburn University using DC electrofishing. Spring collections were not made every year and data were pooled among years for each species. Striped bass, largemouth bass, and spotted bass growth were described using the von Bertalanffy (1938) growth equation based on mean lengths-at-age at capture for each species:

$$L_t = L_\infty (1 - \mathbf{e}^{-k(t - to)})$$

where L_∞ is the maximum theoretical length that can be obtained, k is the growth coefficient, t is age in years, and t_o is the time in years when length would theoretically be equal to zero. For all three species, L_∞ was fixed for the longest individual collected.

Relative weights (Wr) were computed using standard weight equations (Anderson and Neumann 1996) for each species, and compared to diet data to infer any region-time-species interactions. Differences in relative weights among sampling months, and regions were tested using two-way ANOVA, and comparisons made using SNK multiple range tests. When a significant region-by-month interaction was detected, a Bonferroni ($P = 0.05/N$) correction was applied to test for monthly and regional differences. Species-specific length categories were assigned to fish and these were from stock density indices listed by Anderson and Neuman (1996). Relative weights were only analyzed for quality ($\geq$510 mm TL) striped bass and this size fish represented 88% of all striped bass collected. Stock length and larger ($\geq$200 mm TL) black bass were analyzed for relative weight.

Bioenergetics Modeling

Food consumption demands of striped bass, largemouth bass, and spotted bass were estimated with the generalized bioenergetics model and software by Hanson et al. (1997) described as:

$$C = (R + A + S) + (F + U) + (\Delta B + G)$$

where C is consumption, R is respiration, A is active metabolism, S is specific dynamic action, F is egestion, U is excretion, ΔB is somatic growth, and G is gonad production. Consumption and respiration are temperature and size dependent and egestion and excretion are functions of consumption. With temperature and fish size, the energy budget of each species was solved to estimate the amount of food that must be consumed to produce observed growth. Physiological parameters required to conduct bioenergetics modeling have been thoroughly published for striped bass (Hartman and Brant 1995; Table 3), and largemouth bass (Rice et al 1983; Table 3), but parameters for spotted bass have not been throughly developed. Since spotted bass in Lewis Smith Lake are the Alabama *M. p. henshalli* subspecies of spotted bass and exhibited similar growth to largemouth bass, I used physiological parameters developed for largemouth bass for spotted bass (Table 3). Species specific physiological parameters that correspond to the components of the energetics equation described above are listed in the Appendix and were described by Hanson et al. (1997).

Estimates of Density, Biomass, and Mortality for Striped Bass and Black Bass

Age-0 largemouth bass and spotted bass densities were estimated by extrapolating densities determined from littoral 0.02 ha area rotenone samples (Green and Maceina 2000). Perimeter (m) and area (ha) of each sampling region in Lewis Smith lake were calculated using ArcGIS 9.1. Age-0 striped bass densities were obtained from average ADWFF stocking densities that provided low and high stocking rates. Natural mortality for striped bass between age-0 to age-1 was from Moore et al (1991) and a range of high and low mortality was used (Table 4). A range of natural mortality rates for largemouth bass and spotted bass between age-0 and age-1 were used and estimated from Jackson and Noble (2000) (Table 4). Total annual mortality between age-1 and age-3 was assumed to be similar to annual mortality after age-3 estimated from weighted catch-curve regressions for all three species. Total population abundances of striped bass, largemouth bass, and spotted bass, inhabiting Lewis Smith Lake were estimated using density estimates and mortality rates for each species using Fishery Analysis and Simulation Tools (FAST) software (Slipke and Maceina 2006). Based on age-0 densities and subsequent mortality (both fishing and natural), average biomass and prey consumption demands were computed and compared for each cohort and species.

Density of clupeids estimated from hydroacoustic sampling and the length-frequency distribution was used to estimate the number of fish within 1 cm size groups. Biomass of clupeids ($\leq$190 mm, TL) was estimated using the weight-length regression equations, derived by Miranda et al (1998) for threadfin shad and gizzard shad (Table 2). I assumed the majority of clupeids sampled > 100 mm TL were gizzard shad, and clupeids < 100 mm TL were threadfin shad, and associated regression equations were applied accordingly. Densities of clupeids in each sampling region of Lewis Smith Lake were mapped using an inverse distance weighted interpolation of the data colleted from each region in ArcGIS 9.1.

RESULTS

Collection

A total of 718 striped bass, 1,382 largemouth bass, and 1,392 spotted bass were collected for diet analysis. Of the striped bass collected, 615, 15, and 88 were collected with gill nets, longlines, and electrofishing, respectively (Table 5). Of striped bass collected, 661 were sacrificed for age determination. Sample sizes of each species collected from each region is presented in Table 5.

Catch-per-effort (CPE) of striped bass in gill nets averaged 3 fish/net night over the study, with the highest CPE (mean = 5 fish/net night) in December 2006. Catch was significantly higher ($P < 0.10$) in December 2006 than in June 2007 (mean = 1 fish/net night) and July 2006 (mean = 1 fish/net night) and catch was higher ($P < 0.10$) in April 2007 (mean = 4 fish/net night) than in July 2006. Total length of striped bass collected in gill nets averaged 697 mm with minimum and maximum TLs of 368 mm and 1,050 mm, respectively. Catch-per-effort of striped bass captured with longlines averaged 0.5 fish/line/night over the study, and TL averaged 777 mm and minimum and maximum TLs were 564 mm and 961 mm, respectively. Striped bass collected with electrofishing averaged 375 mm TL with minimum and maximum lengths of 210 mm and 850 mm, respectively.

Relative weight

Two-way ANOVA indicated region, month, and the region-by-month interaction were related ($P < 0.01$) to variation in quality (> 510 mm TL) striped bass relative weights. Time of sampling or month was the strongest variable ($F = 35.15$; $P < 0.0001$) that explained differences in striped bass relative weights. For all three regions, relative weights were typically highest in February and April and were generally lowest in late summer and early fall (Figure 2). Overall relative weights were slightly greater ($P < 0.01$) in the Sipsey River (mean $W_r = 94$) and Ryan Creek (mean $W_r = 94$) compared to relative weights in the dam forebay (mean $W_r = 92$).

Two-way ANOVA indicated region, month, and the region-by-month interactions were related ($P < 0.01$) to variation in largemouth bass relative weights. Regional variation in relative weight was the strongest variable ($F = 98.21$; $P < 0.01$) that explained differences in largemouth bass relative weights. Relative weights were greater ($P < 0.01$) in Ryan Creek (mean $W_r = 85$) than in the Sipsey River (mean $W_r = 80$) and the dam forebay (mean $W_r = 79$). For 5 of 6 monthly comparisons, relative weights were higher in either or both Ryan Creek and the Sipsey River compared to the dam forebay (Figure 3).

Two-way ANOVA indicated region, month, and the region-by-month interactions were related ($P < 0.01$) to variation in spotted bass relative weights. In the two-way ANOVA, regional variation was the strongest variable in the model ($F = 55.72$; $P < 0.01$) that explained differences in spotted bass relative weights. Relative weights were greater ($P < 0.01$) in Ryan Creek (mean $W_r = 83$) compared to the Sipsey River (mean $W_r = 79$) and the dam forebay (mean $W_r = 78$). For 4 of 6 monthly comparisons, relative weights of spotted bass were higher in Ryan Creek than in both the dam forebay and the Sipsey River (Figure 3).

Age, Growth and Mortality

The maximum age observed was 14 years for striped bass and the longest length collected was 1,050 mm. The von Bertalanffy equation predicted striped bass reached quality (510 mm), preferred (760 mm), and memorable (890 mm) lengths in 2.2, 5.7, and 9.1 years, respectively (Figure 4). For 3 to 14 year old striped bass, estimated total annual mortality from weighted catch-curve regression analysis was 45% (Figure 5).

For data collected from 2002 to 2007, the maximum age observed was 10 years for largemouth bass and the longest length collected was 580 mm. The von Bertalanffy equation predicted largemouth bass reached quality (300 mm), preferred (380 mm), and memorable (510 mm) lengths in 2.5, 4, 8.8 years, respectively (Figure 4). For 3 to 10 year old largemouth bass, estimated total annual mortality from weighted catch-curve regression was 42% (Figure 5).

For data collected from 2002 to 2007, the maximum age observed was 11 years for spotted bass and the longest length collected was 564 mm. The von Bertalanffy equation predicted spotted bass reached quality (280 mm), preferred (350 mm), and memorable (430 mm) lengths in 2.6, 3.8, and 5.6 years, respectively (Figure 4). For 3 to 11 year old spotted bass, estimated total annual mortality from weighted catch-curve regression analysis was 50% (Figure 5).

Diet Composition

For striped bass, 70% of stomachs contained prey contents and these fish consumed 9,344 prey items (Table 6). Shad (98%) numerically comprised nearly all food consumed. Crayfish (0.9%), sunfish (0.3%), black bass (0.2%), other fish (0.2%) and silversides (0.1%) comprised the remaining striped bass diet numerically (Table 6). Other prey items consisted of flathead catfish *Pylodictis olivaris*, mobile logperch *Percina kathae*, redhorse *Moxostoma* spp., salamander, and unidentifiable fish. Diet composition by wet weight was dominated by shad (64%). Other fish (13%), crayfish (12%), sunfish (6%), black bass (5%) and silversides (≤0.01%) comprised the remaining striped bass diet by weight (Table 7).

For largemouth bass, 50% of stomachs contained prey contents and these fish consumed 1,047 prey items (Table 6). Shad (50%), crayfish (19%), sunfish (16%), silversides (7%), insects (6%), other items (1%), and black bass (1%) were the predominate food items consumed numerically by largemouth bass (Table 6). Other prey items consisted of brown water snake *Nerodia taxispilota*, salamander *Ambystoma* spp., golden shiner *Notemigonus crysoleucas*, blacktail shiner *Cyprinella venusta*, frog *Rana* spp., and unidentifiable fish. Diet composition by wet weight was dominated by crayfish (72%). Sunfish (21%), shad (6%), black bass (1%), insects (0.2%), other items (0.1%), and silversides (0.1%) comprised the remaining largemouth bass diet by weight (Table 7).

For spotted bass, 45% of stomachs contained prey contents and these fish consumed 1,034 prey items (Table 6). Shad (68%), crayfish (15%), sunfish (7%), silversides (5%), insects (2%), other fish (2%), and black bass (0.3%) were the predominate food items consumed numerically by spotted bass (Table 6). Other prey items consisted of mobile logperch, earthworm *Lembricus* spp., flathead catfish, darter *Percidae* spp., shiner *Cyprinella* spp., and unidentifiable fish. Diet composition by wet weight was dominated by crayfish (75%) followed by shad (14%), sunfish (9), black bass (0.6%), other items (0.6%), silversides (0.2%), and insects (0.2%; Table 7).

Frequency of empty stomachs were different among months for striped bass (χ^2 = 123.6, $P < 0.01$), largemouth bass (χ^2 = 142.6, $P < 0.01$) and spotted bass (χ^2 = 106.6, $P < 0.01$; Figure 6). Striped bass and spotted bass occurrence of empty stomachs were similar in February (χ^2 = 0.36, $P = 0.55$), while striped bass had fewer empty stomachs than spotted bass in other months except April ($P < 0.01$). Occurrences of empty stomachs between largemouth bass and spotted bass were similar ($P > 0.1$) between March and December, while spotted bass had higher (χ^2 = 7.04, $P < 0.01$) occurrence of empty stomachs in February than largemouth bass. For all months pooled, number of food items in stomachs were higher ($P < 0.01667$) for striped bass (mean = 19) than largemouth bass (mean = 2) and spotted bass (mean = 2). Largemouth bass and spotted bass consumed higher ($P < 0.0833$) number of food items in either or both February (mean = 3; mean = 2, respectively) and December (mean = 2; mean = 2, respectively) than all other sampling months (Figure 7). Striped bass consumed higher ($P < 0.0833$) number of food items in December (mean = 46) and the lowest number in June (mean = 3), than all other sampling months (Figure 7).

Numerically, overall diet overlap was higher between spotted bass and largemouth bass (overlap = 81), was fairly high between striped bass and spotted bass (overlap = 69), and was less between striped bass and largemouth bass (overlap = 51). High diet overlap ($\geq$60) between largemouth bass and striped bass was observed only in two of six temporal comparisons, but occurred in four of six comparisons between striped bass and spotted bass (Figure 8). With the exception of June 2007, diet overlap was always high ($\geq$73) between largemouth bass and spotted bass. During the summer (June and August), diet overlap between striped bass and largemouth bass was low, but was higher during the summer months between striped bass and spotted bass.

When examining diet overlap by weight of prey consumed, lower overlap was evident between largemouth bass and striped bass (overlap = 25), and spotted bass and striped bass (overlap = 33) compared to numerical overlap indices. High overlap by weight was similar to numeric diet overlap between largemouth bass and spotted bass (overlap = 88; Figure 8). High diet overlap ($\geq$60) between spotted bass and striped bass was observed in only one of six temporal comparisons, while largemouth bass and striped bass overlap among months was low and varied from 7 to 51 (Figure 8). Diet overlap was always high ($\geq$60) between largemouth bass and spotted bass with the exception on June 2007. Diet overlap among striped bass and black bass was highest in April and June, but lower ($\leq$27) in all other sampling months. Highest diet overlap by weight between striped bass and black bass occurred in June.

A weak positive relation ($P < 0.01$) between lengths of consumed shad total lengths and striped bass and spotted bass lengths were evident, while no relation was evident between largemouth bass lengths and consumed shad lengths (Figure 9). Based on analysis of covariance, the slopes of the regression for consumed shad lengths to predator lengths were higher for spotted bass compared to striped bass ($P < 0.01$) and were also for spotted bass than largemouth bass ($P < 0.01$). Thus, spotted bass consumed larger shad than largemouth bass and striped bass controlling for the effects of predator length. A difference between the slopes for striped bass and largemouth bass length-to-shad length regression was not detected ($P = 0.8$). Similarly, the ratio of shad lengths to predator lengths differed ($P < 0.01$) among species and spotted bass (mean = 0.18) consumed larger ($P < 0.01$) shad, followed by largemouth bass (mean = 0.16), then striped bass (mean = 0.08). When all prey items consumed were included in the analysis for the ratio of prey length-to-predator length, spotted bass (mean = 0.18) consumed larger ($P < 0.01$) items followed by largemouth bass (mean = 0.17), then striped bass (mean = 0.08).

Density and Biomass Estimates for Striped Bass and Black Bass

Estimated largemouth bass and spotted bass age-0 population densities in Lewis Smith lake were 28/ha for both species (Table 8). Estimates of black bass total biomass ranged from 1.4 to 8.3 kg/ha (Table 9). Densities of age-0 striped bass were 5/ha and 8/ha at low and high stocking rates, respectively (Table 8), and total biomass ranged from 0.7 to 9.4 kg/ha (Table 9). Biomass of black bass and striped bass were sensitive to changes in age-0 to age-1 mortality rates.

From the hydroacoustic survey conducted in August 2007, gizzard shad and threadfin shad biomass was over 4 times higher in Ryan Creek than the Sipsey River and the Dam forebay (Table 10). Densities of gizzard shad and threadfin shad in the Sipsey

River and the Dam forebay ranged from approximately 1,500 fish/ha to 22,000 fish/ha, while shad densities in Ryan Creek ranged from 1,500 fish/ha to 81,000 fish/ha (Figure 10). Total biomass of shad in Lewis Smith Lake was 188,075 kg (Table10) and based on the correction factor of 5 presented by Jenkins and Morais (1978), total shad production approached 1.0 million kg in Lewis Smith Lake.

Bioenergetics Modeling

Annually, striped bass in Lewis Smith Lake consumed between 42,215 and 392,560 kg of prey, while largemouth bass consumed between 49,809 and 182,037 kg and spotted bass consumed between 37,271 and 106,167 kg of prey at high and low age-0 mortality rates, respectively (Tables 11-18). Total consumption was lowest in February for all three species when water temperatures were below 10° C (Figure A.1). Black bass consumption was highest between June and September when water temperatures were highest (Figure A.1) and for striped bass between October and December when water temperatures were cooler (Figure A.1;Tables 11-18). From the ranges of simulations conducted, total striped bass and black bass consumption averaged 186,100 and 187,642 kg, respectively.

Consumption rates of clupeids for striped bass and consumption rates of crayfish and sunfish for black bass accounted for species specific monthly variations in total consumption rates. Consumption of clupeids was highest in October and December for black bass and striped bass, respectively. Consumption of clupeids by striped bass accounted for between 13 and 82% of total clupeid consumption by all three species.

Overall, striped bass consumption of black bass and sunfish accounted for 8 and 5% of total striped bass consumption, respectively, while clupeids accounted for 65% of total striped bass consumption (Tables 11-18). Conversely, clupeids accounted for only 6 to 16% of total black bass consumption, while crayfish (62 to 72%) were the dominate item consumed followed by sunfish (13 to 29%). At maximum consumption rates, black bass and striped bass could potentially consume 3 and 26% of the total shad production in Lewis Smith Lake, respectively.

Data describing species-specific diets were input into the bioenergetics models as prey proportions (by wet weight) of total diets, while diet compositions were expressed as frequency of total diets. Thus, the proportion of diet comprised by a given prey item may appear to differ in total annual consumption estimates (Tables 11-18) as compared to previously reported total annual diet composition estimates (Table 6).

DISCUSSION

Striped bass consumption of black bass and other sportfish

Striped bass consumptive demand on black bass and sunfish in Lewis Smith Lake were a small, but substantial percentage (13%) of their diet, but was higher than I expected. Numerically striped bass predation on black bass and sunfish were low, and similar to values reported in other reservoirs. In Weiss Lake, Alabama 0.4% of the diets of striped bass numerically consisted of sunfish (Slipke et al. 2001). Non-clupeid species, including white perch *M. americana*, bluegill, and black crappie *Pomoxis nigromaculatus*, comprised 3.8% and 1% numerically of striped bass diets in Badin Lake and Lake Norman, North Carolina, respectively (Thompson et al. 2005). In Norris Reservoir, Tennessee, 5% of striped bass diets by weight consisted of lepomids, while no black bass were consumed by striped bass (Raborn et al. 2002). In Claytor Lake, Virginia, 8.3% (numerically) of striped bass diets consisted of non-clupeids, including sunfish, crappie, yellow perch *Perca flavescens*, and minnows *Notropis* spp. (Kohler and Ney 1981). In Lewis Smith Lake, 36% of the diets by weight of striped bass consisted of non-clupeids, which was much higher than previously reported. Possibly, lower shad abundance in this oligotrophic reservoir was related to a reduction of striped bass consumption of these prey fish.

By weight black bass and sunfish/crappie comprised 5% and 6% of striped bass diets, respectively, although striped bass only consumed 15 black bass which ranged in TL from 25 mm to 305 mm with a mean TL of 178 mm. Striped bass consumed 26 sunfish/crappie which ranged in TL from 71 mm to 290 mm with a mean TL of 127 mm. Thus, although striped bass consumption of black bass and sunfish were a small proportion of their diet numerically, the black bass and sunfish consumed accounted for a higher proportion of the weight of striped bass diets. While black bass consumed 13 black bass which ranged in TL from 65 mm to 129 mm with a mean TL of 107 mm and accounted for 2% of black bass diets. Thus, black bass cannibalism on young black bass was about half that of striped bass predation on black bass.

When consumption estimates were extrapolated to population levels, bioenergetics models estimated that striped bass and black bass could consume up to 19% and 14%, respectively, of the total biomass of black bass in Lewis Smith Lake. However, no black bass greater than 305 mm were consumed by striped bass. Currently a 330 mm to 381 mm slot length limit is enforced for black bass on Lewis Smith Lake. Slot length limits were designed to protect fish within a specified length limit and allow harvest of smaller fish in order to increase growth rates of protected fish and increase abundance of larger fish (Anderson 1976). Eder (1984) found that harvest of largemouth bass less than the 300 mm slot length limit successfully increased largemouth bass population size structure in a Missouri impoundment. Gabelhouse (1984) found that inadequate removal of largemouth bass less than the 300 mm to 380 mm slot length limit in a Kansas impoundment caused the slot length limit to function much like a 380 mm minimum length limit thereby slowing growth of smaller largemouth bass. Although striped bass consumption estimates of black bass were modest, black bass consumed by striped bass were all less than the 330 mm slot length limit. As a result, striped bass consumption of black bass has the potential to increase growth rates of quality sized black bass.

Competitive interaction between striped bass and black bass

Striped bass primarily consumed small (< 100 mm TL) shad in Lewis Smith Lake. By weight, crayfish, sunfish, black bass, and other fish contributed 36% of prey consumed by striped bass. Largemouth bass and spotted bass diets were dominated by shad, crayfish, and sunfish, but the later two items comprised 84 to 93% of spotted bass and largemouth bass diets by weight, respectively. Thompson et al. (2005) reported that diets of striped bass consisted numerically of 92% clupeids in Badin Lake, North Carolina, and 97% clupeids in Lake Norman, North Carolina. In Lake Hamilton, Arkansas, shad accounted for the greatest percentage by weight (85%) and numerically (93%) of prey eaten by striped bass (Filipek and Tommey 1984). Crayfish, bluegill and young-of-year largemouth bass were the predominant food items of largemouth bass in American Horse Lake, Oklahoma, as crayfish accounted for 40% by weight of largemouth bass diets (Summers 1981). In Bull Shoals Reservoir, Arkansas, largemouth bass diets contained primarily crayfish, centrarchids and shad, while spotted bass diets were almost exclusively crayfish (Aggus 1973).

Overall, consumptive prey demand from bioenergetics models were similar between striped bass and black bass in Lewis Smith Lake, although striped bass consumed on average 22 times as many diet items as black bass in December. Diet overlap between striped bass and black bass was relatively low during this time of higher consumption by striped bass and black bass relative weights slightly were depressed. Striped bass diets during December were almost exclusively shad, while black bass diets shifted from mainly shad in October to crayfish in December. This shift in diet composition and the reduction of black bass relative weights in December may have been due to a competitive interaction between striped bass and black bass for food resources during this time. Highest diet overlap values between striped bass and both black bass species occurred in June. In June, black bass relative weights were not depressed even though diet overlap was higher and the potential for competitive interactions between striped bass and black bass species was not evident. Generally, striped bass and black bass partitioned prey resources throughout the rest of the year as diet overlap values by weight were minimal between striped bass and black bass and large temporal fluctuations in relative weights were not evident.

Diet overlap numerically and by weight were high in all temporal comparisons between largemouth bass and spotted bass except during June. These higher diet overlap values between black bass species showed a greater potential for food competition between largemouth bass and spotted bass in Lewis Smith Lake than between striped bass and either largemouth bass or spotted bass. Miranada et al. (1998) found similar high diet overlap values and the potential for intraspecific competition between largemouth bass and spotted bass in all temporal comparison except during summer months in Norris Lake, Tennessee.

Lewis Smith Lake is an oligotrophic reservoir and predator sport fish biomass has been shown to be related to trophic state (Ney 1996). I estimated black bass biomass in Lewis Smith Lake ranged from about 1 to 8 kg/ha, but biomass was likely at the intermediate portion of this range. Swingle (1954) estimated 8-9 kg/ha of black bass in coves and open waters in mesotrophic Lake Martin, Alabama. The average standing stock of black bass in 171 USA reservoirs was 11 kg/ha (Jenkins 1975). In Lake Normandy, Tennessee, black bass biomass averaged 10 kg/ha in this mesotrophic reservoir (Sammons and Bettoli 1998).

Black bass relative weights were consistently higher in the more productive Ryan Creek (chlorophyll *a* = 2.5 mg/m^3) than in the less productive Sipsey River and Dam forebay (chlorophyll *a* = 1.0 and 1.4 mg/m^3, respectively). These higher relative weights in Ryan Creek were related to higher shad biomass estimates and likely other prey items, in Ryan Creek than in the Sipsey River and the Dam forebay. Regional differences in striped bass relative weights were detected as relative weights were slightly higher in Ryan Creek and the Sipsey River, although these differences were not biologically significant. These differences in striped bass and black bass body conditions with changes in trophic state are similar to observed differences in other reservoirs. DiCenzo et al. (1995) and Maceina et al (1996) found that growth and condition of spotted bass and largemouth bass was positively related to chlorophyll *a* levels in Alabama reservoirs. Allen et al. (1999) reported densities and growth of larval shad and age-0 largemouth bass increased with chlorophyll *a* levels across nine Alabama reservoirs. DiCenzo et al (1996) observed higher relative abundance, slower growth, and poorer condition of gizzard shad in eutrophic reservoirs than in oligo-mesotrophic reservoirs which resulted in greater vulnerability of shad to predation.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Consumptive food demand of striped bass and black bass were similar between these two groups. Striped bass predominantly consumed shad, although by weight black bass and sunfish/crappie accounted for 11% of striped bass diets. Black bass diets predominantly consisted of crayfish and shad. For a majority of the year, striped bass and black bass partitioned prey resources, diet overlap was typically minimal, but the potential for a competitive interaction between striped bass and black bass existed only in December. Striped bass consumptive demand of shad constituted 64% of their demand, while black bass demand of shad constituted 22% of their consumptive demand. Although striped bass demand for shad was high, black bass demand was low for shad as these fish consumed more crayfish and sunfish. Thus, the potential for a limited prey resource in Lewis Smith Lake between striped bass and black bass was minimal.

Alabama Department of Wildlife and Freshwater Fisheries currently stocks between 4-8 fish/ha annually into Lewis Smith Lake. North Carolina Wildlife Resources Agency has stocked striped bass into Badin Lake, North Carolina at a rate of 12 fish/ha since 1996 (Thompson et al 2005). Miranda et al (1998) reported stocking densities of striped bass in Norris Reservoir, Tennessee by Tennessee Wildlife Resources Agency ranged from 7-19 fish/ha. Sutton and Ney (2001) reported Virginia Game and Inland

Fisheries stocked striped bass at 36 and 27 fish/ha into Smith Mountain Lake, Virginia in 1994 and 1995, respectively. Although Lewis Smith Lake stocking rates are lower than most reservoirs, Cyterski (1999) observed that increased stocking rates of fingerling striped bass had negative effects on the number and condition of harvestable size striped bass in Smith Mountain Lake, Virginia. By weight, striped bass consumption of black bass in Lewis Smith Lake, was minimal and for all stomachs examined (N = 718), only 15 black bass (≤ 305 mm) were consumed. With the 330-380 mm slot limit for black bass, ADWFF encourages anglers to harvest small black bass to reduce density in an attempt to improve growth rates. Striped bass consumption of small black bass, although low, provided an additional management tool to reduce small black bass in Lewis Smith Lake. Competitive interactions for prey resource between striped bass and black bass was minimal and striped bass only consumed a few small black bass. Results of this project suggest annual stocking of striped bass can be continued at the current stocking rates without significant negative impacts on black bass growth and population abundance.

TABLES

Table 1. Regression equations ($TL = b_o + b_1X$) used for estimating total length (TL, mm) of prey fish from X (standard, backbone, carapace length and otolith radius) in Lewis Smith Lake. The intercepts (b_o), slopes (b_1), and r^2 are reported.

	Standard Length			Backbone Length			Otolith Radius			Carapace Length		
Species	b_o	b_1	r^2	b_o	b_1	r^2	b_o	b_1	r^2	b_o	b_1	r^2
Gizzard Shad[a]	6.99	1.22	0.99	4.54	1.47	0.97						
Threadfin Shad[a]	1.34	1.26	0.98	17.04	1.26	0.92						
Dorosoma Spp.[b]				0.29	1.63	0.98						
Bluegill[a,c]	4.65	1.22	0.99	13.28	1.66	0.92	0.24	1.34	0.93			
Micropterus spp[d,c]	-0.725	1.27	0.99				0.45	1.19	0.97			
Crayfish[c]										6.49	1.99	0.95
Silversides[e]	-1.59	1.20	0.99									

[a] Values derived from Raborn et al (2002).

[b] Values derived from Thompson et al (2005).

[c] Values derived from Sammons (unpublished data).

[d] Values derived from Irwin (2001).

[e] Values derived from Glover (unpublished data).

Table 2. Weight-length regression equations ($\log_{10}(Y) = b_0 + b_1 * \log_{10}(X)$) used for estimating wet weight of prey fish in Lewis Smith Lake. Y is weight in grams and X is total length in millimeters.

Species	Equation	Coefficient of determination
Gizzard Shad[a]	$Y = -5.40 + 3.14(X)$	0.90
Threadfin Shad[a]	$Y = -4.49 + 2.70(X)$	0.71
Sunfish[b]	$Y = -5.27 + 3.26(X)$	0.98
Crayfish[b]	$Y = -4.03 + 3.24(X)$	0.99
Largemouth Bass[a]	$Y = -5.07 + 3.07(X)$	0.99
Spotted Bass[a]	$Y = -4.90 + 3.01(X)$	0.99
Brook Silverside[c]	$Y = -5.07 + 2.86(X)$	0.99
Insects[d]	$Y = -3.07 + 2.29(X)$	0.92

[a] Values derived from Miranda et al (1998).

[b] Values derived from Irwin (2001).

[c] Values derived from Glover (unpublished data).

[d] Values derived from Ganihar (1969).

Table 3. Physiological parameters for modeled species that correspond to the various equations of the fish bioenergetics model described in the appendix. Parameters for largemouth bass and spotted bass were taken from Rice et al. (1983), and striped bass from Hartman and Brandt (1995). Blanks indicate no parameter is needed for the species-specific model.

			Striped Bass			
Parameters	Largemouth Bass	Spotted Bass	Age-0	Age-1	Age-2	Adults
CA	0.33	0.33	0.3021	0.3021	0.3021	0.3021
CB	-0.325	-0.325	-0.2523	-0.2523	-0.2523	-0.2523
CQ	2.65	2.65	2.6	6.6	6.6	7.4
CTO	27.5	27.5	21.6	19	18	15
CTM	37	37	22.7	28	29	28
CTL			28.3	30	32	30
CK1			0.047	0.262	0.255	0.323
CK4			0.713	0.85	0.9	0.85
RA	0.00279	0.00279	0.001456	0.0028	0.0028	0.0028
RB	-0.355	-0.355	-0.2702	-0.218	-0.218	-0.218
RQ	0.811	0.811	0.08339	0.076	0.076	0.076

Table 3. (continued)

Parameters	Largemouth Bass	Spotted Bass	Striped Bass			
			Age-0	Age-1	Age-2	Adults
RTO	0.0196	0.0196	0.9014	0.5002	0.5002	0.5002
RTM	0	0	0	0	0	0
RTL	0	0	0	0	0	0
RK1	1	1	1	1	1	1
RK4	0	0	0	0	0	0
ACT	1	2	1	1	1	1
BACT	0	0	0	0	0	0
SDA	0.163	0.163	0.172	0.172	0.172	0.172
FA	0.104	0.104	0.104	0.104	0.104	0.104
UA	0.068	0.068	0.068	0.068	0.068	0.068
PED	4186	4186	5023	6488	6488	6488

Table 4. Age-0 and age-1 and older annual mortality rates (%) estimated for targeted species in Lewis Smith Lake. Mortality rates were derived from catch-curves unless otherwise noted.

Species	Age 0 to Age 1	Age1 and older[c]
Striped Bass	69 to 96[a]	45
Largemouth Bass	76 to 96[b]	42
Spotted Bass	76 to 96[b]	50

[a] Mortality rates obtained from Moore et al. (1991).

[b] Mortality rates obtained from Jackson and Noble (2000).

[c] Catch curves were computed for age 3 and older fish, and I assumed annual mortality was similar between age 1 and age 3.

Table 5. Numbers of striped bass (STR), largemouth bass (LMB), and spotted bass (SPB) collected from each sampling region with corresponding sampling gear in Lewis Smith Lake for food habits analysis.

	Dam Forebay			Sipsey River			Ryan Creek		
Gear	STR	LMB	SPB	STR	LMB	SPB	STR	LMB	SPB
Electrofishing	35	474	349	7	421	493	37	487	550
Gill nets	152			125			347		
Longlines	5			3			7		
Total	192	474	349	135	421	493	391	487	550

Table 6. Number of stomachs retrieved and their numeric diet contents from striped bass, largemouth bass, and spotted bass from Lewis Smith Lake.

			Dorosoma		*Lepomis*		*Micropterus*		Crayfish		*Labidesthes*		Insects		Other	
Species	N	With food (%)	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Striped Bass	718	70	9,194	(98)	26	(0.28)	15	(0.16)	84	(0.90)	10	(0.11)	0	-	15	(0.16)
Largemouth Bass	1,382	50	523	(50)	170	(16)	10	(0.95)	199	(19)	74	(7)	65	(6)	13	(1)
Spotted Bass	1,392	45	700	(68)	74	(7)	3	(0.29)	158	(15)	58	(6)	23	(2)	18	(2)

Table 7. Wet weight of prey (Wt, g) and percentage of total consumption (%) consumed by striped bass, largemouth bass and spotted bass in Lewis Smith Lake.

	Total	*Dorosoma*		*Lepomis*		*Micropterus*		Crayfish		*Labidesthes*		Insects		Other	
Species	Wt	Wt	%	Wt	%	Wt	%	Wt	%	Wt	%	Wt	%	Wt	%
Striped Bass	31,726	20,293	(64)	2,005	(6)	1,459	(5)	3,891	(12)	0.95	(0.003)	0	-	4,077	(13)
Largemouth Bass	16,798	1,066	(6)	3,463	(21)	150	(1)	12,042	(72)	24	(0.1)	37	(0.2)	16	(0.1)
Spotted Bass	9,197	1,314	(14)	863	(9)	55	(0.6)	6,866	(75)	15	(0.2)	23	(0.2)	60	(0.6)

Table 8. Estimated age-0 largemouth bass, and spotted bass, densities by sampling regions and lake totals derived from Green and Maceina (2000), and age-0 striped bass densities derived from high and low stocking rates.

	Largemouth bass		Spotted bass		Striped bass high stocking		Striped bass low stocking	
	N	N/ha	N	N/ha	N	N/ha	N	N/ha
Ryan Creek	16,322	7	50,477	22				
Dam forebay	4,738	4	15,077	13				
Sipsey River	213,010	41	174,065	34				
Overall	239,070	28	239,619	28	68,800	8	43,000	5

Table 9. Estimated population densities of striped bass (STR), largemouth bass (LMB), and spotted bass (SPB) in Lewis Smith Lake.

Age	STR 5/ha cm 0.69	STR 5/ha cm 0.96	STR 8/ha cm 0.69	STR 8/ha cm 0.96	LMB cm 0.96	LMB cm 0.76	SPB cm 0.96	SPB cm 0.76
0	43,000	43,000	68,800	68,800	234,070	234,070	239,619	239,619
1	13,330	1,720	21,328	2,752	8,895	54,538	9,105	55,831
2	7,331	946	11,730	1,514	5,159	31,632	4,553	27,916
3	4,032	520	6,452	832	2,992	18,347	2,276	13,958
4	2,218	286	3,548	458	1,735	10,641	1,138	6,979
5	1,220	157	1,952	252	1,006	6,172	569	3,489
6	671	86	1,073	138	584	3,580	284	1,745
7	369	47	590	76	339	2,076	142	872
8	203	26	325	42	196	1,204	71	436
9	112	14	178	23	114	698	25	218
10	61	8	98	13	66	405	18	109
11	34	4	54	7			9	54
12	18	2	30	4				
13	10	1	16	2				
14	5	1	9	1				

Table 9. Continued.

	STR 5/ha cm 0.69	STR 5/ha cm 0.96	STR 8/ha cm 0.69	STR 8/ha cm 0.96	LMB cm 0.96	LMB cm 0.76	SPB cm 0.96	SPB cm 0.76
Total Number	72,615	46,818	116,183	74,913	255,156	363,363	257,820	351,226
Number/ha	8.4	5.4	13.5	8.7	29.6	42.2	29.9	40.8
Total weight (kg)	50,769	6,551	81,231	10,481	7,616	46,697	4,162	25,520
Weight/ha	5.9	0.7	9.4	1.2	0.9	5.4	0.5	2.9

Table 10. Gizzard shad and threadfin shad density and biomass estimates derived from hydroacoustics sampling in sampling region in Lewis Smith Lake.

	Ryan creek	Dam forebay	Sipsey river
Density (number/ha)	27,115	5,903	5,751
Total Biomass (kg)	118,560	12,964	56,551
Biomass (kg/ha)	52	11	11
Area (ha)	2,280	1,179	5,141

Table 11. Total monthly consumption estimates (kg) of prey for striped bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for low stocking rate (5/ha) and low age-0 to age-1 mortality (0.69).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	1,544	0	0	12,634	0	0	0	14,178
February	1,103	0	0	9,022	0	0	0	10,125
March	1,192	1,210	1,393	11,090	0	0	0	14,885
April	457	4,128	4,751	8,287	0	0	0	17,623
May	449	4,430	8,587	5,434	0	846	3	19,749
June	1,322	1,404	11,890	3,192	0	2,487	9	20,304
July	915	1	12,784	5,694	0	1,441	5	20,840
August	4,510	227	6,070	10,567	0	0	0	21,374
September	5,215	268	1,212	15,058	0	0	0	21,753
October	1,592	90	413	22,677	0	3	0	24,775
November	671	570	2,940	23,255	0	220	0	27,656
December	1,021	1,006	2,766	27,089	0	195	0	32,077
Total	19,991	13,334	52,806	153,999	0	5,192	17	245,339

Table 12. Total monthly consumption estimates (kg) of prey for striped bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for low stocking rate (5/ha) and high age-0 to age-1 mortality (0.96).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	199	0	0	1,628	0	0	0	1,827
February	142	0	0	1,163	0	0	0	1,305
March	154	156	179	1,429	0	0	0	1,918
April	59	532	612	1,068	0	0	0	2,271
May	58	572	1,110	702	0	109	0	2,551
June	193	201	1,735	462	0	364	1	2,956
July	144	0	2,035	916	0	225	1	3,321
August	814	41	1,063	1,885	0	0	0	3,803
September	1,009	52	235	2,934	0	0	0	4,230
October	328	18	85	4,735	0	1	0	5,167
November	145	123	637	5,031	0	48	0	5,984
December	219	216	596	5,809	0	42	0	6,882
Total	3,464	1,911	8,287	27,762	0	789	2	42,215

Table 13. Total monthly consumption estimates (kg) of prey for striped bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for high stocking rate (8/ha) and low age-0 to age-1 mortality (0.69).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	2,470	0	0	20,213	0	0	0	22,683
February	1,764	0	0	14,434	0	0	0	16,198
March	1,908	1,936	2,229	17,743	0	0	0	23,816
April	735	6,605	7,602	13,259	0	0	0	28,201
May	719	7,088	13,739	8,695	0	1,353	5	31,599
June	2,115	2,247	19,024	5,106	0	3,980	15	32,487
July	1,464	2	20,455	9,110	0	2,306	9	33,346
August	7,217	363	9,713	16,908	0	0	0	34,201
September	8,344	429	1,940	24,093	0	0	0	34,806
October	2,547	144	661	36,285	0	5	0	39,642
November	1,074	912	4,704	37,211	0	352	0	44,253
December	1,634	1,610	4,425	43,346	0	313	0	51,328
Total	31,991	21,336	84,492	246,403	0	8,309	29	392,560

Table 14. Total monthly consumption estimates (kg) of prey for striped bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for high stocking rate (8/ha) and high age-0 to age-1 mortality (0.96).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	319	0	0	2,608	0	0	0	2,927
February	228	0	0	1,862	0	0	0	2,090
March	246	250	287	2,289	0	0	0	3,072
April	94	852	981	1,710	0	0	0	3,637
May	93	916	1,778	1,124	0	175	1	4,087
June	310	323	2,777	701	0	583	2	4,696
July	230	0	1,466	360	0	0	1	2,057
August	1,302	66	1,701	3,017	0	0	0	6,086
September	1,616	83	375	4,696	0	0	0	6,770
October	524	30	137	7,579	0	1	0	8,271
November	233	198	1,019	8,052	0	76	0	9,578
December	351	345	953	9,297	0	67	0	11,013
Total	5,546	3,063	11,474	43,295	0	902	4	64,284

Table 15. Total monthly consumption estimates (kg) of prey for largemouth bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for low age-0 to age-1 mortality (0.76).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	39	344	4,512	434	0	11	7	5,347
February	26	229	3,010	289	0	7	5	3,566
March	28	1,102	3,703	500	1	10	8	5,352
April	14	4,328	3,592	1,060	4	13	15	9,026
May	80	8,835	5,339	1,545	84	25	22	15,930
June	324	11,645	10,021	1,057	314	49	14	23,424
July	379	10,542	15,521	595	340	49	12	27,438
August	191	6,008	19,593	533	116	23	18	26,482
September	313	3,649	20,204	1,451	19	9	23	25,668
October	521	2,373	16,061	2,460	5	2	22	21,444
November	262	1,676	7,996	1,320	4	0	24	11,282
December	86	1,693	4,723	540	8	0	28	7,078
Total	2,263	52,424	114,275	11,784	895	198	198	182,037

Table 16. Total monthly consumption estimates (kg) of prey for largemouth bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for high age-0 to age-1 mortality (0.96).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	6	53	697	67	0	2	1	826
February	4	35	466	45	0	1	1	552
March	4	171	574	78	0	1	1	829
April	2	666	553	163	1	2	2	1,389
May	12	1,343	813	234	13	4	3	2,422
June	80	2,832	2,454	252	77	12	3	5,710
July	112	3,108	4,617	176	100	14	4	8,131
August	61	1,928	6,296	171	37	7	6	8,507
September	103	1,194	6,619	477	6	3	7	8,409
October	176	800	5,417	829	2	1	8	7,233
November	86	544	2,607	431	1	0	8	3,677
December	26	507	1,419	162	2	0	8	2,124
Total	672	13,181	32,532	3,085	239	47	52	49,809

Table 17. Total monthly consumption estimates (kg) of prey for spotted bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for low age-0 to age-1 mortality (0.76).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	182	73	2,936	439	1	1	1	3,633
February	118	47	1,913	286	1	0	1	2,366
March	127	532	2,055	721	6	31	9	3,481
April	28	3,889	2,631	3,345	59	279	68	10,299
May	60	2,392	972	2,183	26	153	42	5,828
June	116	2,185	10,786	1,877	92	256	39	15,351
July	109	1,176	13,824	808	100	184	12	16,213
August	29	1,775	11,677	1,047	92	141	9	14,770
September	67	1,708	9,923	2,020	59	96	6	13,879
October	132	1,116	7,104	2,737	14	45	2	11,150
November	60	608	3,651	1,400	2	16	9	5,746
December	12	451	2,366	595	3	10	14	3,451
Total	1,040	15,952	69,838	17,458	455	1,212	212	106,167

Table 18. Total monthly consumption estimates (kg) of prey for spotted bass in Lewis Smith Lake. Estimates were derived from bioenergetics and simulations were for high age-0 to age-1 mortality (0.96).

Month	Black Bass	Sunfish	Crayfish	Clupeid	Insect	Other	Silverside	Total
January	27	11	445	66	0	0	0	549
February	18	7	293	44	0	0	0	362
March	20	82	318	112	1	5	1	539
April	9	370	151	337	4	24	6	901
May	4	601	416	517	9	43	10	1,600
June	34	625	3,157	537	27	74	11	4,465
July	41	437	5,199	301	37	69	4	6,088
August	13	743	4,943	436	39	60	4	6,238
September	29	774	4,487	896	27	44	2	6,259
October	66	566	3,598	1,372	7	23	1	5,633
November	32	309	1,865	725	1	8	4	2,944
December	6	220	1,158	295	2	5	7	1,693
Total	299	4,745	26,030	5,638	154	355	50	37,271

FIGURES

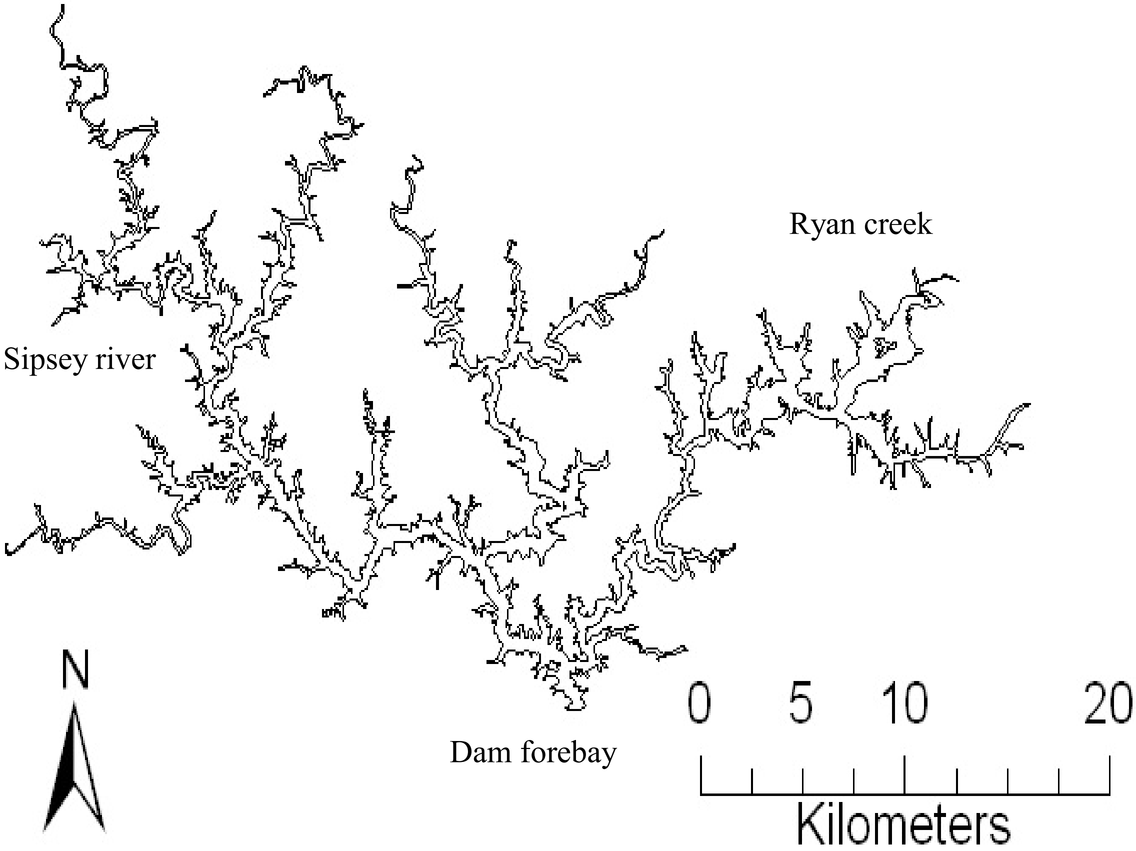

Figure 1. Map of Lewis Smith Lake and sampling regions.

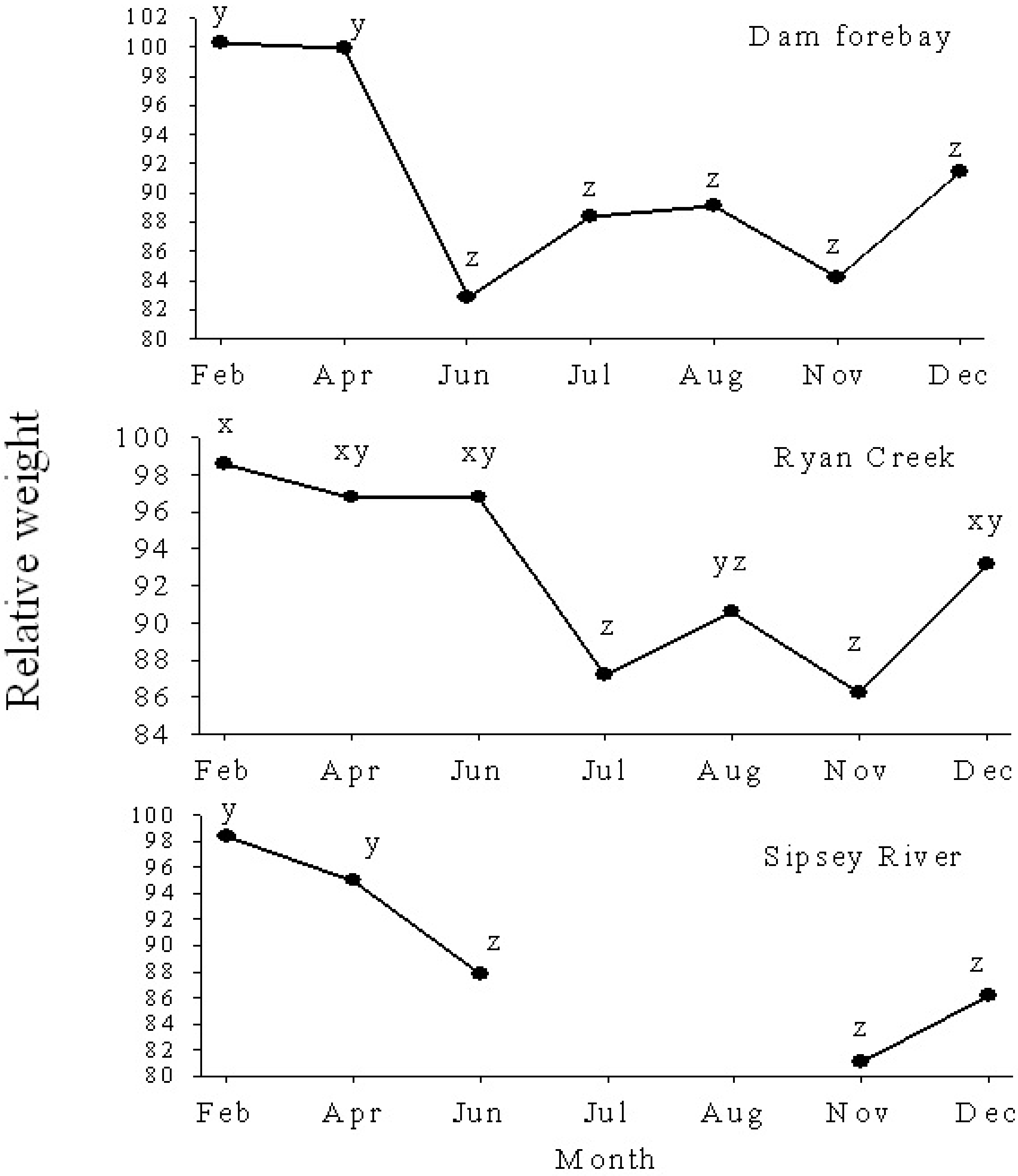

Figure 2. Mean relative weights of quality size (≥ 510 mm, TL) striped bass for each sampling region across sampling months in Lewis Smith Lake. Mean values followed by the same letter for a specific month were not statistically ($P \geq 0.00833$; Bonferroni corrected) different.

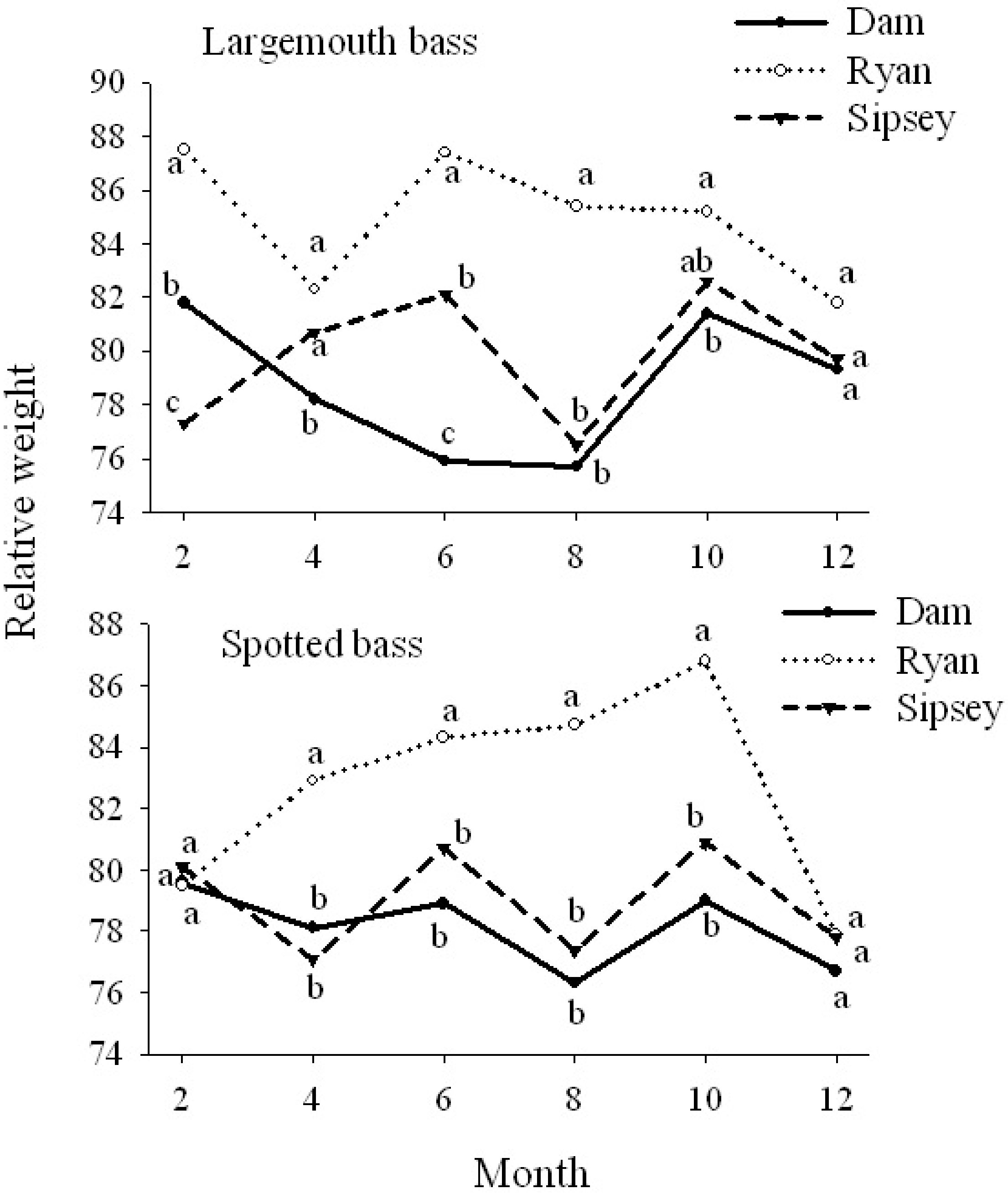

Figure 3. Mean relative weights of largemouth bass and spotted bass in each sampling region over each sampling month in Lewis Smith Lake. Mean values in each region followed by the same letter for a specific month were not statistically (P ≥0.01667; Bonferroni corrected) different.

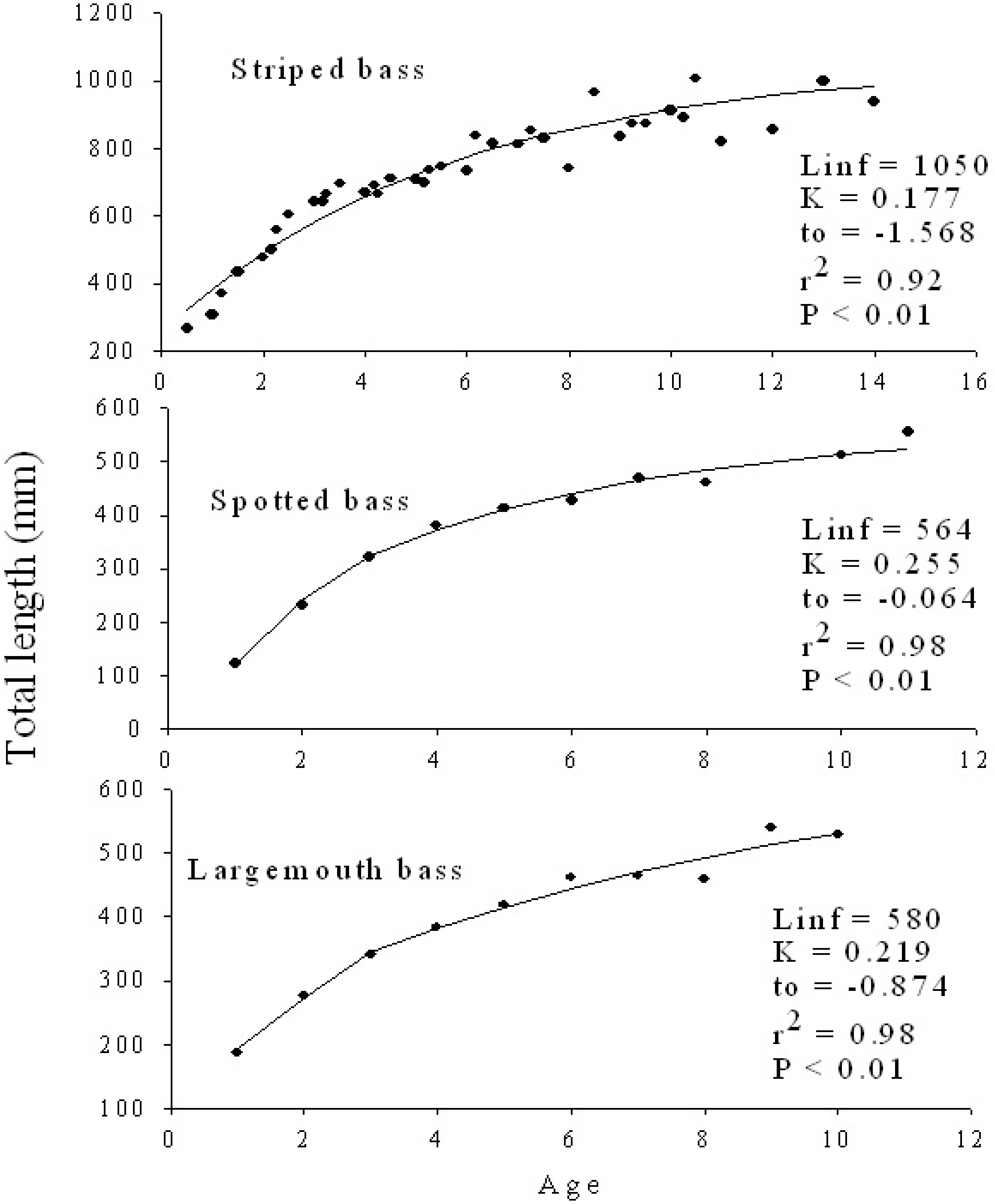

Figure 4. von Bertalanffy growth curve coefficients for striped bass, spotted bass, and largemouth bass. Data plotted are mean lengths at age and black bass were collected by ADWFF and AU between 2002 and 2007.

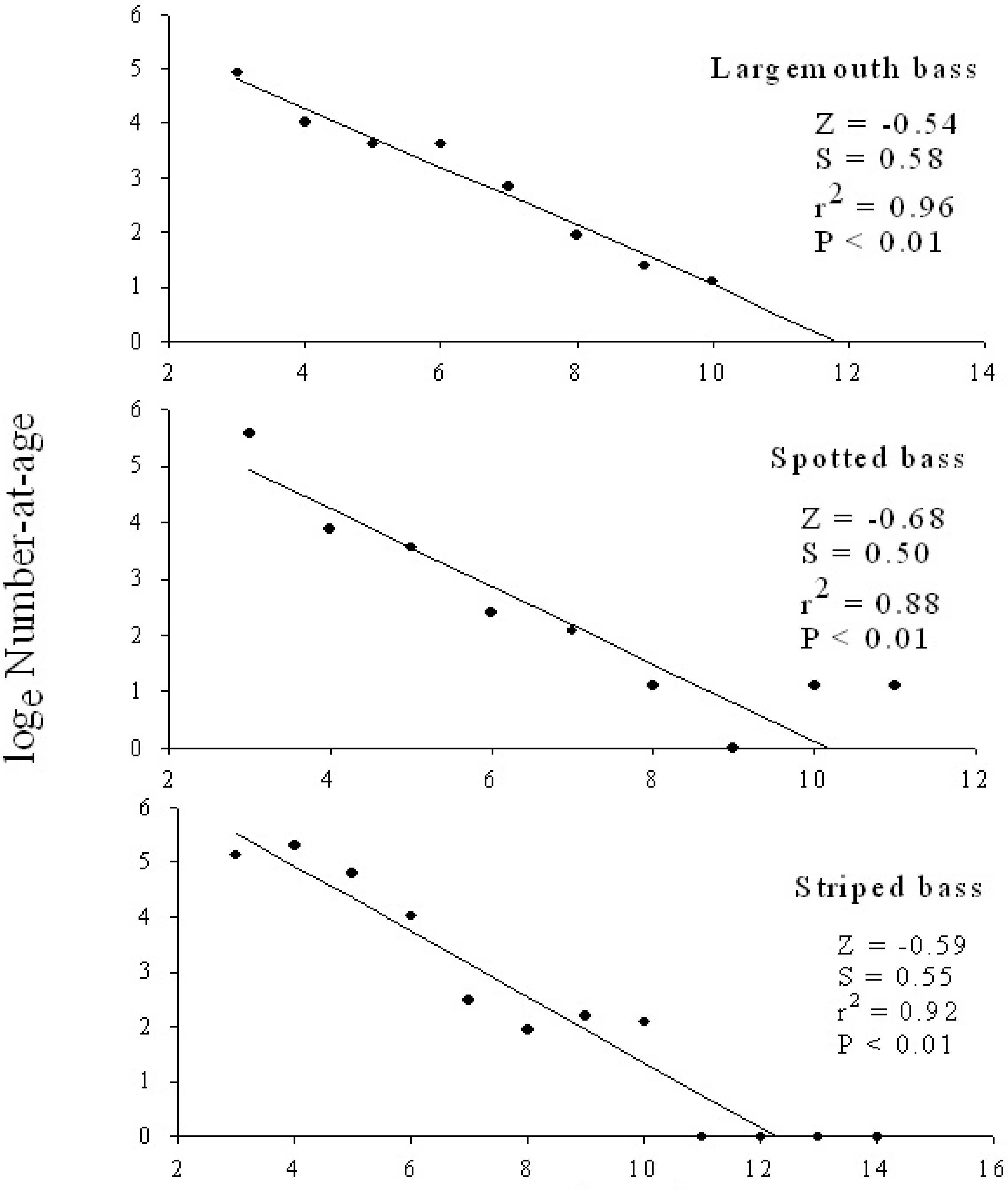

Figure 5. Weighted catch-curve regression and associated statistics for largemouth bass, spotted bass and striped bass. Black bass were collected by ADWFF and AU between 2002 and 2007.

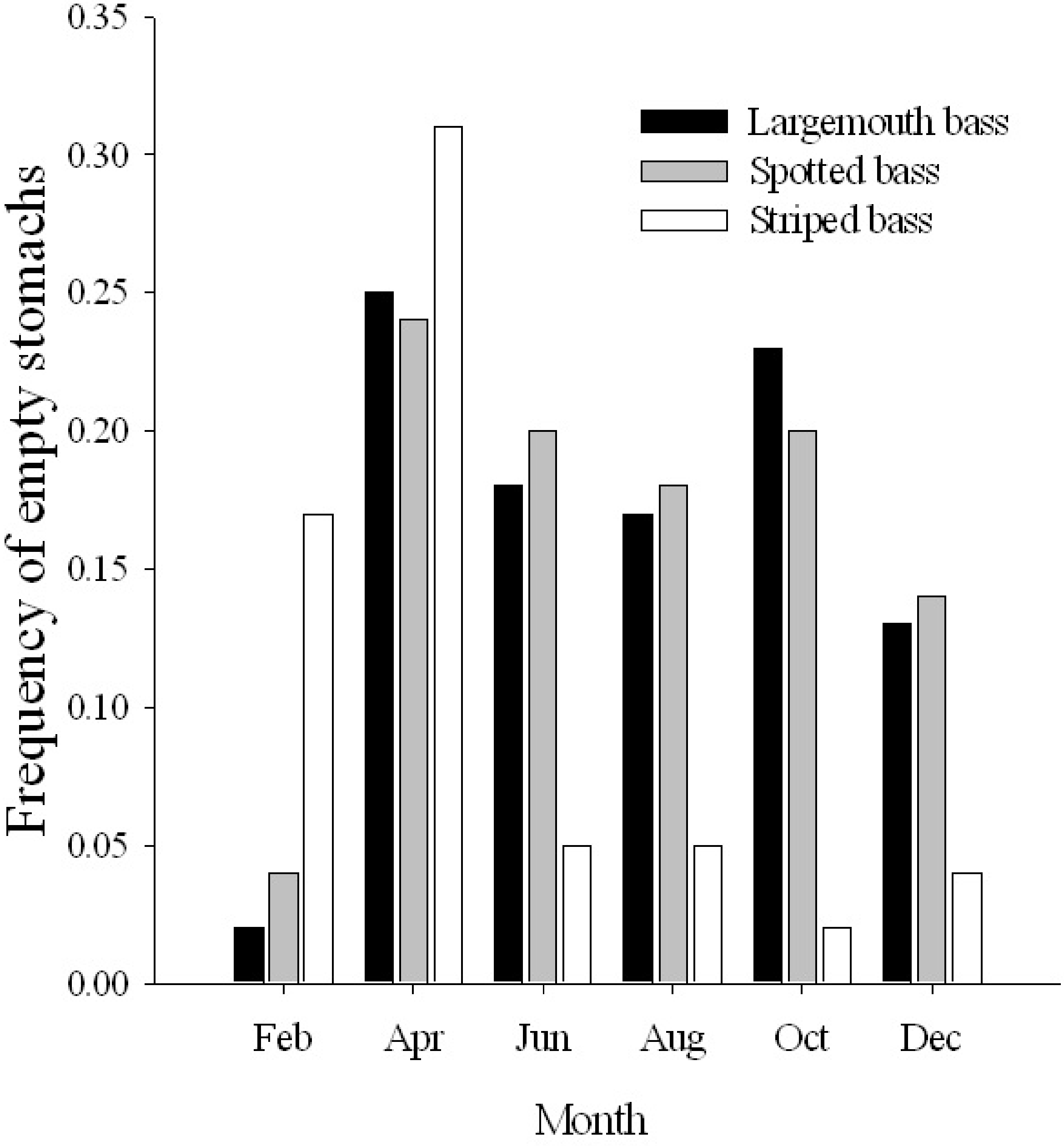

Figure 6. Frequency of occurrence of empty stomachs in largemouth bass, spotted bass and striped bass stomachs across sampling months in Lewis Smith Lake.

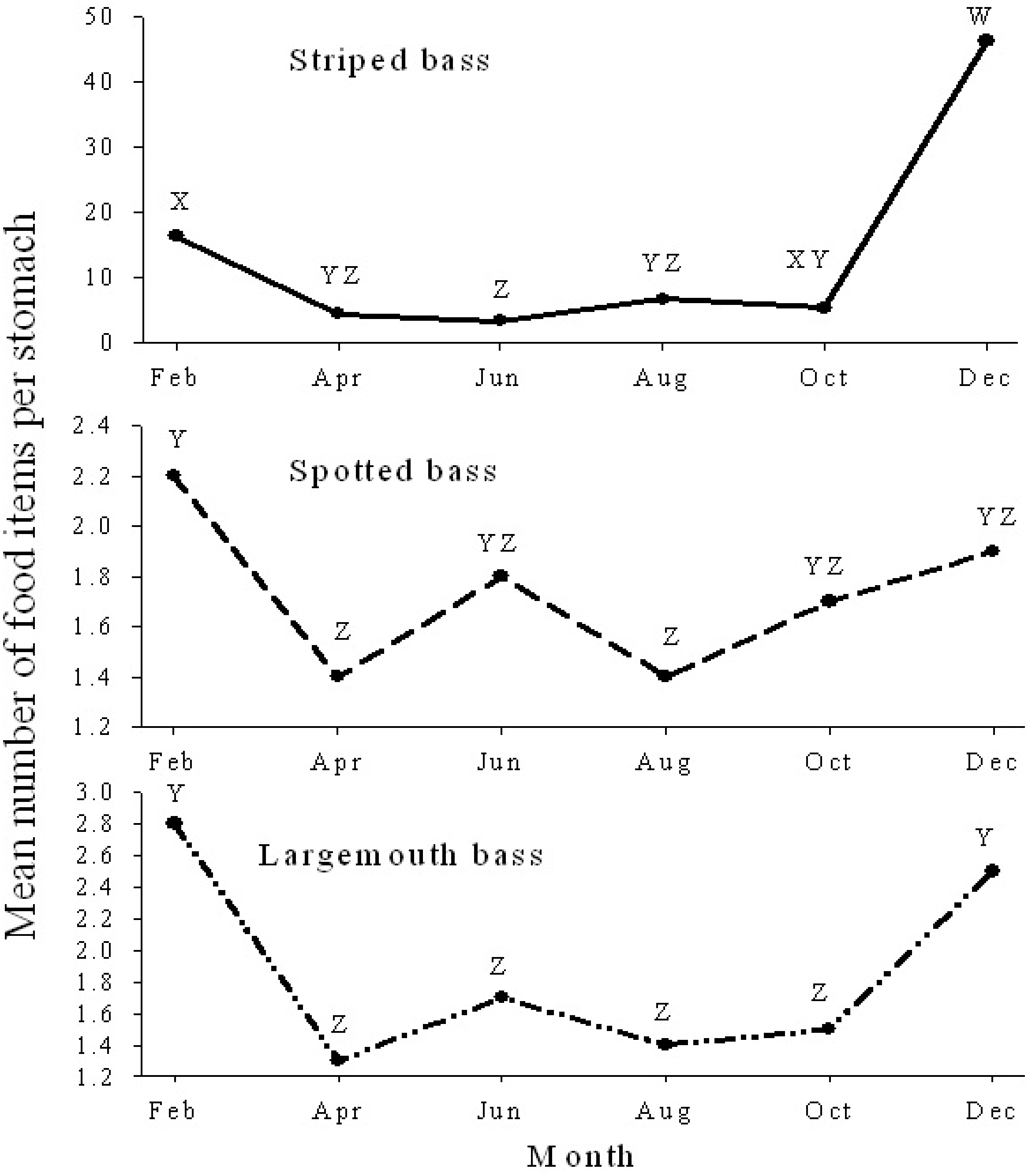

Figure 7. Mean number of food items observed in striped bass, spotted bass, and largemouth bass, stomachs across sampling months in Lewis Smith Lake. Mean values followed by the same letter for a specific month were not significantly (P ≥ 0.00833; Bonferroni corrected) different.

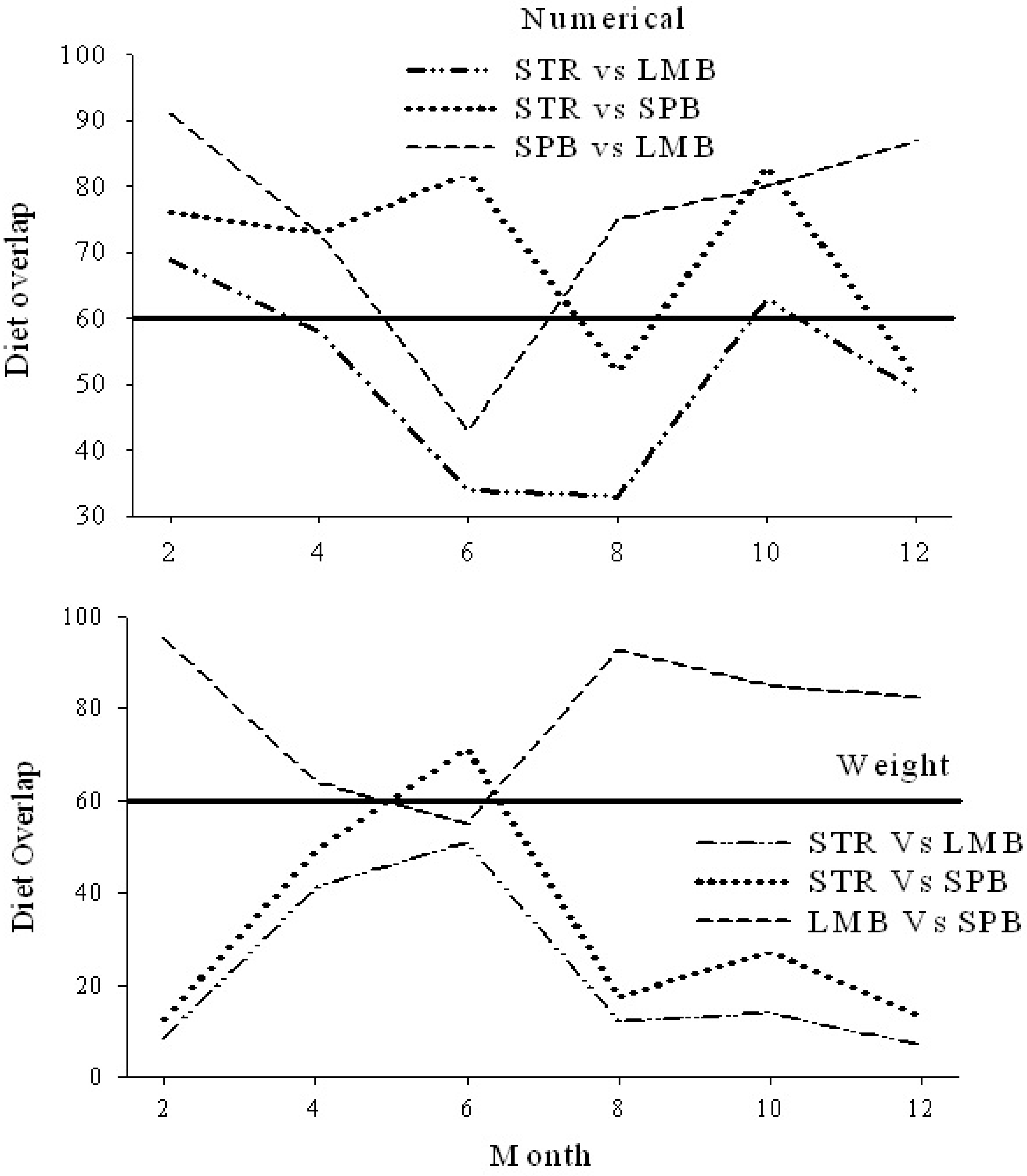

Figure 8. Schoener percent resource overlap index by number of prey items and by wet weight of prey items for striped bass (STR), largemouth bass (LMB), and spotted bass (SPB) for each sampling month. Overlap values are expressed as percentages. Solid line indicates minimum significant diet overlap.

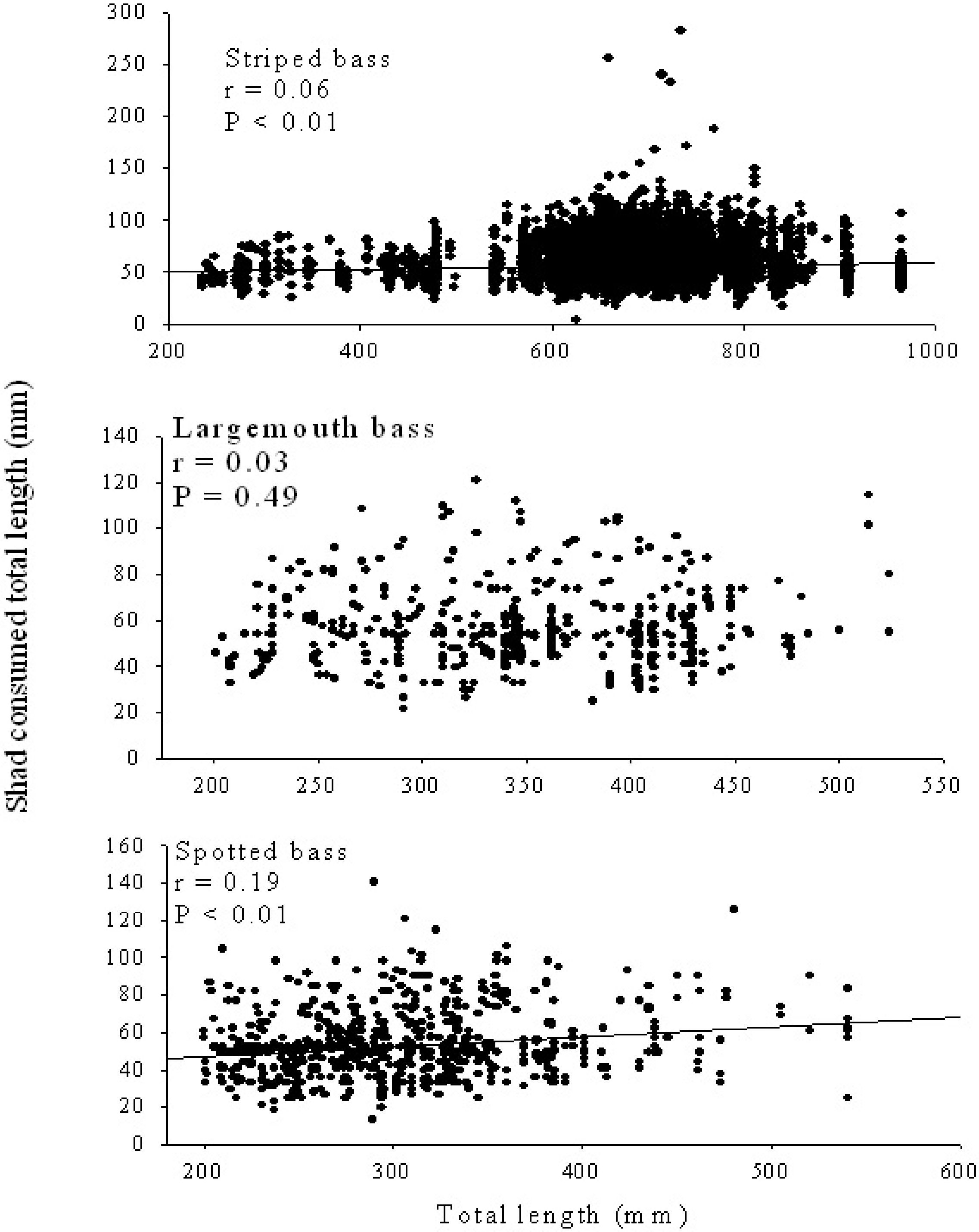

Figure 9. Relationships between lengths of shad consumed by striped bass, largemouth bass, and spotted bass lengths in Lewis Smith Lake.

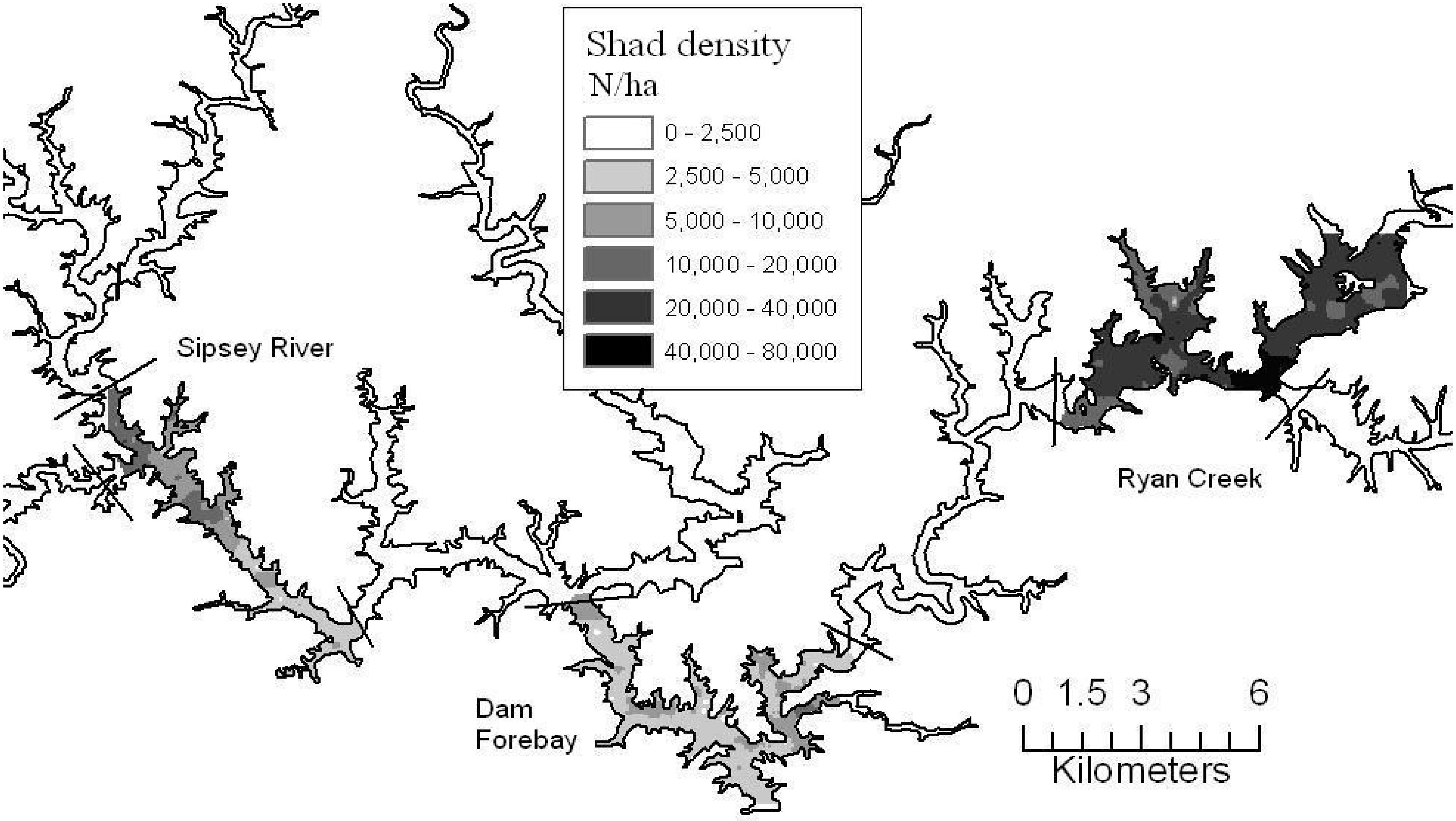

Figure 10. Estimated clupeid densities (n/ha) in each study region from hydroacoustic sampling. Densities outside survey areas were not estimated.

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APPENDIX

BIOENERGETICS MODEL PARAMETERS

Consumption

Consumption was estimated as the proportion of maximum daily ration for a fish at a particular mass and temperature. This maximum specific feeding rate (gram of prey per gram body mass per day) was modified by a water temperature dependence function and a proportionality constant (P-value) that accounts for ecological constraints on the maximum feeding rate. The p-value can range from 0 to 1, with 0 representing no feeding, and 1 indicating the fish is feeding at its maximum rate (based on size and temperature). The following equations were used to estimate consumption:

$$C = C_{max} * p * f(T)$$

$$C_{max} = CA * W^{CB}$$

where, C is the specific consumption rate (g/g/d), C_{max} is the maximum specific feeding rate (g/g/d), p is proportion of maximum consumption, $f(T)$ is temperature dependence function, T is water temperature (C), W is fish mass (g), CA is the intercept of the allometric mass function, and CB is the slope of the allometric mass function. The temperature dependence function was solved using the following equations:

For striped bass,

$$f(T) = K_a * K_b$$

where:

$$KA = (CK1 * L1) / (1 + CK1 * (L1 - 1))$$

$$L1 = e^{(G1 * (T - CQ))}$$

$$G1 = (1/(CTO - CQ)) * \log_e ((0.98 * (1 - CK1)) / (CK1 * 0.02))$$

$$KB = (CK4 * L2) / (1 + CK4 * (L2 - 1))$$

$$L2 = E^{(G2*(CTL - T))}$$

$$G2 = (1 / (CTL - CTM)) * \log_e ((0.98 * (1 - CK4)) / (CK4 * 0.02))$$

where, Ka is the increasing portion of the temperature dependence function, K_b is the decreasing portion of the temperature dependence function, CQ is the lower water temperature at which the temperature dependence is a small fraction (CK1) of the maximum rate, CTO is the water temperature corresponding to 0.98 of the maximum consumption rate, CTM is the water temperature ($\geq$CTO) corresponding to 0.98 of the value above which consumption ceases, and CTL is the water temperature at which dependence is some reduced fraction (CK4) of the maximum consumption rate.

For black bass,

$$f(T) = V^x * e^{(x(1-V))}$$

where:

$$V = (CTM - T) / (CTM - CTO)$$

$$X = (Z^2 * (1 + (1 + 40/Y)^{0.5})^2) / 400$$

$$Z = \log_e (CQ) * (CTM - CTO)$$

$$Y = \log_e (CQ) * (CTM - CTO + 2).$$

Species specific parameters for consumption equations are listed in Table 3.

Respiration

Respiration (the amount of energy used by the fish in routine metabolism) is dependent on fish size, activity, and water temperature. These losses were determined by first calculating resting metabolism as a function of mass, and then increasing this value with a temperature dependent function and a factor representing activity. The total metabolic rate of the fish was estimated by adding the cost of respiration to the cost of digestion (specific dynamic action) of the fish. Specific dynamic action was estimated as a constant proportion of assimilated energy (consumption minus egestion). The following equations were used to estimate respiration and the proportion of assimilated energy lost to specific dynamic action;

$$R = RA * W^{RB} f(T) * ACTIVITY$$

$$S = SDA * (C - F)$$

where, R is the specific rate of respiration (g/g/d), RA is the intercept of mass dependence function, W is the fish mass (g), RB is the slope of mass dependence function, $f(T)$ is the temperature dependence function, T is the water temperature (C), ACTIVITY is the activity multiplier, S is the proportion of assimilated energy lost to specific dynamic action, SDA is the specific dynamic action, C is the specific consumption rate (g/g/d), F is the specific egestion rate (g/g/d). The $f(T)$ and ACTIVITY functions were solved as:

$$f(T) = e^{RQ * T}$$

$$ACTIVITY = e^{RTO * VEL}$$

where:

$$VEL = RK1 * W^{RK4}, \text{ when } T > RTL, \text{ or}$$

$$VEL = ACT * W^{RK4} * e^{(BACT * T)}, \text{ when } T \leq RTL$$

where, RQ is the rate at which respiration increases with temperature, T is the water temperature (C), RTO is set to desired velocity when swimming speed is considered constant, RK1 is set to one when swimming speed is considered constant, W is the fish mass (g), RK4 is set to zero when swimming speed is considered constant, RTL is set to zero when swimming speed is considered constant, ACT is set on one when swimming speed is considered constant, and BACT is set to zero when swimming speed is considered constant. If swimming speed is modeled as a function of mass or mass and temperature, then RTO is the coefficient for swimming speed dependence on metabolism (cm/s), RTL is the cutoff temperature at which the activity relationship changes (C), RK1 is the intercept of swimming speed above the cutoff temperature (cm/s), RK4 is the mass dependence coefficient for swimming speed at all water temperatures, ACT is the intercept (cm/s a for 1 gram fish at 0 ° C) of the relationship for swimming speed versus mass at water temperatures less than RTL, and BACT is the water temperature dependence coefficient of swimming speed at water temperatures below RTL ($°C^{-1}$). Species specific parameters for respiration equations are listed in Table 3.

Egestion and excretion

Egestion (fecal waste, F) and excretion (nitrogenous waste, U) were computed as a constant proportion of consumption, or as functions of water temperature and consumption. Egestion and excretion were computed as a proportion of consumption as:

$$F = FA * C$$

$$U = UA * (C - F)$$

where, C is the consumption estimated as described above, FA is a constant proportion of consumption, UA is a constant proportion of assimilated energy. Species specific parameters for egestion and excretion equations are listed in Table 3.

Energy density

Values of predator energy density (PED) were obtained from Hansen et al (1997) and are listed in Table 3.

Table A.1. P-values (proportion of maximum consumption) from bioenergetics models for striped bass, largemouth bass, and spotted bass in Lewis Smith Lake. Values were derived from bioenergetics simulations.

Cohort	Striped bass	Spotted bass	Largemouth bass
age 0	0.66	0.56	0.66
age 1	0.38	0.45	0.46
age 2	0.36	0.42	0.43
age 3	0.32	0.40	0.41
age 4	0.31	0.39	0.40
age 5	0.31	0.38	0.39
age 6	0.32	0.37	0.38
age 7	0.31	0.37	0.37
age 8	0.32	0.36	0.36
age 9	0.32	0.36	0.35
age 10	0.32	0.35	0.35
age 11	0.32	0.35	
age 12	0.32		
age 13	0.32		
age 14	0.32		

Table A.2. Total consumption rate (g/g) estimates of targeted prey items based on observed growth for striped bass, largemouth bass, and spotted bass in Lewis Smith Lake. Values were derived from bioenergetics simulations.

Age	Striped bass	Spotted bass	Largemouth bass
0	18.08	14.70	15.53
1	6.17	6.62	6.51
2	5.03	4.73	4.65
3	4.31	3.84	3.74
4	3.95	3.35	3.24
5	3.72	2.98	2.86
6	3.63	2.72	2.61
7	3.45	2.54	2.43
8	3.43	2.41	2.29
9	3.34	2.31	2.16
10	3.27	2.23	2.08
11	3.21	2.17	
12	3.16		
13	3.12		
14	3.15		

Table A.3. Monthly dry weight energy values (cal/g) of prey items used in bioenergetics analysis. Values were derived empirically unless otherwise noted. A reduced caloric value for crayfish was used to correct of percent undigestibility.

Month	*Dorosoma* spp.[a]	*Lepomis* Spp.	Brook Silverside	Crayfish[a]	Insects[a]	Other[a]
January	1,303	1,094	820	923	972	1,117
February	1,348	1,094	820	923	972	1,090
March	1,391	1,094	820	923	972	1,117
April	1,408	1,094	820	923	972	1,160
May	1,433	1,094	820	923	972	1,130
June	1,462	1,094	820	923	972	1,110
July	1,468	1,094	820	923	972	1,090
August	1,493	1,094	820	923	972	1,090
September	1,229	1,094	820	923	972	1,030
October	1,337	1,094	820	923	972	1,080
November	1,433	1,094	820	923	972	1,150
December	1,300	1,094	820	923	972	1,000

[a] Values derived from Miranda et al (1998).

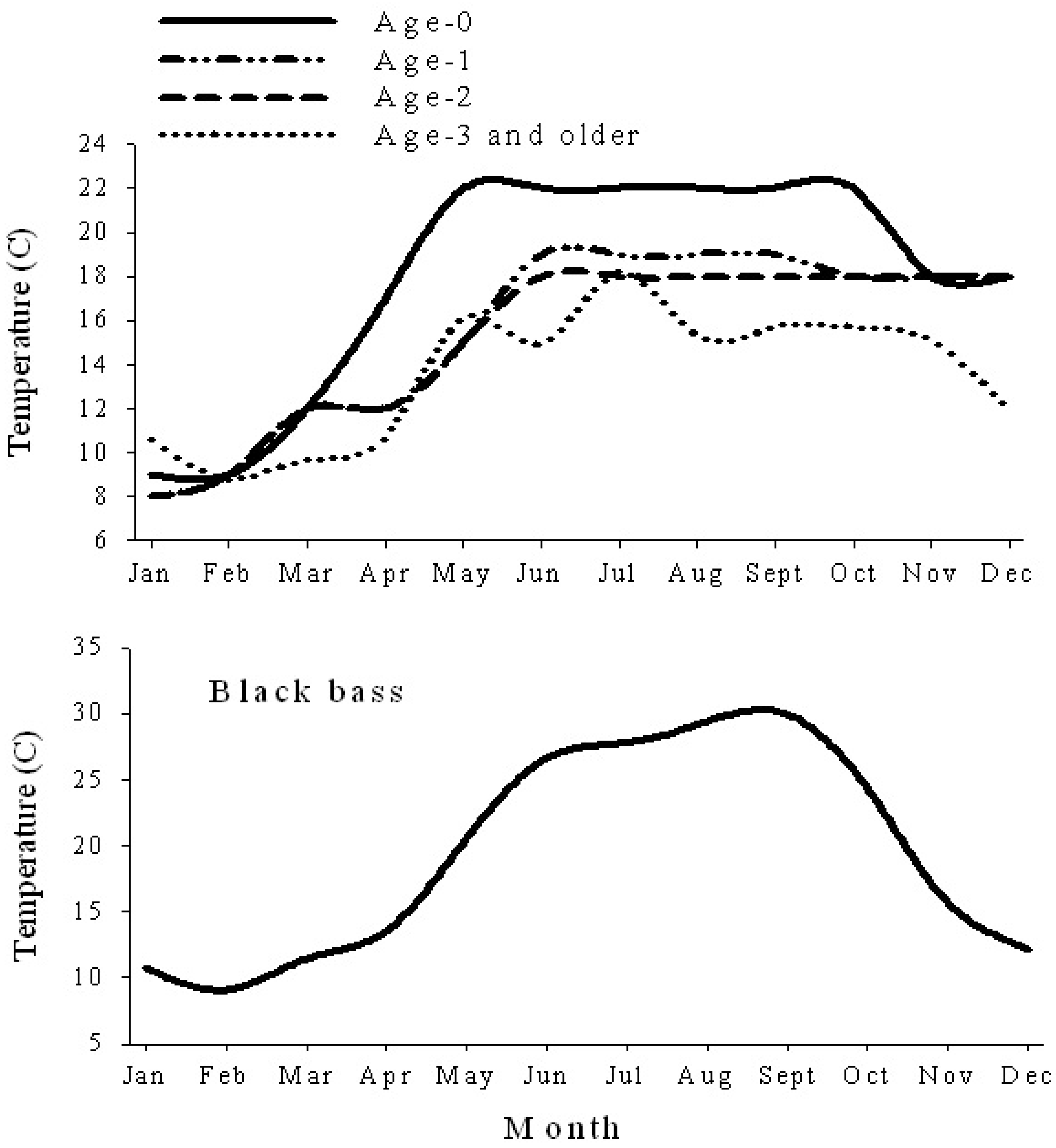

Figure A.1. Mean monthly water temperatures obtained from data loggers which were used in bioenergetics modeling based on age for striped bass and for all ages of black bass species. For striped bass, temperatures corresponding to 98% of their maximum consumption rates from Hanson et al (1997) were used, and for black bass, observed temperatures in the top 3 m of the water column was used.