

DIET COMPOSITION AND GROWTH RATES OF BLACK CRAPPIE *Pomoxis nigromaculatus* RELATIVE TO BENTHIC FOOD AVAILABILITY AT THREE FLORIDA LAKES

By

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To my family, who are the meaning of life.

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Abstract of Thesis Presented to the Graduate School
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Factors influencing black crappie growth are an important research need for management of black crappie fisheries. I evaluated the diets and growth of black crappie in relation to benthic food availability and population structures (e.g., abundance) among three Florida systems: Lakes Lochloosa, Marian, and Monroe. The simplified Morisita index was used to measure similarity of diet contents (i.e., mean numbers) relative to benthic macroinvertebrate densities throughout sampling periods. Manly's α index of selectivity was used to measure selective predation by black crappie for benthic prey taxa. Black crappie at Lake Monroe obtained the largest size at age, whereas Lake Marian had the smallest size at age. Lake Marian had the highest abundances of black crappie based on otter trawl mean catch per unit effort data and Lochloosa Lake had the lowest abundance. Manly's α index of selectivity resulted in two major trends. Black crappie at Lakes Lochloosa and Marian were consistently selective of Diptera pupae, whereas black crappie at Lake Monroe were consistently selective of Mysidacea *Americamysis almyra*. Differences in prey availability and prey selection were influential in producing differences in the diet composition and ontogenetic diet shifts of black crappie among the three study lakes. Results were variable for different taxa, but indicated that benthic prey availability can influence

consumption rates of prey items by black crappie, particularly for more utilized taxa. The diet, prey availability, and black crappie population structure differences among lakes likely contributed to the variation in population growth rates.

INTRODUCTION

Black crappie *Pomoxis nigromaculatus* support important recreational fisheries in Florida including 22% of the state's freshwater anglers and more than 5.8 million days of annual fishing effort (U.S. Department of Interior 2001). Factors that influence growth and abundance of black crappie are thus important to the management of black crappie fisheries. Understanding how black crappie growth rates are related to diet composition and benthic food availability is an important research need for management of black crappie fisheries.

The diets of both black crappie and white crappie *P. annularis* are well documented. In Florida alone, food items found in black crappie diets have included crustacean zooplankton, such as cladocera and copepoda; diptera larvae, pupae and adults, particularly Chironomidae and Chaoboridae; *Palaemonetes* and *Mysidopsis* shrimp; and various fishes, especially shads *Dorosoma spp.* (Chable 1947; Reid 1949; Huish 1957; Ager 1975). Keast (1968) and Hanson and Quadri (1979) found that diets of black crappie did not vary greatly throughout their distribution. Conversely, Mathur and Robbins (1971) suggested that differences in feeding habits among populations of white crappie were due to differences in food availability at those water bodies.

Ontogenetic diet shifts from zooplankton to aquatic insects to fish occur in many fishes including Eurasian perch *Perca fluviatilis* (Hjelm et al. 2000), yellow perch *Perca flavescens* (Keast 1977), walleye *Sander vitreus* (Galarowicz et al. 2006), largemouth bass *Micropterus salmoides* (Keast and Eadie 1985; Olson 1996; Garcia-Berthou 2002), and northern pike *Esox lucius* (Frost 1954). Diet shifts occur as a result of morphological changes (i.e., larger gape width), which allow fish to utilize larger food items (McCormick 1998; Hjelm et al. 2000). It is optimal for individuals to select prey items that maximize the net energy gain, which typically are the larger items available (Mittelbach 1981). Higher quality foods can produce faster growth

(Buijse and Houthuijzen 1992; Frankiewicz et al. 1996), which allows the transition to the next larger prey item (Frankiewicz et al. 1996; Olson 1996), alters resource competition (Keast and Eadie 1985), and allows piscivorous fish to maintain or obtain a size advantage over prey fish (Timmons et al. 1980; Keast and Eadie 1985; Olson 1996). Olson (1996) found that largemouth bass with faster growth rates in the invertebrate-feeding stage became piscivorous significantly faster than fish with slower growth rates at the same stage. An increase in growth also influences recruitment by limiting mortality (Post et al. 1998; Olson 1996) and reducing risk of predation (Frankiewicz et al. 1996; Post et al. 1998). Applegate et al. (1967) attributed the growth rates of juvenile largemouth bass at one Arkansas reservoir to be twice as fast as those at another Arkansas reservoir because of greater availability and consumption of midge larvae between the diet shift from zooplankton to fish. At one Florida lake, Wicker and Johnson (1987) found that periods of high mortality of age-0 largemouth bass occurred directly after periods when low fish prey: predator biomass ratios occurred.

Juvenile black crappie exhibit shifts from primarily zooplankton to a combination of zooplankton and macroinvertebrates at about 65 to 100 mm TL (Reid 1949; Keast 1968; Tucker 1972; Pine and Allen 2001; Dockendorf and Allen 2005). Fish become a common prey item when crappies *Pomoxis* spp. attain a TL of 140 to 200 mm (Keast 1968; Ellison 1984; O'Brien et al. 1984; Schramm et al. 1985; Muoneke et al. 1992; Mittelbach and Persson 1998). Crappies will continue to feed on zooplankton when they are greater than 150 mm TL (Muoneke et al. 1992) and have been found to feed on fish when as small as 60 mm TL (Reid 1949; Huish 1957). However, it is important for crappies to shift their diet to optimize growth and survival. For example, Muoneke et al. (1992) credited the reduced growth of white crappie at an Oklahoma reservoir to their inability to become piscivorous at 150 mm TL. Dockendorf and Allen (2005)

found larger age-0 black crappie at one Florida lake, which had a higher frequency of fish in their diets, in comparison to two other Florida populations. Ellison (1984) found lower growth and survival rates of black crappie feeding as insectivores and planktivores than for white crappie that had switched to a fish diet at the same Nebraska lake, particularly after the crappie reached 200 mm TL.

Seasonal and monthly trends of crappie diets have been analyzed in numerous studies (Pearse 1918; Dendy 1946; Reid 1949; Ball and Kilambi 1972; Mathur 1972; Liao et al. 2002). Fish become a more important, if not the most important, part of the crappie diet in the summer and/or fall months. Ball and Kilambi (1972) found crappie diets to be 92% fish in the summer months at an Arkansas reservoir. In the spring, fall, and winter seasons, fish were consumed to a lesser degree, and benthic insects, annelids, and crustaceans increased in importance. Likewise, Dendy (1946) found a high proportion of aquatic insects and zooplankton in adult black crappie diets in the spring and early summer, but fish dominated the diets in the late summer and fall at a Tennessee reservoir. Reid (1949) also found a Florida black crappie population to feed largely on fish in the summer and fall. The foods consumed during the summer are considered the most important on a yearly basis, because this is when much of the annual growth occurs and energy requirements are the highest (Ball and Kilambi 1972; Ellison 1984). At Lake George, Florida, Huish (1953) found that black crappie made most of their annual growth from April through November.

Lochloosa Lake, Florida, had a successful black crappie fishery prior to 1992, when fishing effort and harvest dropped significantly (Hujik et al. 2002). For five years, the fishery showed no signs of improvement and consequently, the Florida Fish and Wildlife Conservation Commission (FWC) stocked more than 500,000 advanced fingerling (100 mm – 150 mm TL)

black crappie from 1997 to 2001. Hujik et al. (2002) found that angler effort and harvest were 30% and 85% lower, respectively, for the post-stocking period (1997-2002) when compared to the pre-stocking period (1988-1996). Catch curve analysis estimated 93% total annual mortality of black crappie \geq age-1 in 1999 and 71% in 2001 (Hujik et al. 2002). Although 71% total annual mortality is comparable to the average of other crappie populations in the U.S. compiled by Allen and Miranda (1995) and Allen et al. (1998), the 93% estimate is on the upper range of those reported. Because exploitation was apparently low since stocking began, natural mortality was suspected to be the primary component of total annual mortality. This led to the question of whether food availability at Lochloosa Lake was limiting the growth and survival of black crappie larger than 200 mm total length (TL), which is also the approximate age and length that crappie are recruited into sport fisheries (Schramm et al. 1985; Larson et al. 1991; Miranda and Dorr 2000). I compared diets and benthic food availability of black crappie at Lochloosa Lake with that of two other Florida lakes, that supported successful black crappie fisheries.

I evaluated the diets of black crappie \geq 110 mm TL at three Florida lakes in comparison to the benthic macroinvertebrate availability within these lakes. My objectives were to (1) compare differences in diets among size groups of black crappie within each lake, (2) compare differences in diets across size groups among the three lakes, (3) relate diets to benthic food availability, and (4) evaluate trends between diet composition and fish growth rates among the three lakes.

METHODS

Study Lakes

Lakes Lochloosa, Marian, and Monroe were the study lakes for this research (Figure 1). Lakes Lochloosa and Marian are hypereutrophic and Lake Monroe is eutrophic, according to average chlorophyll a concentrations sampled between 1993 and 2002, as classified by Forsburg and Ryding (1980; Table 1). These lakes were selected because of the differences in their black crappie population characteristics. Lochloosa Lake is a 2,310-ha lake in eastern Alachua County and the fishery characteristics were described above. Lake Marian is a 2,323-ha lake located in southern Osceola County. It was listed as one of FWC's top-ten black crappie lakes of 2003 and is known for producing high recreational catches of black crappie, although it is not known for catches of large black crappie (Hale and Alred 2003). Lake Monroe is a 3,808-ha lake located in Seminole and Volusia counties. It was also listed as one of FWC's 2003 top-ten black crappie lakes (Hale and Alred 2003) and is known for producing large black crappie. There was a 304-mm minimum length limit on the black crappie fishery at Lake Monroe from 1998 to 2005.

Black Crappie Collection

Otter trawls have frequently been used as a method for sampling black crappie at Florida water bodies (Huish 1953; Ager 1975; Schramm et al. 1985; Allen et al. 1999; Pine 2000). Huish (1957) used shrimp trawls to collect bluegill *Lepomis macrochirus*, readear sunfish *Lepomis microlophus*, and black crappie at Lake George, Florida as early as 1950 because commercial seines did not catch fish < 152 mm TL effectively. Similarly, Allen et al. (1999) found otter trawls to be preferred over trap nets for sampling black crappie due to a larger size range of fish caught, reduced sampling effort required, precision of catch per effort, and reduced sampling expenses.

Otter trawls (4.6 m mouth, 4.9 m long, 38.1 mm stretch mesh body, and 31.8 mm stretch mesh bag) were used to collect black crappie from each lake during the study. Sample periods included August, October, and December of 2002 and February, April, June, August, and October of 2003. A minimum of three trawls were pulled at each lake during each period. During each period, the first three or four trawls in Lakes Monroe and Marian were pulled at separate fixed sites. Trawls pulled at Lochloosa Lake were scattered throughout the lake, because Lochloosa Lake was sampled much more intensively than the other systems (below). Time length of the trawls was adjusted based on catch. Black crappie were measured to the nearest mm TL. I attempted to collect 10 fish in each of four size classes from Lakes Marian and Monroe and 30 fish in each of four size classes from Lochloosa Lake during each sampling period. The size classes include (1) 110 – 149, (2) 150 – 189, (3) 190 – 229, and (4) > 230 mm TL. The fish collected for stomach analysis were immediately stored on ice to reduce the likelihood of regurgitation (Doxtater 1963), and then taken to the laboratory. Fish that could not be immediately processed at the laboratory were frozen for later analysis.

Processing of Fish and Stomachs

At the laboratory, each fish was measured to the nearest mm TL, weighed to the nearest gram, and the sagittal otoliths were removed. The stomach and hindgut of each fish were removed from the esophagus to the anal opening. The stomach was placed into a labeled jar with 10% buffered formalin acetate for preservation. Formalin was eventually replaced by 95% ethanol, prior to stomach content analysis.

A dissecting microscope was used when sorting through the contents of the stomachs. Individual food items were categorized (Table 2) and counted for each taxonomic group. When contents were partially digested, countable parts such as eyes and head capsules were counted to obtain consumption estimates of those items. For example, two diptera pupae eyes made up one

individual. All remaining unidentifiable contents were placed together and categorized as unidentified digested material. Each category was wet weighed to the nearest 10^{-4} g.

Stomachs and hindguts, that were completely full of small digested parts (e.g., Diptera eyes), were subsampled to reduce sampling time. All larger items (e.g., fish, *Palaemonetes*, etc.) were separated from the bulk of the contents, identified, counted, and weighed. The remaining diet contents were stirred and visually divided into quarter sections, using one section as the subsample. The contents of the subsample were categorized, counted, and weighed. The remaining portion of the sample was placed together and wet weighed to the nearest 10^{-4} g. Results were used to extrapolate the remainder of the sample.

Age Estimation

Numerous studies have validated the use of otoliths for accurate age assessments for crappies (Schramm and Doerzbacher 1982; Hammers and Miranda 1991; Ross et al. 2005). Whole views of otoliths were read for aging. If three or more rings were found, one otolith from each fish was sectioned transversely from the ventral to dorsal gradient using a South Bay Technology, Inc. low-speed diamond-wheel saw. Two sections, 0.5 mm wide, were cut from each sectioned otolith. The sections were mounted on a labeled glass slide using Thermo Shandon Synthetic Mountant with the inner-nucleus side facing up. Two independent readers aged each fish using a dissecting microscope. The age-class of the fish was equal to the number of rings if the collection date was in the latter half of the year. However, the age-class of a fish, collected in the first half of the year, was equal to the number of rings if a new ring had recently formed at the margin, or the number of rings plus one if a new ring had not yet formed at the margin. Any disagreement in age-class between readers was reexamined, and if conflict remained, a third reader was used. If no agreement could be reached with a third reader, that fish was not used in the analyses.

Based on an observation of peak hatch dates of black crappie at the north Florida Lake Wauberg, between mid-March and mid-April (Pine and Allen 2001), the hatch date of all fish in this study was set at March 1st. A March 1st hatch date could act as a midpoint for the possible earlier spawning periods of black crappie in the more southern lakes of Marian and Monroe and the later spawning period of the north Florida Lochloosa Lake, which is latitudinally equivalent to Lake Wauberg. An age of each fish was then set based on the proportion of the year that occurred between March 1st and the collection date.

Macroinvertebrate Collection and Processing

Benthic macroinvertebrates were sampled at eight fixed sites in each lake using a petite Ponar during each sampling period from December 2002 to October 2003. The sites were selected based on substrate types and locations that corresponded with the trawl sites. The contents of each sample were sieved through a 300- μ m mesh bucket and preserved in a labeled jar with 95% denatured ethanol.

The petite Ponar (15.24 cm long and 15.24 cm wide) is a smaller version of the Ponar grab designed by Powers and Robertson (1967). Ponars have been compared with other forms of benthic samplers (Flannagan 1970; Hudson 1970; Howmiller 1971; Elliott and Drake 1981) and across a variety of substrate types (Nalepa et al. 1988; Int Panis et al. 1995). The reliability of the various samplers for adequate assessment of benthic community structure and abundance depends on the sediment type (Flannagan 1970; Hudson 1970; Howmiller 1971; Elliott and Drake 1981; Int Paris et al. 1995). In studies where three or more grabs were compared, the Ponar has been found to be the most adequate benthic sampler among a range of substrate types (Flannagan 1970; Hudson 1970; Elliot and Drake 1981).

A dissecting microscope was used when sorting through the samples. If the contents included a large quantity of sand, a sugar solution flotation procedure described by Anderson

(1959) was used to reduce processing time. If the content of a Ponar was large, a fixed fraction of the sample was processed. Contents were poured into a pan and stirred to form a homogeneous sample and weighed. A proportion of the sample based on weight, was removed from the pan and used as a subsample. Proportions used as subsamples included 0.50, 0.25 and 0.125, depending on the total sample volume. Macroinvertebrates contained in the subsample were removed, identified taxonomically, and counted. Subsample data were used to estimate total sample contents.

Data Analysis

Population Abundance and Size Structure

Mean catch per unit of effort (CPUE) values were used as an index to compare crappie population relative abundance among the three lakes. Black crappie were classified into four size groups (Size classes 2, 3, 4, and all fish) and mean CPUE values were calculated for each lake and sampling period. A one-way ANOVA was used to compare mean log transformed CPUE values among lakes for each group. Values of CPUE were $\log(X + 1)$ transformed to improve the homogeneity of variances. The least squares means (LSMEANS) procedure was used to determine differences between lakes when ANOVAs were significant (SAS Institute 1997). I assumed that mean CPUE values were proportional to the population densities (Hubert 1996).

Size structure of black crappie ≥ 110 mm TL, captured with otter trawls at each of the three lakes, was expressed with a length frequency histogram for the last four sampling periods. A chi-square test was used to determine if the proportion of black crappie among the four size classes was homogeneous among lakes.

Age and Growth Comparisons

Ages of black crappie, collected from the three lakes, were used to make inferences about the age structure of black crappie at each lake. Fish ages and total lengths were used to fit linear, von Bertalanffy (VBGM) and Gompertz growth models for each lake. Residuals of the observed versus predicted total lengths were plotted against the predicted values to evaluate the fit of the three models for each lake. A variance ratio test was used to assess differences in the models and choose the best-fit model for the data in the form of

$$F = \frac{MSE_{1 \text{ df}_1}}{MSE_{2 \text{ df}_2}}$$

where MSE_1 and MSE_2 are the mean squared errors obtained by using separate growth models for the same lake, with degrees of freedom df_1 and df_2 , respectively. The larger MSE was used as the numerator and F was compared to an F -statistic at $P = 0.05$. A significant result meant the model used to receive MSE_2 had a better fit to the data. After comparisons among all three models were made, the one that best fit the data was used to estimate mean TL at age for each lake.

The likelihood ratio test described by Kimura (1980) and Haddon (2001) was used to compare growth curves among the three lakes using the VBGM

$$L_t = L_\infty (1 - e^{-k[t-t_0]})$$

where L_t is the mean length at age t , L_∞ is the asymptotic maximum length, k is the growth rate coefficient determining how quickly L_∞ is obtained, and t_0 is the hypothetical age when length is equal to zero. The likelihood ratio test compares two or more non-linear equations by first treating them as separate populations and then combining all observations as if they were from the same population to make a new growth curve with new values for parameters k , t_0 and L_∞ .

Cerrato (1990) suggested using the likelihood ratio test over three other tests when comparing VBGMs because of more accurate and reliable results. This test uses a chi-square statistic to see if the combined curve residual sum of squares is significantly different from the sum of the residual sum of squares for each model separately as

$$\chi_k^2 = N \times \ln \left(\frac{RRS_\omega}{RRS_\Omega} \right)$$

where k is the degrees of freedom (equal to the number of parameters fixed), N is the total number of observations used, RRS_ω is the total residual sum of squares derived from fitting the curves together, and RRS_Ω is the total residual sum of squares derived from fitting all curves separately. This analysis tested the hypothesis that the quality of fit was not significantly different for a combined model versus separate models. To test the hypotheses that parameters (i.e., L_∞ and k) of the growth curves were different, I fitted the VBGM for each lake using only the value of the parameter in question, obtained from the combined equation. A chi-square statistic was calculated again for each hypothesis (L_∞ values are different, etc.) where RRS_ω is the total residual sum of squares derived from fitting the curves with one of the parameter constraints and RRS_Ω is the same total residual sum of squares derived from fitting all curves separately with no constraints. Likelihood ratio tests were then used to make pair-wise comparisons among the three lakes using the same procedures as above.

Diet Comparisons

Mean percent weights of prey categories were used to compare diet compositions of black crappie. Percent weights were calculated as

$$\%Wt_i = \frac{Wt_i \times 100}{Wt_j}$$

where W_{t_i} is the weight of category i found in a stomach and W_{t_j} is the total weight of all categories found in that stomach. Empty stomachs and stomachs which contained nothing but unidentified digested material were not included in the analysis for $\%W_t$. Unidentifiable digested material was not included for the summation of W_{t_j} , because it would distort the description of the identifiable prey categories. Weights of partially digested items were not projected into whole weights for two reasons. First, this would require substantial extrapolation. Second, individual species or life stages within a particular prey category (e.g., Chironomidae larvae) might be far different in size. Thus, predicted weights would not be accurate without further identification or classification. Percent composition by weight of dietary items provides an idea of the relative importance of various food types to the nutrition of fish (Bowen 1996). However, Liao et al. (2001) found percent weight indices to overemphasize the importance of larger prey taxa.

Diet compositions of black crappie were compared using multivariate analysis of variance (MANOVA). Crow (1979) suggested the use of a MANOVA for diet comparisons when it was desirable to test for differences in more than one prey species because it simultaneously evaluates multiple prey categories, whereas a series of univariate ANOVAs on separate prey variables may not reveal among-group differences. Individual $\%W_{ts}$ of each category were arcsine-transformed to normalize the data (Kleinbaum et al. 1998; Zar 1999). The arcsine-transformed $\%W_{ts}$ of prey categories were pooled into four major categories (Table 3) based on taxonomy, size, and previous published findings about shifts in crappie diets. Mean arcsine-transformed $\%W_{ts}$ of the major categories were then calculated for each group. A three-way MANOVA was used to evaluate if mean arcsine-transformed percent composition by weight of the four major prey categories in the stomach contents varied with lake, period, and size class. A

significant interaction of the treatments lead to univariate F tests by analysis of variance (ANOVA), to expose which prey categories were responsible for the interaction. Significant interactions of the ANOVAs were explained graphically and by comparisons of the treatment means using the LSMEANS procedure adjusted for the Tukey-Kramer multiple comparison test (SAS Institute 1997).

To evaluate diet shifts with fish size among the three lakes, the %Wt data for all periods were pooled for each size class at each lake. Comparisons of ontogenetic diet shifts were made by two-way ANOVAs, using the mean arcsine-transformed values for %Wt of the major diet categories as the dependent variable, with lake, size class, and the interaction of these variables as factors. The LSMEANS procedure adjusted for Tukey-Kramer was used to separate the means if the ANOVA was significant (SAS Institute 1997).

I used an index of stomach fullness to evaluate total prey weight standardized for fish size among lakes with the equation

$$IF_i = \left(\left(\sum_{i=1}^N \frac{\text{TotalStomachContentWetWeight}_i}{\text{TotalFishStandardWetWeight}_i} \right) / N \right) \times 100\%$$

where i is an individual observation in a set of N total fish. The total stomach content wet weight included all material found in a stomach. An index of fullness is a useful measurement of diet because it is relative to fish size (Hyslop 1980). Standard wet weights based on individual total lengths were used in the IF equation because of differences of the length-weight relationships among the three lakes. Standard weights were taken from a standard weight equation by using the logarithmic transformations of the pooled length-weight data, in the form

$$\log_{10}(\text{Wt}) = a' + b \cdot \log_{10}(\text{TL})$$

where Wt is weight, TL is total length, a' is the y-axis intercept, and b is the slope of the equation. Because the sample sizes of length-weight data were not equal among the three lakes, the sample size for each lake in the pooled data was limited to the number of observations in the smallest sample by randomly selecting data from the lakes with larger samples. This procedure provided a length-weight relationship that was weighted equally for all lakes. The standard weight equation was

$$\log_{10}(Wt) = -5.458 + 3.246 \cdot \log_{10}(TL).$$

Average total stomach content weights were then compared with one-way and two-way ANOVAs using mean log-transformed IF values as the dependent variable and lake, size class, and the interaction as factors. The individual IF observations were $\log(X + 1)$ transformed to homogenize the variances. The LSMEANS procedure adjusted for the Tukey-Kramer multiple comparison test (SAS Institute 1997) was used to compare mean IF values between lakes, size classes, and lakes for each size class.

Macroinvertebrate Density Comparisons

Estimated densities of the macroinvertebrate taxa used in selectivity and similarity indices were compared among lakes by one of two methods. Chironomidae larvae densities were $\log(X + 1)$ transformed and ANOVAs were used for each sample period using lakes as the treatments and the log-transformed Chironomidae larvae densities as the variables. If a significant difference was found, the LSMEANS procedure adjusted for Tukey's multiple comparison test (SAS Institute 1997) was used to compare values between lakes to determine the difference(s). Comparisons among lake mean densities of the other macroinvertebrate taxa were made with a Kruskal-Wallis test because of the non-normal structure of the data, even after transformations were conducted. If significant differences were found, nonparametric multiple comparisons for

data with tied ranks (i.e., Dunn test) were made to locate where differences occurred (Zar 1999). Mysidacea and Isopoda (i.e., Suborder Anthuridea) were not included in this analysis because they were only found at Lake Monroe.

Ponar-Diet Comparisons

Between-lake comparisons of mean %*Wt*, mean number, and/or occurrence of prey taxa in black crappie diets were used to express how density differences of macroinvertebrate taxa between lakes could influence black crappie diets. Mean number of prey items was calculated as

$$\overline{No}_i = \frac{No_i}{n}$$

where No_i is the total number of prey taxa i found in stomachs from a group of n total fish.

Occurrence was considered as presence of a prey item in black crappie diets.

Selective feeding of black crappie on benthic macroinvertebrates at each lake was measured using Manly's α index of preference for each size class in six sampling periods. The sampling periods included December of 2002 and February, April, June, August, and October of 2003. Manly et al. (1972) originally developed the index, which was later refined by Chesson (1978). Manly's α estimates were calculated for individual black crappie as

$$\alpha_i = \frac{r_i}{n_i} \left(\frac{1}{\sum_{j=1}^m \left(\frac{r_j}{n_j} \right)} \right)$$

where α_i is Manly's α (preference index) for prey type i , r_i and r_j is the proportion of prey type i and j in the diet (number of individuals), n_i and n_j is the proportion of prey type i and j in the environment (petite Ponar density), and j is an individual prey type out of m possible prey types. Mean Manly's α estimates were calculated for each size class in each sampling period by

$$\bar{\alpha}_i = \frac{\sum_{\alpha=1}^K \alpha_i}{K}$$

where α_i is one observation out of a total of K observations made for that group. Inferences of prey selection were made using $\alpha_i = 1/m$ as an indication level where values greater than, equal to, and less than α_i indicate preference, no selection, and avoidance of that prey item, respectively. Taxa used in Manly's α indices include Chironomidae larvae, Chaoboridae larvae, Ceratopogonidae larvae, Diptera pupae, Ephemeroptera larvae, Trichoptera larvae, Amphipoda, Isopoda, Hydracarina, and Mysidacea. These taxa were chosen because they were represented in both the benthic grabs and black crappie diets. These taxa could also be effectively sampled with the benthic grabs and would be available for black crappie consumption. Individual taxa were not included in Manly's α estimates for periods or lakes when they were not observed in the benthic grabs or diets. Consumption of a particular resource is considered selective when the relative proportion of that resource in the diet is greater than the relative proportion available in the environment (Chesson 1978).

The simplified Morisita index of similarity was used to measure similarity of diet contents (i.e., mean numbers) relative to benthic densities for individual taxa throughout sampling periods for each lake. Taxa and sampling periods included in similarity indices were the same used in the selectivity indices. Horn (1966) suggested this version to ignore cases where negative numbers would appear in Morisita's original function. The simplified Morisita index is in the form of

$$C_H = \frac{2 \sum X_{ij} X_{ik}}{\left[\left(\sum X_{ij}^2 / N_j^2 \right) + \left(\sum X_{ik}^2 / N_k^2 \right) \right] N_j N_k}$$

where C_H is the simplified Morisita index of similarity, X_{ij} and X_{ik} are the numbers of individuals from sampling period i in sample j and sample k , N_j is the total number of individuals in sample j , N_k is the total number of individuals in sample k , j represents diets, and k represents petite Ponars. Values of the index range from 0 (no similarity) to 1 (complete similarity).

RESULTS

Catch rates of black crappie with otter trawls varied widely among lakes (Table 4). One-way ANOVAs resulted in significant differences of mean log-transformed CPUE values among lakes for each group (all $P < 0.0029$). Lake Marian had the highest CPUE value for all groups of black crappie (LSMEANS procedure; all $P < 0.0001$) and required the least amount of effort (total trawls = 37; total minutes = 108) to collect the desired number of individuals for diet analyses. Individual tow times of each trawl at Lake Marian were reduced because of the extremely high catch rates. Mean CPUE values did not differ significantly for size classes 2 ($P = 0.3453$) and 3 ($P = 0.6457$) black crappie between Lakes Lochloosa and Monroe, but Lochloosa Lake had the lowest mean CPUE for size class 4 ($P < 0.0001$) and all black crappie ($P = 0.0119$). Thus, Lochloosa Lake required the greatest amount of effort (total trawls = 186; total minutes = 1080) to collect enough specimens for diet analysis.

Length frequency distributions also differed among the three sampling lakes (Figure 2). Chi square tests between lakes and size classes were significant for each period tested (all $P < 0.0001$), indicating that black crappie at Lakes Lochloosa and Monroe had higher proportions in size class 1 compared to Lake Marian. Lake Marian consistently had a higher proportion of black crappie in size class 3 compared to Lakes Lochloosa and Monroe (Figure 2). Lochloosa Lake generally had the lowest proportion of black crappie in the largest size class, whereas Lakes Marian and Monroe were comparable (Figure 2).

A total of 1,351 black crappie were used for age and growth comparisons. Lakes Lochloosa, Marian, and Monroe had sample sizes of 734, 317, and 300, respectively. Lochloosa Lake had the greatest percent of black crappie collected \leq age 1 (75.1 %) and the lowest percent of black crappie \geq age 2, with only one observation as high as age 6. Lake Marian had both the

oldest individual black crappie observed (age 11) and the highest percentage of black crappie collected \geq age 2 (56.4 %). The oldest black crappie collected at Lake Monroe were age 8.

Linear, Gompertz and VBGM growth models (Table 5) were developed using the age at length data for the three lakes. Variance ratio tests resulted in significantly lower *MSE* values obtained from the Gompertz growth model and VBGM when compared to the linear growth model for all three lakes (all $P < 0.0005$). There was no significant difference found in the variance between the Gompertz growth model and VBGM for any of the study lakes (all $P > 0.39$). The residual plots of the VBGMs expected versus observed TL at age values (Figure 3) were uniformly distributed, which supports the use of this function. The VBGMs were chosen to estimate mean TL at age of black crappie for each lake and were used to plot the expected growth curves (Figure 4).

The likelihood ratio test used to compare the VBGMs among the three lakes was significant ($\chi^2 = 212.3$; $df = 3$; $P < 0.0001$), indicating that at least one curve was significantly different from at least one of the other two curves. Tests of the individual parameters L_∞ and k of the three growth models were also significant at $P < 0.05$, indicating that the parameter being tested was significantly different in at least one of the growth models. Pairwise comparisons between the three growth curves showed that each model was significantly different from the other at $P < 0.0001$. Lake Monroe had a significantly higher L_∞ than Lochloosa Lake ($\chi^2 = 5.21$; $df = 1$; $P = 0.0357$), which had a significantly higher L_∞ than Lake Marian ($\chi^2 = 4.41$; $df = 1$; $P = 0.0225$). The estimate of k was higher at Lochloosa Lake than for Lakes Marian ($\chi^2 = 7.73$; $df = 1$; $P = 0.0054$) and Monroe ($\chi^2 = 6.48$; $df = 1$; $P = 0.0109$), but k did not differ significantly between the latter two lakes ($\chi^2 = 0.18$; $df = 1$; $P = 0.6695$). Thus, growth

rates varied among populations with Lake Monroe having the largest mean TL-at-age, Lochloosa intermediate, and Lake Marian the lowest size-at-age.

A total of 1,047 black crappie stomachs were examined for diet contents (Table 6). Lakes Lochloosa, Marian, and Monroe had sample sizes of 431, 317, and 299, respectively. There were 48 (4.6 %) empty stomachs and 49 (4.7 %) stomachs that contained nothing but unidentifiable digested material, which were not included in the mean %*Wt* analysis.

Diets varied widely among lakes, size groups, and periods. The arcsine-transformed mean %*Wt* of major prey categories in black crappie diets was significantly different due to the lake, size class, and period interaction (MANOVA, Wilk's Lambda: $F_{164, 3399} = 2.45, P < 0.0001$). Univariate ANOVAs of the four major prey categories revealed significant three-way interactions for microcrustaceans ($F_{41, 855} = 4.06, P < 0.0001$), insects ($F_{41, 855} = 2.29, P < 0.0001$), macrocrustaceans ($F_{41, 855} = 1.55, P = 0.0157$), and fish ($F_{41, 855} = 2.99, P < 0.0001$). Thus, all of the major prey categories were responsible for the significant three-way interaction found in the MANOVA (Figures 5-8), which caused inconsistent differences for the importance of the major prey categories throughout the sampling periods, lakes, and size classes. For example, the mean arcsine-transformed %*Wt* value of microcrustaceans of size class 1 black crappie diets collected from Lochloosa Lake during October 2003 was higher than Lake Marian (Tukey-Kramer test; $P = 0.0094$), whereas Lake Monroe was not significantly different from Lochloosa Lake ($P = 0.0631$) or Lake Marian ($P = 1.000$). During this same sampling period, there was no significant difference of the mean arcsine-transformed %*Wt* values of microcrustaceans between any of the lakes for size class 4 fish (all $P = 1.000$). When considering size class 1 in February 2003, the mean arcsine-transformed %*Wt* value of Lochloosa Lake was significantly smaller than both Lake Marian ($P < 0.0001$) and Lake Monroe

($P < 0.0001$), whereas there was no difference between Lake Marian and Lake Monroe ($P = 0.9999$). Thus, the diet composition expressed as mean %*Wt* for all the major prey categories (i.e., microcrustaceans, insects, macrocrustaceans, and fish) exhibited inconsistent differences among periods, size classes, and lakes.

Two seasonal trends of major diet categories were evident in black crappie diets at all three study lakes (Figures 5-8). Microcrustaceans were a more important component of the diets during the winter (December and February) and were least important during the summer (June and August), with spring (April) and fall (October) varying depending on the lake and size class (Figure 5). No seasonal trends among lakes were evident in the mean %*Wt* values obtained for insects and macrocrustaceans in black crappie diets because of high variation of those values among the periods, size groups, and lakes (Figures 6 and 7). Fish prey generally increased in black crappie diets from the spring to the fall, whereas it was less important during the winter (Figure 8). This was more noticeable in the smaller size classes of fish, which had lower mean %*Wt* values of fish throughout the seasons than the larger size classes.

Ontogenetic diet shifts of black crappie were evident at each lake (Figure 9). In general, mean %*Wt* values of microcrustaceans decreased and fish increased as crappie increased in size in each lake. There was no lake-size class interaction for mean arcsine-transformed %*Wt* values for microcrustaceans (ANOVA: $F_{6, 938} = 1.05, P = 0.3891$) or fish ($F_{6, 938} = 0.20, P = 0.9762$), which is supported by the parallelism present among lake values through all size classes (Figure 9). However, trends in the values for insects and macrocrustaceans were different among lakes as black crappie increased in size. A significant lake-size class interaction was found for the insect ($F_{6, 938} = 2.19, P = 0.0419$) and macrocrustacean ($F_{6, 938} = 5.67, P < 0.0001$) categories, which was due to the lack of parallelism across lakes and size classes, particularly for

macrocrustaceans (Figure 9). Insect values obtained in size class 4 black crappie from Lochloosa Lake were significantly lower than in size classes 1, 2, and 3 (Tukey-Kramer test, all $P < 0.003$) and insect values in size class 4 black crappie from Lake Marian were significantly lower than those in size classes 1 and 3 (all $P < 0.05$). However, there were no significant differences between any size classes in the insect values from Lake Monroe (all $P > 0.05$). Lake Monroe macrocrustacean values were significantly lower for size class 4 than size classes 1, 2, and 3 (all $P \leq 0.0005$), whereas there were no differences in macrocrustacean values found between any of the size classes for Lochloosa Lake or Lake Marian (all $P > 0.05$). When comparing insect and macrocrustacean values between lakes for individual size groups, Lochloosa Lake and Lake Marian had no significant differences (all $P > 0.05$). When compared to Lake Monroe, these two lakes had significantly higher values of insects (all $P \leq 0.01$) for all size classes except size class 4 and significantly lower values of macrocrustaceans (all $P < 0.0001$) for every size class. Hence, differences in ontogenetic diet shifts of black crappie between lakes were due to the intermediate sized prey categories (insects and macrocrustaceans) rather than microcrustaceans or fish.

There were four prey types that made up the majority of the %*Wt* values of the insect and macrocrustacean prey categories (Table 7). These included Chironomidae larvae, Chaoboridae larvae, Diptera pupae, and Mysidacea. Chironomidae larvae was a highly consumed prey type by black crappie in size classes 1, 2, and 3 among all systems. However, there were differences in the %*Wt* values of Chaoboridae larvae, Diptera pupae, and Mysidacea among lakes. While black crappie at Lochloosa Lake preyed highly upon Diptera pupae and black crappie at Lake Marian preyed highly upon Diptera pupae and Chaoboridae larvae, these two prey types were not highly utilized by black crappie at Lake Monroe. This resulted in higher %*Wt* values of the

insect category at Lakes Lochloosa and Marian relative to Lake Monroe. Black crappie at Lake Monroe instead utilized the additional resource of Mysidacea (i.e., *Americamysis almyra*) as a prey item, which caused the macrocrustacean category %*Wt* values to be much larger than what was found in the other two systems. Diet shifts of the insect and macrocrustacean prey categories occurred when the %*Wt* values were consistently higher throughout size classes within a system. Therefore, differences in the utilization of Chaoboridae larvae, Diptera pupae, and Mysidacea by black crappie among systems led to the differences in ontogenetic diets shifts among systems.

There was not a significant lake-size class interaction found for the mean $\log(X + 1)$ -transformed total stomach content *IF* values (ANOVA; $F_{6, 935} = 1.36, P = 0.2293$). Tukey-Kramer multiple comparison tests resulted in no significant differences (all $P \geq 0.05$) found between lakes for any size class, implying that total consumption expressed as a function of fish weight was similar across all lakes for each size class. The main effects showed significant differences of the *IF* values for both lakes ($F_{2, 935} = 5.87, P = 0.0029$) and size classes ($F_{3, 935} = 7.63, P < 0.0001$). Tukey-Kramer multiple comparison tests resulted in greater *IF* values at Lakes Lochloosa and Marian compared with Lake Monroe (both $P < 0.008$), whereas the prior two lake's *IF* values were not significantly different from each other ($P = 0.9797$). Size class 1 black crappie *IF* values were greater when compared to size classes 3 ($P = 0.0001$) and 4 ($P = 0.0006$), and greater than size class 2 *IF* values by a marginal significance ($P = 0.0579$). There were no differences found in the *IF* values among size classes 2, 3, and 4 (all $P > 0.30$). Thus, black crappie at Lakes Lochloosa and Marian consumed a greater amount (i.e., weight) of total prey when expressed as a function of fish weight than black crappie at Lake Monroe. Also,

size class 1 black crappie had larger diets in proportion to fish weight compared to larger size classes of black crappie.

Differences in densities of benthic macroinvertebrates among lakes were significant for four taxa including Chironomidae larvae, Chaoboridae larvae, Amphipoda, and Hydracarina. Mean densities of all taxa are listed in Table 8. Chironomidae larvae densities were significantly different among lakes in December 2002 (ANOVA; $F_{2, 21} = 6.30$, $P = 0.0072$) and marginally significant in February 2003 ($F_{2, 21} = 3.31$, $P = 0.0563$). Differences occurred due to higher densities of Chironomidae larvae at Lochloosa Lake than at Lake Monroe for December (Tukey test; $q = 4.9855$; $df = 21, 3$; $P = 0.0055$) and February ($q = 3.6146$; $df = 21, 3$; $P = 0.0465$). Differences among lakes for Chaoboridae larvae and Hydracarina densities were found in all periods (Kruskal-Wallis test; all $H_{CS} > H_{0.05, 8, 8, 8} = 5.805$), except the February 2003 Hydracarina values ($H_C = 4.062$; $df = 8, 8, 8$; $P > 0.05$). Lake Marian had higher densities of Chaoboridae larvae when compared to Lake Monroe for each sample period (Dunn test; all $Q_s > Q_{0.05, 3} = 2.394$). Chaoboridae densities at Lochloosa Lake were greater than those at Lake Monroe during April ($Q = 2.856$; $df = 3$; $0.01 < P < 0.02$) and June ($Q = 3.246$; $df = 3$; $0.001 < P < 0.005$) and lower than those at Lake Marian during August ($Q = 2.766$; $df = 3$; $0.01 < P < 0.02$) and October ($Q = 2.799$; $df = 3$; $0.01 < P < 0.02$). Lake Marian had higher densities of Hydracarina than Lochloosa Lake in each period when differences were found among lakes and higher densities than Lake Monroe in April, June, and October (all $Q_s > Q_{0.05, 3} = 2.394$). A significant difference of Amphipoda densities among lakes was found in October 2003 ($H_C = 6.553$; $df = 8, 8, 8$; $P < 0.05$), when densities at Lake Monroe were greater than those at Lochloosa Lake ($Q = 2.429$; $df = 3$; $0.02 < P < 0.05$). There were no significant differences found among lakes in the densities of Ephemeroptera larvae, Trichoptera

larvae, Ceratopogonidae larvae, or Diptera pupae during any sample period

(all $H_{CS} < H_{0.05, 8, 8, 8} = 5.805$).

Differences in macroinvertebrate densities (i.e., Chironomidae larvae, Chaoboridae larvae, and Hydracarina) among lakes were accompanied by dietary differences in black crappie for these same prey taxa. In December 2002 and February 2003, when Chironomidae larvae densities were higher at Lochloosa Lake in comparison to Lake Monroe, the mean number of Chironomidae larvae consumed by black crappie from Lochloosa Lake was also higher than at Lake Monroe (Figure 11). High Chaoboridae larvae densities at Lake Marian were accompanied by both higher %*Wt* and higher mean number of Chaoboridae larvae values in black crappie diets, when compared to Lakes Lochloosa and Monroe (Table 7 and Figure 11). At Lake Marian, higher Hydracarina densities were associated with occurrence of this prey item in the diets of black crappie. Although Hydracarina was never found in large quantities and only occurred in 5 black crappie stomachs out of 317 examined from Lake Marian, this prey item never occurred in any of the stomachs examined from Lakes Lochloosa or Monroe. Hence, higher densities of macroinvertebrate taxa caused increased occurrence and/or consumption of those prey taxa in black crappie diets.

Two major trends in prey selection were detected with Manly's α index (Figure 10). First, black crappie of all sizes at Lakes Lochloosa and Marian were highly selective of Diptera pupae during most periods. Second, black crappie of all sizes at Lake Monroe were highly selective of Mysidacea during most periods. While black crappie at Lakes Lochloosa and Marian did not have Mysidacea as a prey option, black crappie at Lake Monroe had Diptera pupae as a prey option but selected Mysidacea.

Manly's α index produced various results for the remainder of the prey taxa (Figure 10). Selection for Chaoboridae larvae at Lakes Lochloosa and Marian was generally higher than for Lake Monroe. Black crappie at Lake Marian were more selective of Chironomidae larvae than at Lakes Lochloosa and Monroe. Ceratopogonidae larvae, Ephemeroptera larvae, Trichoptera larvae, Amphipoda, and Isopoda were generally avoided prey taxa, but results were inconsistent and these prey taxa were occasionally considered either not preferred or highly selected among all size classes of black crappie. Hydracarina was always considered an avoided prey taxa.

The simplified Morisita index produced various results of C_H values for the different taxa (Table 9). Relative increases and decreases of taxa density and mean number in diets are shown in Figure 11. Overall, Chironomidae larvae and Diptera pupae produced the highest C_H values throughout most size classes at each lake. An exception occurred for Diptera pupae for size class 4 black crappie from Lake Monroe ($C_H = 0.09$). The reason for such a low value (no similarity), was due to the August 2003 sampling period when 2 individual fish consumed over one thousand Diptera pupae each. This raised the mean number of Diptera pupae in the stomachs far above what was sampled in the environment for that period and was much greater than the mean numbers found in diets for the other periods. Chaoboridae larvae ($C_H = 0.69 - 0.92$) and Ephemeroptera larvae ($C_H = 0.55 - 0.80$) values were higher for Lake Marian black crappie throughout all size classes than at Lochloosa Lake and Lake Monroe for the same size classes. The similarities of Mysidacea ($C_H = 0.72 - 0.93$), Trichoptera ($C_H = 0.63 - 0.75$), Amphipoda ($C_H = 0.47 - 0.86$), and Isopoda ($C_H = 0.67 - 0.93$) were relatively high in Lake Monroe samples throughout most size classes, while these same taxa either were not present or had lower C_H values at the other lakes. Overall, higher C_H values were detected for taxa which were more

utilized within a system. Thus, I was able to detect a relationship between seasonal abundance of benthic prey and black crappie diets within a lake, particularly for taxa that were highly utilized.

Some tradeoffs of utilized prey resources were found for benthic macroinvertebrates as densities of those prey taxa changed. For example, black crappie at Lake Monroe increased their consumption of Chironomidae larvae in June 2003 when the highest Chironomidae densities occurred relative to the other sampling periods were recorded (Figure 11). At this same time, Mysidacea densities were declining along with the consumption of Mysidacea by black crappie (Figure 11).

Table 1. Mean water quality parameters for Lakes Lochloosa (Source: Florida LAKEWATCH 1997), Marian (Source: FWC unpublished data), and Monroe (Source: Florida LAKEWATCH 2003). Water quality parameters include years sampled (Yrs), number of sampling dates (n), total phosphorus (TP $\mu\text{g/L}$), total nitrogen (TN $\mu\text{g/L}$), chlorophyll (CHL $\mu\text{g/L}$), secchi depth, and trophic state.

Lake	Yrs	n	TP ($\mu\text{g/L}$)	TN ($\mu\text{g/L}$)	CHL ($\mu\text{g/L}$)	Secchi (m)	Trophic state
Lochloosa	1993-96	40	48	1816	63	0.48	hypereutrophic
Marian	2000-02	5	111	1759	42	0.66	hypereutrophic
Monroe	2000-02	21	89	1628	19	0.61	eutrophic

*Trophic state based on Forsburg and Ryding (1980).

Table 2. List of types and common names of prey used to numerically and gravimetrically describe black crappie diet contents.

Prey type	Common name	Prey type	Common name
Nematoda	Roundworms	Neuroptera	Spongillaflies
Oligochaeta	Aquatic earthworms	Trichoptera	Caddisflies
Hirudinea	Leeches	Coleoptera	Beetles
Cladocera	Water fleas	Hymenoptera	Ants and Wasps
Copepoda	Copepods	Arachnida-Araneae	Spiders
Copepoda-Argulus	Fish lice	Orthoptera	Grasshoppers
Ostracoda	Seed shrimp	Diptera	Flies, Midges, etc.
Mysidacea	Opossum shrimp	Chironomidae larvae	Midge larvae
Isopoda	Aquatic sow bugs	Chironomidae pupae	Midge pupae
Amphipoda	Scuds, Sideswimmers	Chironomidae adult	Midge adult
Cambaridae	Crayfish	Chaoboridae larvae	Phantom midge larvae
Palaemonidae	Grass shrimp	Chaoboridae pupae	Phantom midge pupae
Hydracarina	Water mites	Chaoboridae adult	Phantom midge adult
Unidentified Insect	Insects	Ceratopogonidae	Biting midge larvae
Plecoptera	Stoneflies	Stratiomyidae	Soldier fly larvae
Ephemeroptera	Mayflies	Fish	
Odonata	Odonates	Gastropoda	Snails
Odonata-Anisoptera	Dragonflies	Vegetation	
Odonata-Zygoptera	Damselflies	Detritus	
Hemiptera	Bugs	Miscellaneous material	
Hemiptera-Corixidae	Water boatmen	Digested material	
Megaloptera	Dobsonflies		

Table 3. Four major prey categories used in the MANOVA procedure and the individual prey items included in each category.

Major prey category	Individual prey types included in major prey categories	
Microcrustaceans	Cladocera	Copepoda
	Copepoda-Argulus	Ostracoda
Insects	Unidentified Insect	Plecoptera
	Ephemeroptera	Odonata
	Odonata-Anisoptera	Odonata-Zygoptera
	Hemiptera	Hemiptera-Corixidae
	Megaloptera	Neuroptera
	Trichoptera	Coleoptera
	Hymenoptera	Orthoptera
	Diptera	Chironomidae
	Chaoboridae	Ceratopogonidae
	Stratiomyidae	Arachnida-Araneae ^a
	Hydracarina ^a	
	Macrocrustaceans	Mysidacea
Amphipoda		Palaemonidae
Cambaridae		
Fish	Fish	

^a Arachnida and Hydracarina are not true insects, but were included within the insect prey category.

Table 4. Otter trawl capture and collection data for black crappie from Lakes Lochloosa, Marian, and Monroe during each sampling period. Total time is the total number of minutes trawls were pulled at each lake. Total catch is the total number of black crappie caught in all trawls. Mean CPUE was calculated for black crappie for size class 2 (150 – 189 mm TL), size class 3 (190 – 229 mm TL), size class 4 (> 230 mm TL), and all fish. Total fish collected include all black crappie sacrificed for diet and age analysis in size classes 1 (110 – 149 mm TL), 2, 3, and 4.

Sampling period	# of Trawls	Total time (min)	Total catch	Mean CPUE (fish/min)				Total collected				
				Size class 2	Size class 3	Size class 4	All fish	Size class 1	Size class 2	Size class 3	Size class 4	All size classes
Lochloosa Lake												
Aug-2002	a	a	a	a	a	a	a	10	10	10	10	40
Oct-2002	23	91	221 ^b	0.3 ^b	0.1 ^b	0.1 ^b	2.7 ^b	43	15	15	12	85
Dec-2002	48	323	a	a	a	a	a	32	11	10	23	76
Feb-2003	24	120	316	0.3	0.2	0.1	2.6	30	31	25	11	97
April-2003	26	160	260	0.3	0.2	0.1	1.8	30	30	22	10	92
June-2003	22	130	1,065	0.9	0.2	0.4	8.7	29	34	27	30	120
Aug-2003	23	148	978	1.0	0.1	0.1	6.9	31	30	19	15	95
Oct-2003	20	108	729	1.0	0.3	0.3	6.7	28	30	29	30	117
All Periods	186 ^c	1,080 ^c	3,569 ^c	0.6	0.2	0.2	4.8	233	191	157	141	722

a Data not recorded.

^b Values do not include all trawls in sampling period.

^c Totals based on data with missing values.

Table 4. Continued.

Sampling period	# of Trawls	Total time (min)	Total catch	Mean CPUE (fish/min)				Total collected				
				Size class 2	Size class 3	Size class 4	All fish	Size class 1	Size class 2	Size class 3	Size class 4	All size classes
Lake Marian												
Aug-2002	2	10	400	25.1	7.5	3.4	40.0	10	10	10	10	40
Oct-2002	6	12	365	6.0 ^b	3.1 ^b	8.3 ^b	30.4	9	10	10	10	39
Dec-2002	3	6	172	10.0	4.7	3.5	28.7	10	10	10	10	40
Feb-2003	4	8	97	5.4	2.3	2.0	12.1	10	10	10	10	40
Apr-2003	5	15	242	4.3 ^b	5.8 ^b	3.1 ^b	16.1	10	10	10	10	40
Jun-2003	7	23	336	3.8 ^b	4.3 ^b	3.7 ^b	13.9	10	10	10	8	38
Aug-2003	6	22	177	0.9	2.4	1.9	8.0	10	10	10	10	40
Oct-2003	4	12	237	3.3	7.5	5.8	19.8	10	10	10	10	40
All Periods	37	108	2,026	5.6	4.3	4.0	19.0	79	80	80	78	317

Table 4. Continued.

Sampling period	# of Trawls	Total time (min)	Total catch	Mean CPUE (fish/min)				Total collected				
				Size class 2	Size class 3	Size class 4	All fish	Size class 1	Size class 2	Size class 3	Size class 4	All size classes
Lake Monroe												
Aug-2002	26	130	855	0.1	0.2	1.1	6.6	10	10	10	10	40
Oct-2002	22	110	232	0	0.1	0.7	2.1	10	0	8	10	28
Dec-2002	9	43	404	0.2	0.4	2.4	9.0	10	10	10	10	40
Feb-2003	11	55	305	0.2	0.1	1.1	5.5	10	10	4	10	34
Apr-2003	18	130	630	0.9 ^b	0 ^b	1.2 ^b	4.9	10	10	8	10	38
Jun-2003	15	75	594	3.5	0.1	0.6	7.9	10	10	10	10	40
Aug-2003	5	25	261	1.0	0.4	1.2	10.4	10	10	10	10	40
Oct-2003	4	20	149	0.7	0.8	1.0	7.5	10	10	10	10	40
All Periods	110	588	3,430	0.7	0.2	1.0	5.9	80	70	70	80	300
Total	333 ^c	1,736 ^c	9,025 ^c					392	341	307	299	1,339

Table 5. Linear, Gompertz, and von Bertalanffy growth functions of black crappie in Lakes Lochloosa, Marian, and Monroe based on the collected total length at age data. L_t is the expected length at age t (years).

Lake	Growth function
Linear	
Lochloosa	$L_t = 100.27 + 44.90(t)$
Marian	$L_t = 128.42 + 27.34(t)$
Monroe	$L_t = 123.85 + 36.70(t)$
Gompertz	
Lochloosa	$L_t = 312.0 \times e^{\left(-e^{(-0.6411(t-0.7057))}\right)}$
Marian	$L_t = 311.1 \times e^{\left(-e^{(-0.4745(t-0.5182))}\right)}$
Monroe	$L_t = 344.4 \times e^{\left(-e^{(-0.4917(t-0.5689))}\right)}$
von Bertalanffy	
Lochloosa	$L_t = 342.3\left(1 - e^{(-0.3724(t+0.3761))}\right)$
Marian	$L_t = 328.5\left(1 - e^{(-0.3077(t+0.8268))}\right)$
Monroe	$L_t = 370.5\left(1 - e^{(-0.2999(t+0.8039))}\right)$

Table 6. Number of black crappie stomachs examined for diet contents, number of empty stomachs observed, and number of stomachs with 100 % digested material in each of the three study lakes. Total stomachs examined are listed for size classes 1 (110 – 149 mm TL), 2 (150 – 189 mm TL), 3 (190 – 229 mm TL), and 4 (\geq 230 mm TL). The numbers in parentheses for empty stomachs and stomachs with 100 % digested material indicate the percentages that those stomachs made up for all size classes of stomachs examined.

Sampling period	Total stomachs examined					Empty stomachs	Stomachs with 100 % digested material
	Size class 1	Size class 2	Size class 3	Size class 4	All size classes		
Lochloosa Lake							
Aug-2002	10	10	10	10	40	1 (2.5)	6 (15.0)
Oct-2002	43	15	15	12	85	2 (2.4)	8 (9.4)
Dec-2002	32	11	10	23	76	1 (1.3)	0
Feb-2003	9	10	10	11	40	0	0
Apr-2003	10	10	10	10	40	2 (5.0)	0
Jun-2003	9	11	10	15	45	1 (2.2)	7 (15.6)
Aug-2003	10	10	10	15	45	1 (2.2)	5 (11.1)
Oct-2003	10	10	10	30	60	5 (8.3)	9 (15.0)
All Periods	133	87	85	126	431	13 (3.0)	35 (8.1)
Lake Marian							
Aug-2002	10	10	10	10	40	1 (2.5)	1 (2.5)
Oct-2002	9	10	10	10	39	5 (12.8)	1 (2.6)
Dec-2002	10	10	10	10	40	1 (2.5)	0
Feb-2003	10	10	10	10	40	2 (5.0)	1 (2.5)
Apr-2003	10	10	10	10	40	1 (2.5)	0
Jun-2003	10	10	10	8	38	1 (2.6)	0
Aug-2003	10	10	10	10	40	1 (2.5)	3 (7.5)
Oct-2003	10	10	10	10	40	2 (5.0)	2 (5.0)
All Periods	79	80	80	78	317	14 (4.4)	8 (2.5)

Table 6. Continued.

Sampling period	Total stomachs examined					Empty stomachs	Stomachs with 100 % digested material
	Size class 1	Size class 2	Size class 3	Size class 4	All size classes		
Lake Monroe							
Aug-2002	10	10	10	10	40	5 (12.5)	1 (2.5)
Oct-2002	10	0	8	10	28	4 (14.3)	0
Dec-2002	10	10	10	10	40	0	1 (2.5)
Feb-2003	10	10	4	10	34	0	0
Apr-2003	10	10	8	10	38	0	0
Jun-2003	10	10	10	10	40	0	0
Aug-2003	10	10	10	10	40	7 (17.5)	0
Oct-2003	9	10	10	10	39	5 (12.8)	4 (10.3)
All Periods	79	70	70	80	299	21 (7.0)	6 (2.0)
Total	291	237	235	284	1047	48 (4.6)	49 (4.7)

Table 7. Mean percent weight values (%*Wt*) of dominant prey types in the Insect and Macrocrustacean (Macro) prey categories found in black crappie diets in size classes 1 (110 – 149 mm TL), 2 (150 –189 mm TL), 3 (190 – 229 mm TL), and 4 (\geq 230 mm TL) at Lakes Lochloosa, Marian, and Monroe. Prey types listed include Chironomidae larvae (Chi), Chaoboridae larvae (Cha), and Diptera pupae (Dip) in the Insect prey category and Mysidacea (Mys) in the Macro prey category. %*Wt* values are based on pooled data from all sampling periods.

Size class	Chi % <i>Wt</i>	Cha % <i>Wt</i>	Dip % <i>Wt</i>	Insect % <i>Wt</i>	Mys % <i>Wt</i>	Macro % <i>Wt</i>
Lochloosa Lake						
1	29.63	4.34	31.84	71.05	0	5.22
2	21.55	7.46	25.35	66.79	0	4.23
3	14.32	1.19	30.36	60.21	0	7.55
4	6.32	0.43	21.75	37.71	0	2.60
Lake Marian						
1	24.61	11.73	17.79	60.54	0	0.22
2	15.21	17.56	12.73	58.11	0	6.26
3	10.20	19.54	20.03	59.47	0	7.63
4	2.70	15.16	17.38	37.70	0	3.00
Lake Monroe						
1	14.16	5.95	1.37	25.63	39.12	48.20
2	17.71	3.40	2.60	33.92	31.92	42.11
3	18.46	3.39	1.67	30.42	34.46	46.71
4	3.66	0.59	11.40	20.65	14.83	21.72

Table 8. Mean densities (number/m²) of taxa collected with petite Ponars in each period from Lakes Lochloosa, Marian, and Monroe. Periods include December of 2002 and February, April, June, August, and October of 2003. Taxa include Chironomidae larvae (Chi), Chaoboridae larvae (Cha), Ceratopogonidae larvae (Cer), Diptera pupae (Dip), Mysidacea (Mys), Trichoptera larvae (Tri), Ephemeroptera larvae (Eph), Amphipoda (Amp), Isopoda (Iso), and Hydracarina (Hyd).

Period	Mean taxa density									
	Chi	Cha	Cer	Dip	Mys	Tri	Eph	Amp	Iso	Hyd
Lochloosa Lake										
December	26,065	328	3,272	5	0	0	603	2,282	0	0
February	11,313	441	3,488	38	0	22	1,528	1,109	86	22
April	3,848	102	926	22	0	5	151	495	108	0
June	5,102	86	947	0	0	0	258	409	0	0
August	7,809	899	215	11	0	43	86	0	0	0
October	5,145	1,948	463	0	0	43	43	0	0	43

Table 8. Continued.

Period	Mean taxa density									
	Chi	Cha	Cer	Dip	Mys	Tri	Eph	Amp	Iso	Hyd
Lake Marian										
December	8,939	2,508	355	0	0	0	129	2,018	0	167
February	10,220	2,185	145	27	0	0	65	97	0	108
April	10,893	1,948	43	75	0	22	22	86	0	355
June	6,044	2,508	75	43	0	118	11	285	0	350
August	17,405	1,243	97	48	0	11	0	22	0	296
October	3,374	2,842	11	0	0	0	5	22	0	248
Lake Monroe										
December	1,706	38	161	0	16	32	43	81	38	5
February	2,164	43	86	27	5	22	172	199	0	22
April	2,626	16	129	70	38	5	0	113	86	0
June	27,270	22	108	70	16	75	0	291	15	0
August	11,727	0	32	0	5	32	86	576	457	5
October	2,007	22	54	0	0	27	27	264	388	22

Table 9. Simplified Morisita index values of similarity for various taxa comparing density found with petite Ponars to the total number found in black crappie diets through all sampling periods. Comparisons were made for black crappie in size classes 1 (110 – 149 mm TL), 2 (150 – 189 mm TL), 3 (190 – 229 mm TL), and 4 (\geq 230 mm TL) at Lakes Lochloosa, Marian, and Monroe. Taxa used in comparisons include Chironomidae larvae (Chi), Chaoboridae larvae (Cha), Ceratopogonidae larvae (Cer), Diptera pupae (Dip), Ephemeroptera larvae (Eph), Trichoptera larvae (Tri), Mysidacea (Mys), Amphipoda (Amp), Isopoda (Iso), and Hydracarina (Aca). Values range from 0 (no similarity) to 1.0 (complete similarity). Dashes indicate cases when no individuals were found in the diets. Blanks indicate cases when no individuals were found in the diets or Ponars.

Size class	Taxa									
	Chi	Cha	Cer	Dip	Eph	Tri	Mys	Amp	Iso	Aca
Lochloosa Lake										
1	0.92	0.43	0.23	0.95	0.09	0		0.32	-	-
2	0.85	0.82	0.23	0.88	0.33	0.29		0.61	-	-
3	0.90	0.45	0.27	0.93	0.33	-		0.50	-	-
4	0.59	0.53	0.41	0.95	-	-		0.45	-	-
Lake Marian										
1	0.69	0.69	0.10	0.92	0.55	0.99		0.04		-
2	0.91	0.92	0.28	0.85	0.80	0.28		0.07		0.39
3	0.92	0.74	0.23	0.66	0.60	0.17		0.08		0.39
4	0.81	0.85	0.22	0.66	0.60	-		0.05		0.39
Lake Monroe										
1	0.92	0.59	0.31	0.74	0.19	0.65	0.93	0.70	0.93	-
2	0.94	0.39	0.31	0.91	0	0.69	0.77	0.86	0.69	-
3	0.93	0.60	0.58	0.81	0.19	0.75	0.92	0.47	0.70	-
4	0.89	0.30	0.38	0.09	0.42	0.63	0.72	0.67	0.67	-

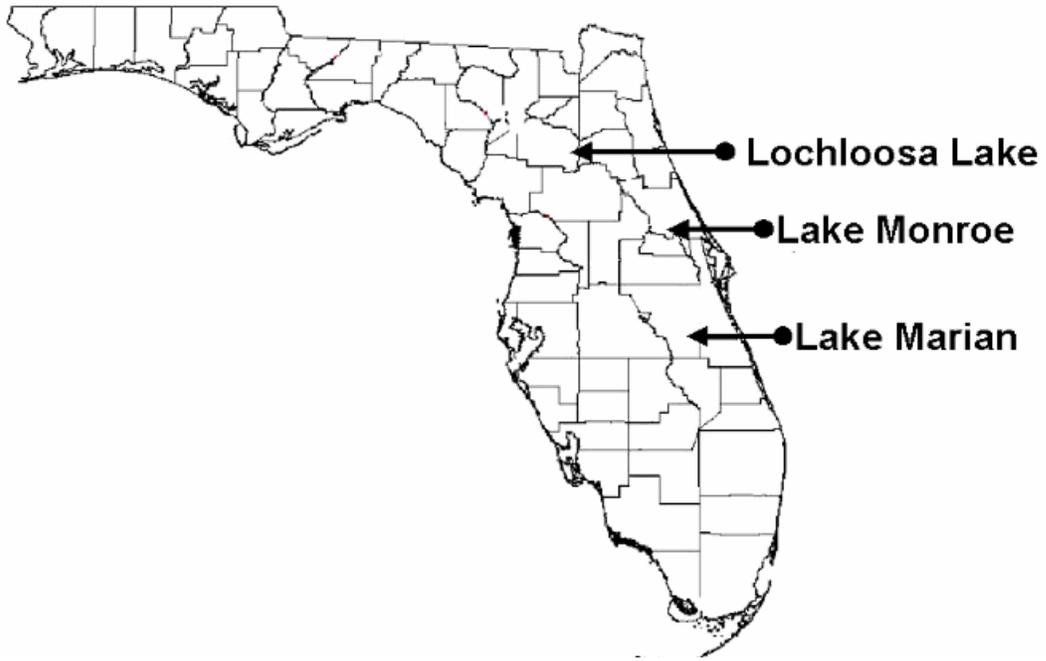


Figure 1. General locations of Lochloosa Lake, Lake Marian, and Lake Monroe in the state of Florida.

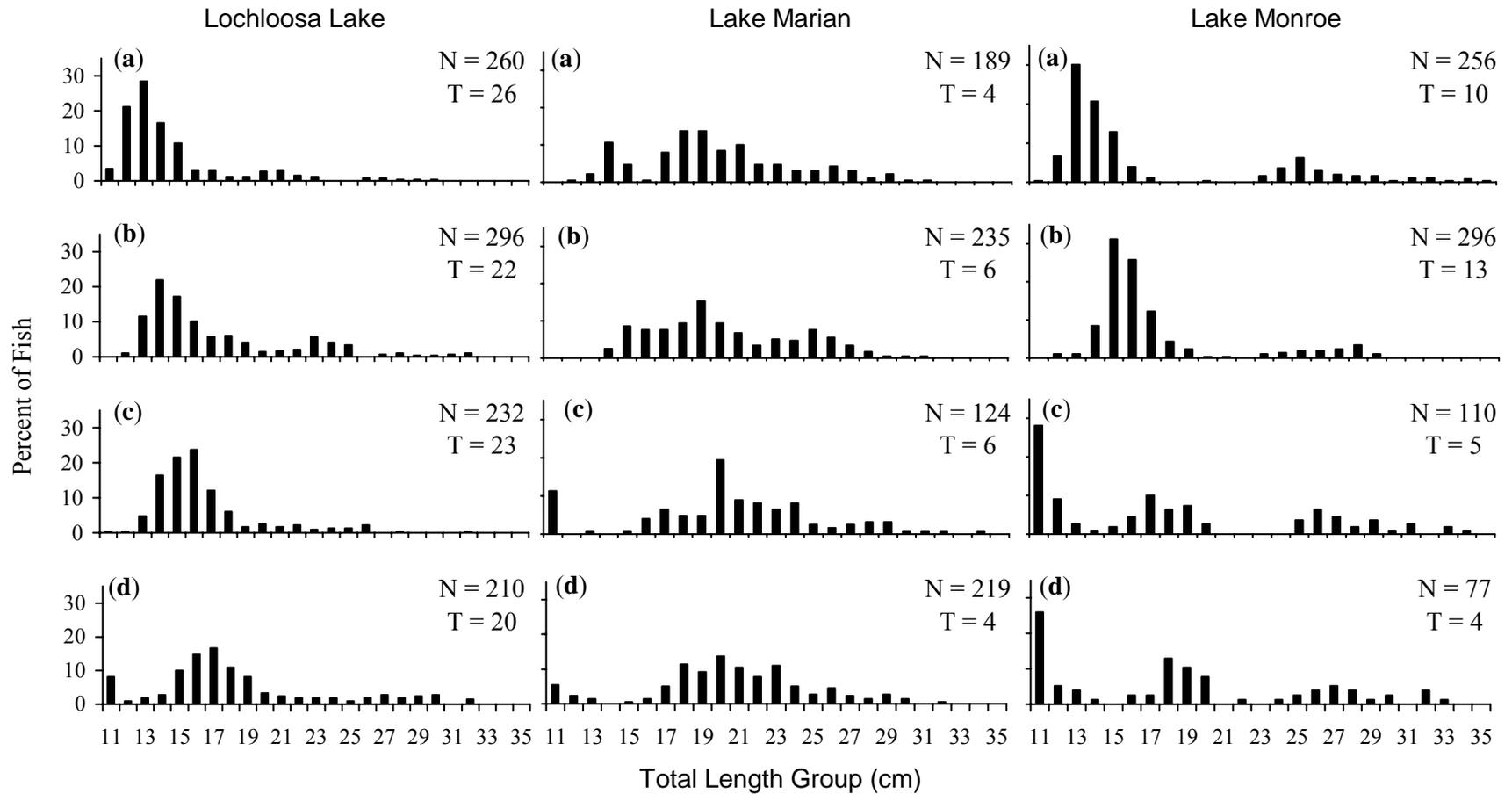


Figure 2. Relative length frequencies of black crappie ≥ 110 mm TL captured with otter trawls at Lakes Lochloosa, Marian, and Monroe for sampling periods (a) April, (b) June, (c) August, and (d) October of 2003. N is the total number of crappie represented in each graph, and T is the number of trawls used to collect the fish.

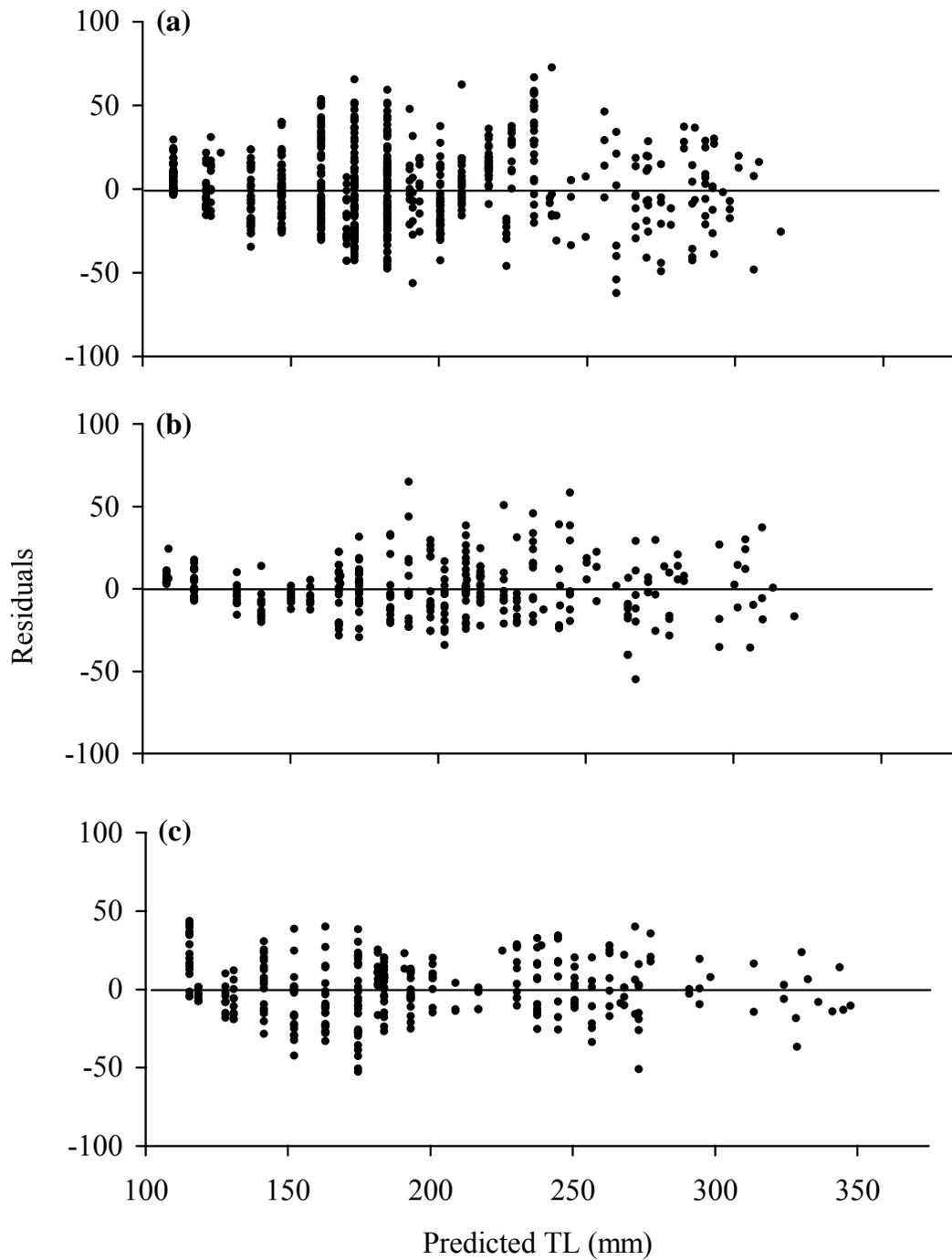


Figure 3. Residuals of the expected total length at age values from the observed total length at age values when using the respective von Bertalanffy growth models for Lakes (a) Lochloosa, (b) Marian, and (c) Monroe.

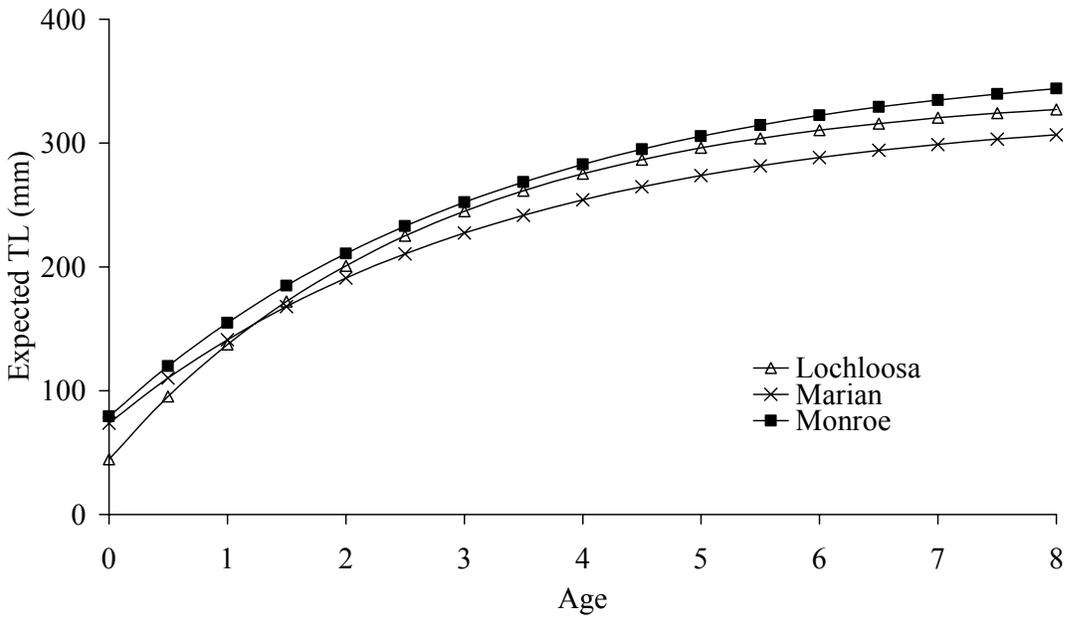


Figure 4. Mean total length (TL) at age (yrs) of black crappie in Lakes Lochloosa, Marian, and Monroe using their respective von Bertalanffy growth model.

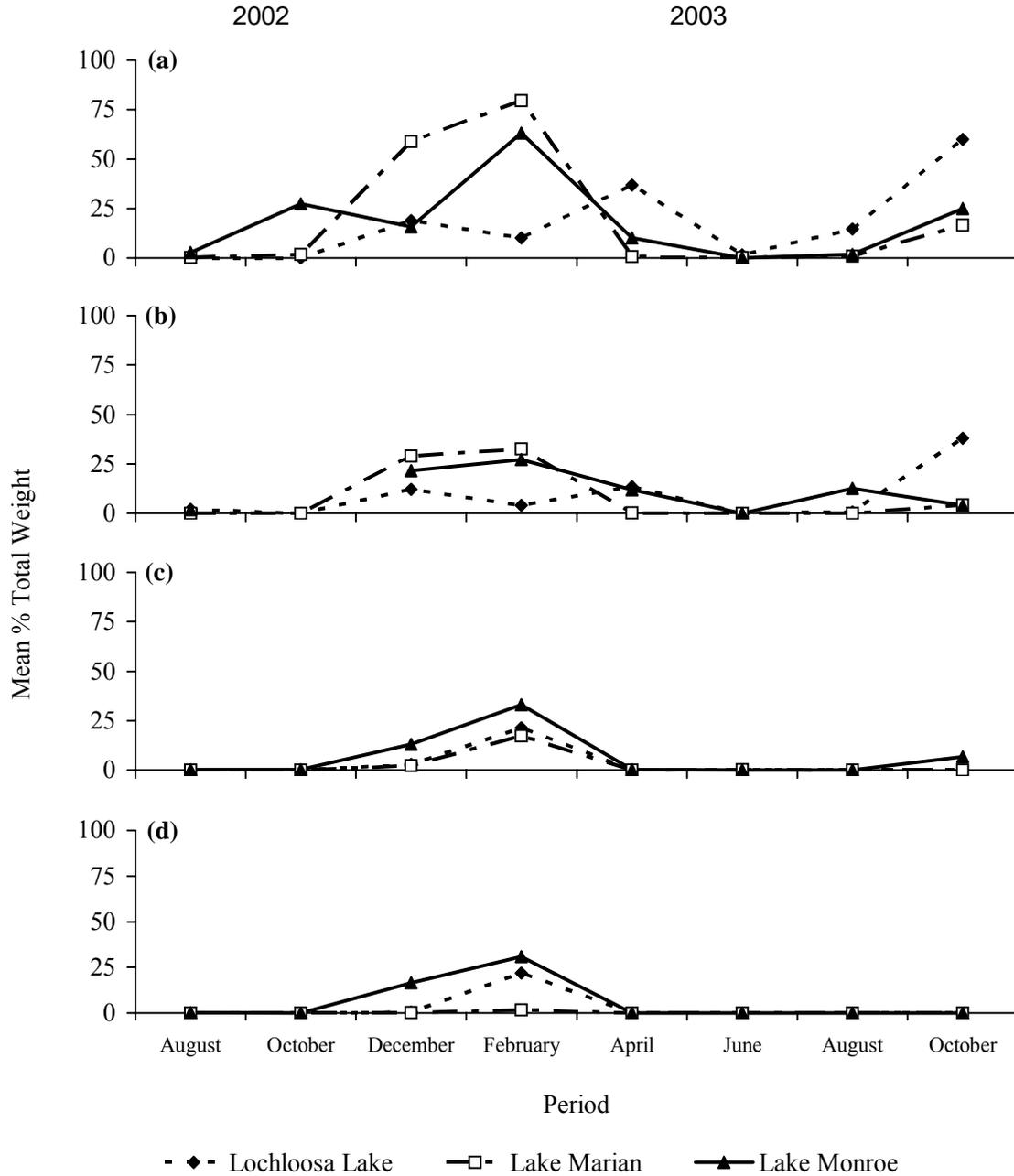


Figure 5. Mean percent of total diet weight of microcrustaceans (y axis) for black crappie at Lakes Lochloosa, Marian, and Monroe during sampling periods (x axis) for size classes (a) 1 (110-149 mm TL), (b) 2 (150-189 mm TL), (c) 3 (190-229 mm TL), and (d) 4 (≥ 230 mm TL).

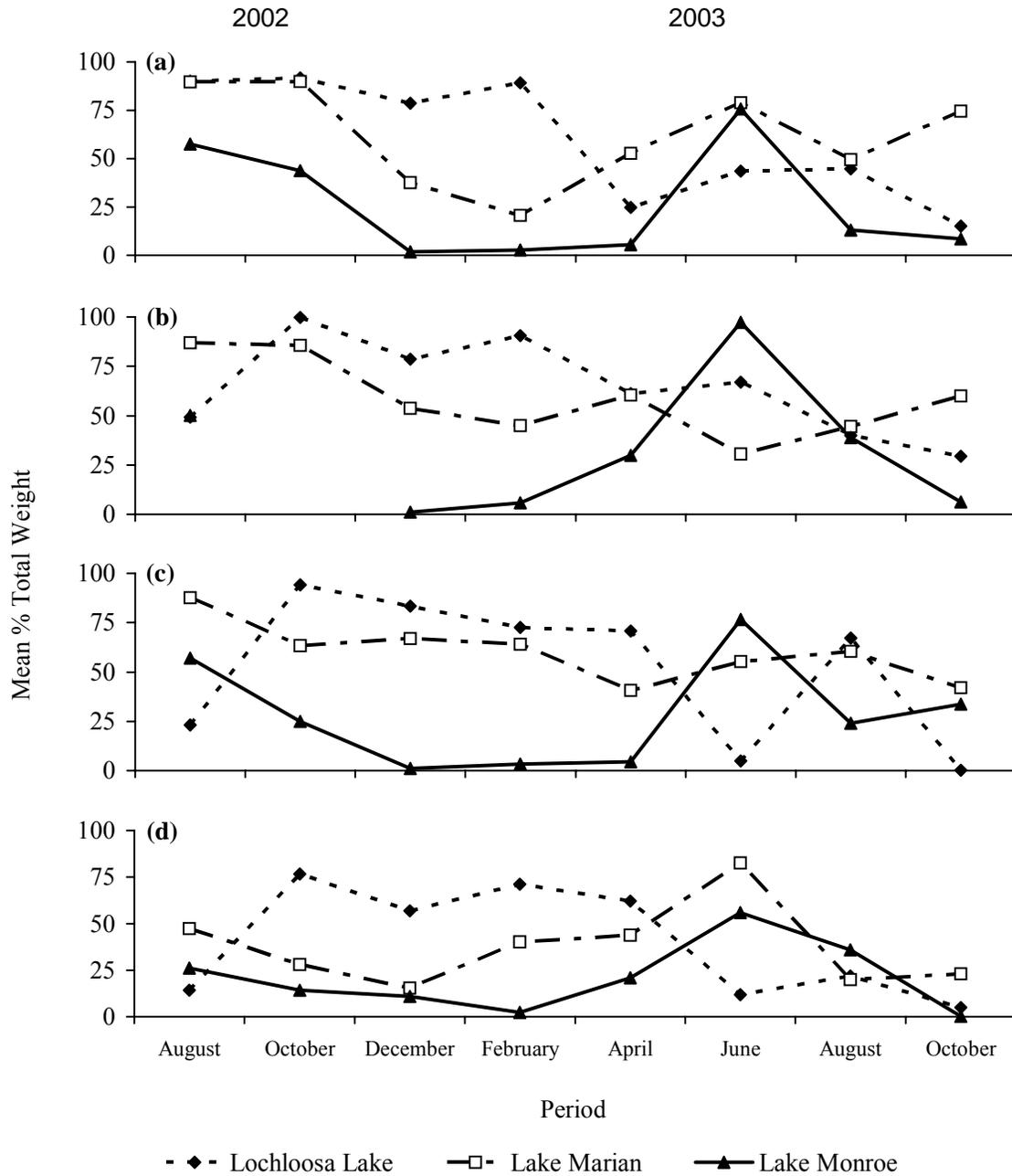


Figure 6. Mean percent of total diet weight of insects (y axis) for black crappie at Lakes Lochloosa, Marian, and Monroe during sampling periods (x axis) for size classes (a) 1 (110-149 mm TL), (b) 2 (150-189 mm TL), (c) 3 (190-229 mm TL), and (d) 4 (≥ 230 mm TL).

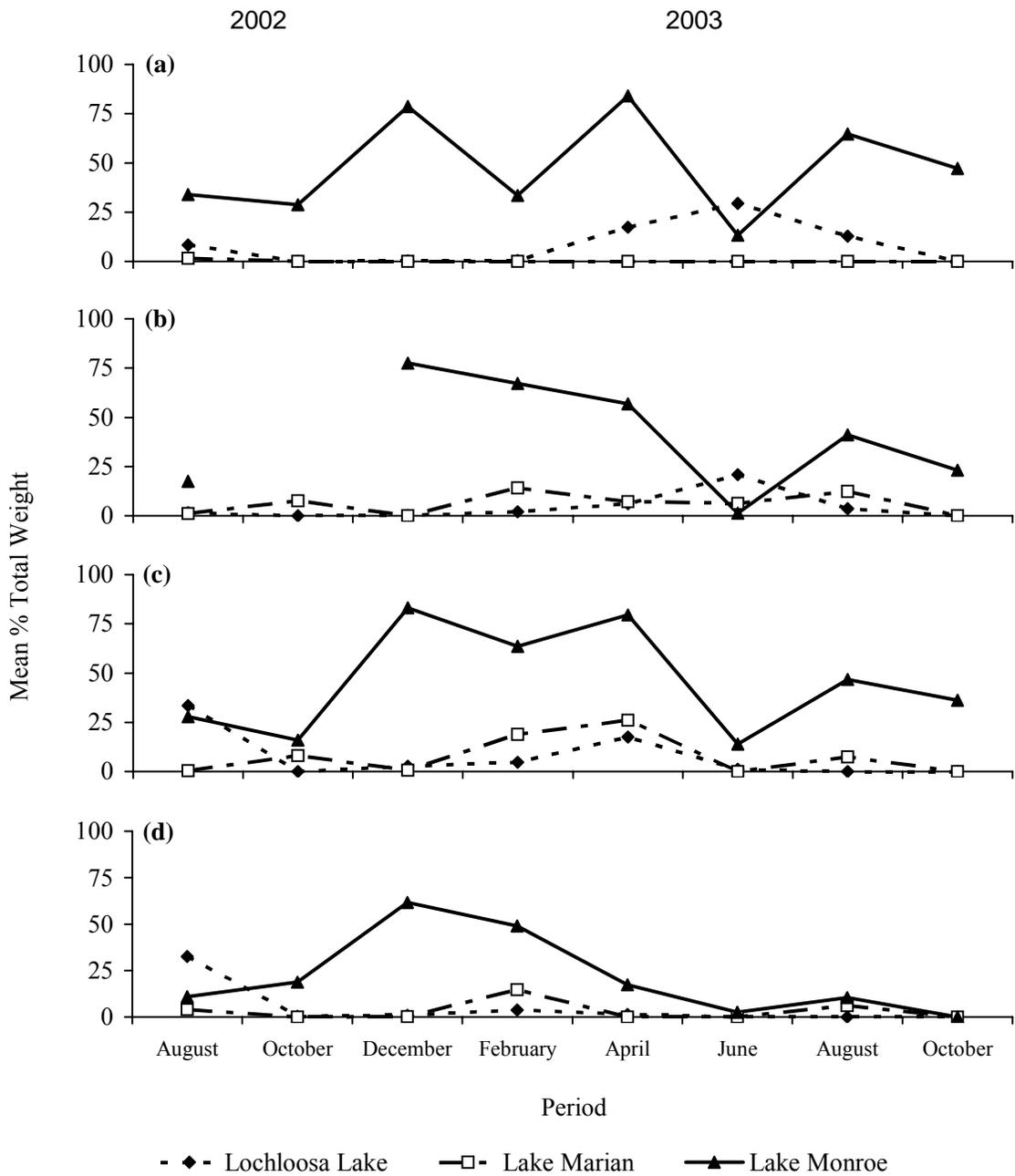


Figure 7. Mean percent of total diet weight of macrocrustaceans (y axis) for black crappie at Lakes Lochloosa, Marian, and Monroe during sampling periods (x axis) for size classes (a) 1 (110-149 mm TL), (b) 2 (150-189 mm TL), (c) 3 (190-229 mm TL), and (d) 4 (≥ 230 mm TL).

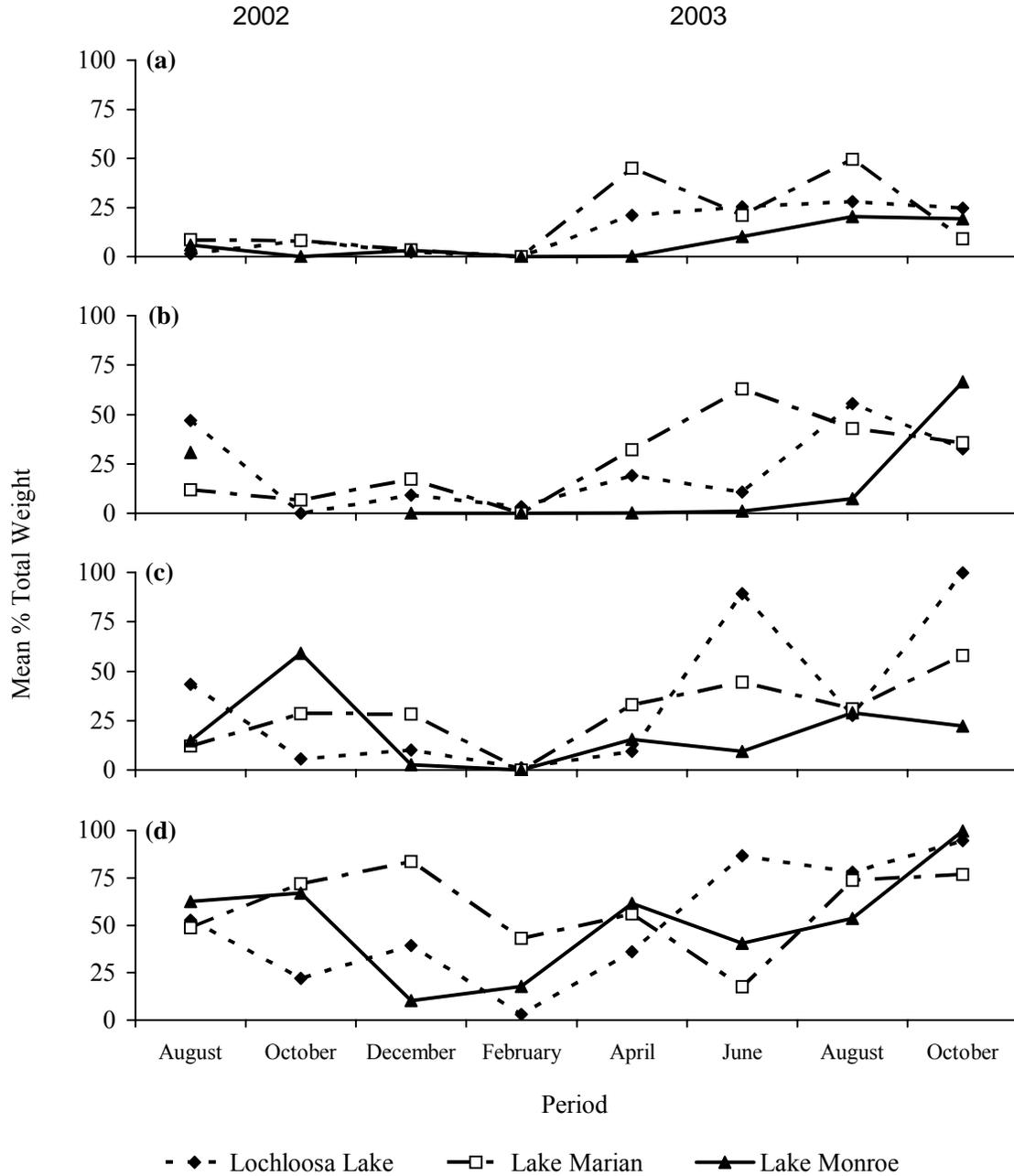


Figure 8. Mean percent of total diet weight of fish (y axis) for black crappie at Lakes Lochloosa, Marian, and Monroe during sampling periods (x axis) for size classes (a) 1 (110-149 mm TL), (b) 2 (150-189 mm TL), (c) 3 (190-229 mm TL), and (d) 4 (≥ 230 mm TL).

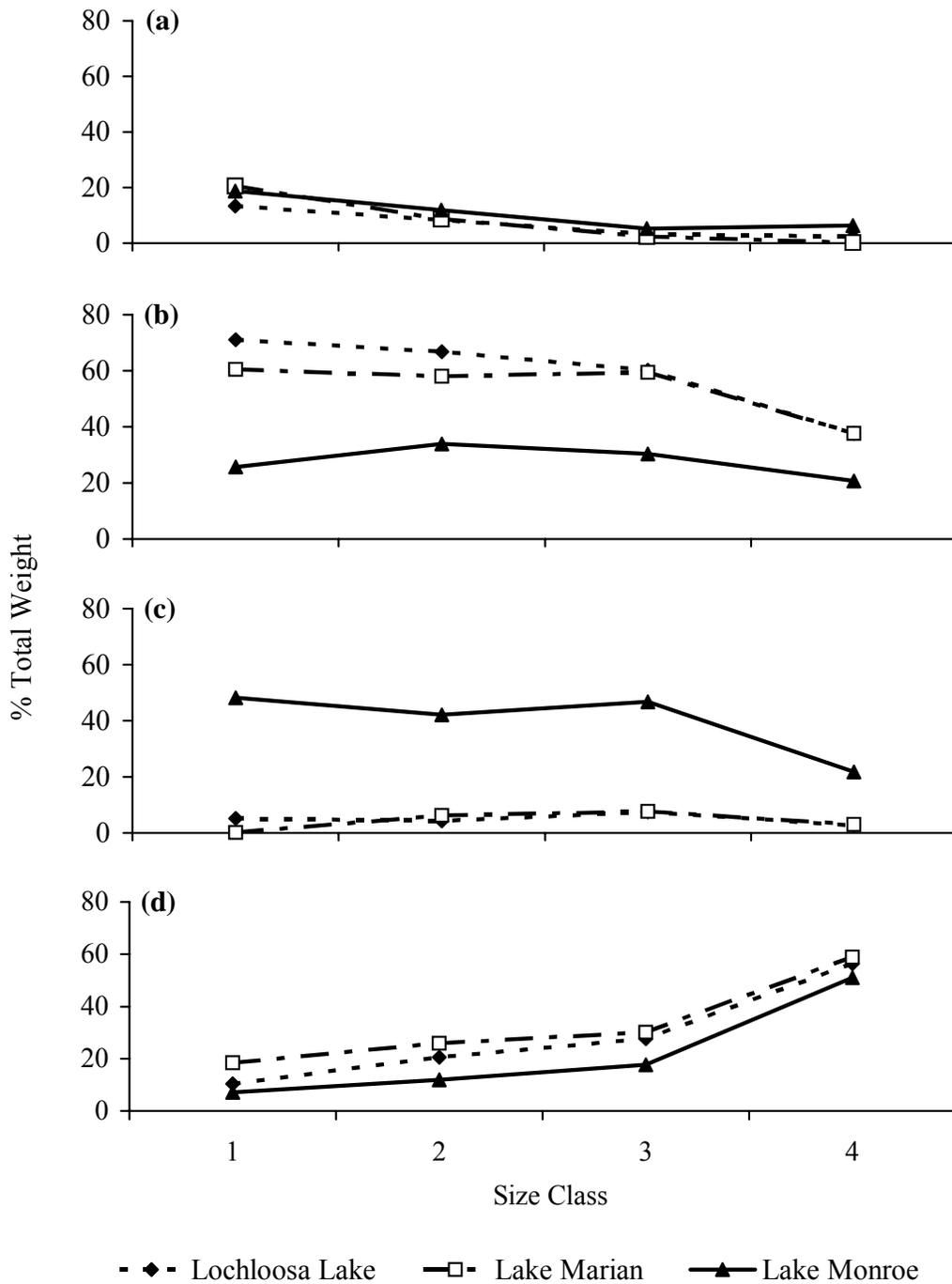


Figure 9. Mean percent total weight of (a) microcrustaceans, (b) insects, (c) macrocrustaceans, and (d) fish in the diets of black crappie of size classes 1 (110-149 mm TL), 2 (150-189 mm TL), 3 (190-229 mm TL), and 4 (\geq 230 mm TL) from Lakes Lochloosa, Marian, and Monroe.

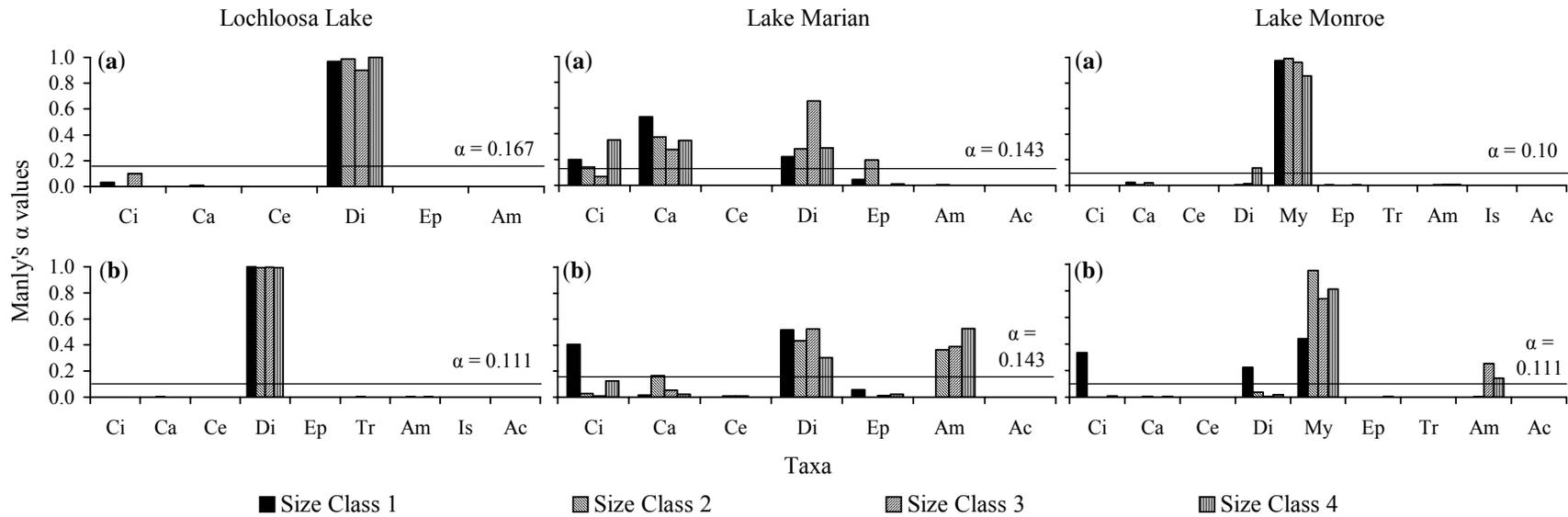


Figure 10. Mean Manly's α values indicating selection of prey taxa by black crappie in size classes 1 (110-149 mm TL), 2 (150-189 mm TL), 3 (190-229 mm TL), and 4 (≥ 230 mm TL) from Lakes Lochloosa, Marian, and Monroe during (a) December of 2002 and (b) February, (c) April, (d) June, (e) August, and (f) October of 2003. Taxa included in selectivity indices are Chironomidae larvae (Ci), Chaoboridae larvae (Ca), Ceratopogonidae larvae (Ce), Diptera pupae (Di), Mysidacea (My), Ephemeroptera larvae (Ep), Trichoptera larvae (Tr), Amphipoda (Am), Isopoda (Is), and Hydracarina (Ac). Taxa not found in stomachs or petite Ponars for a particular sampling period and/or lake were not included in that index. Trendline with α value above it indicates level of selectivity. Values greater than, equal to, or less than trendline indicates selection, no preference, or avoidance of prey taxa, respectively.

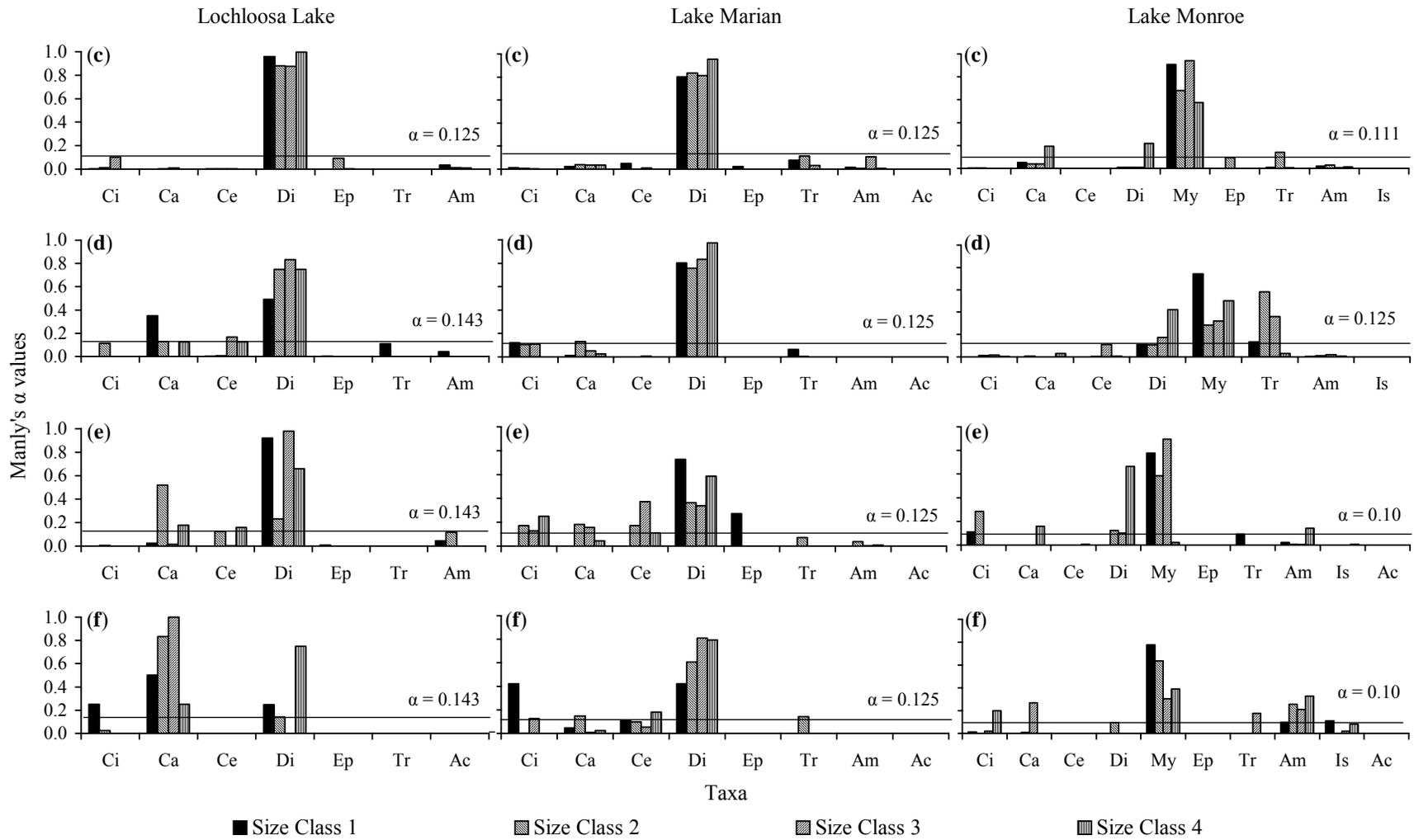


Figure 10. Continued.

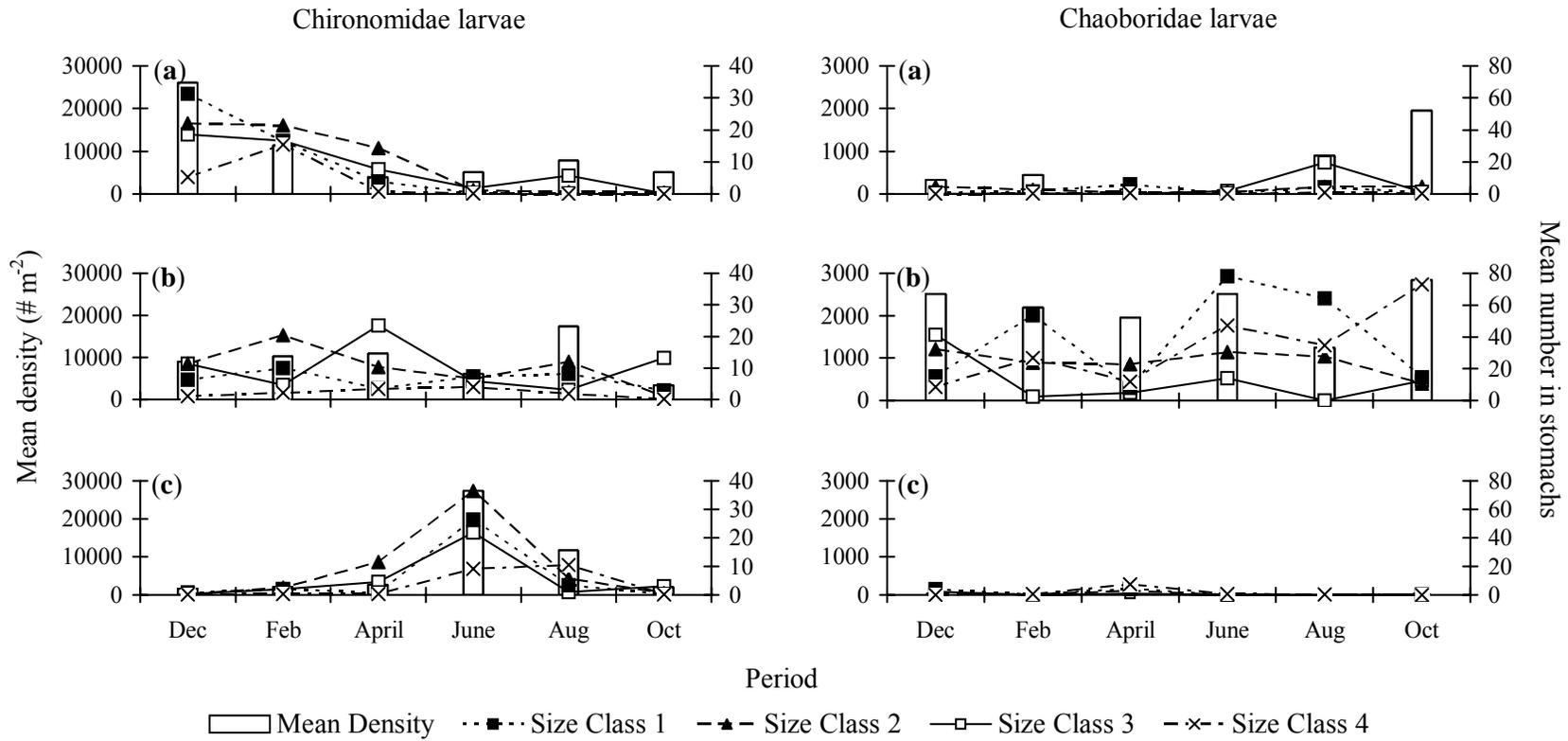


Figure 11. Mean Chironomidae larvae, Chaoboridae larvae, Diptera pupae, and Mysidacea densities collected with petite Ponars and mean numbers found in black crappie stomachs of size classes 1 (110-149 mm TL), 2 (150-189 mm TL), 3 (190-229 mm TL), and 4 (≥ 230 mm TL) from Lakes (a) Lochloosa, (b) Marian, and (c) Monroe during sampling periods December (Dec) of 2002 and February (Feb), April, June, August (Aug) and October (Oct) of 2003. Mysidacea was not found with petite Ponars or in black crappie diets at Lakes Lochloosa and Marian.

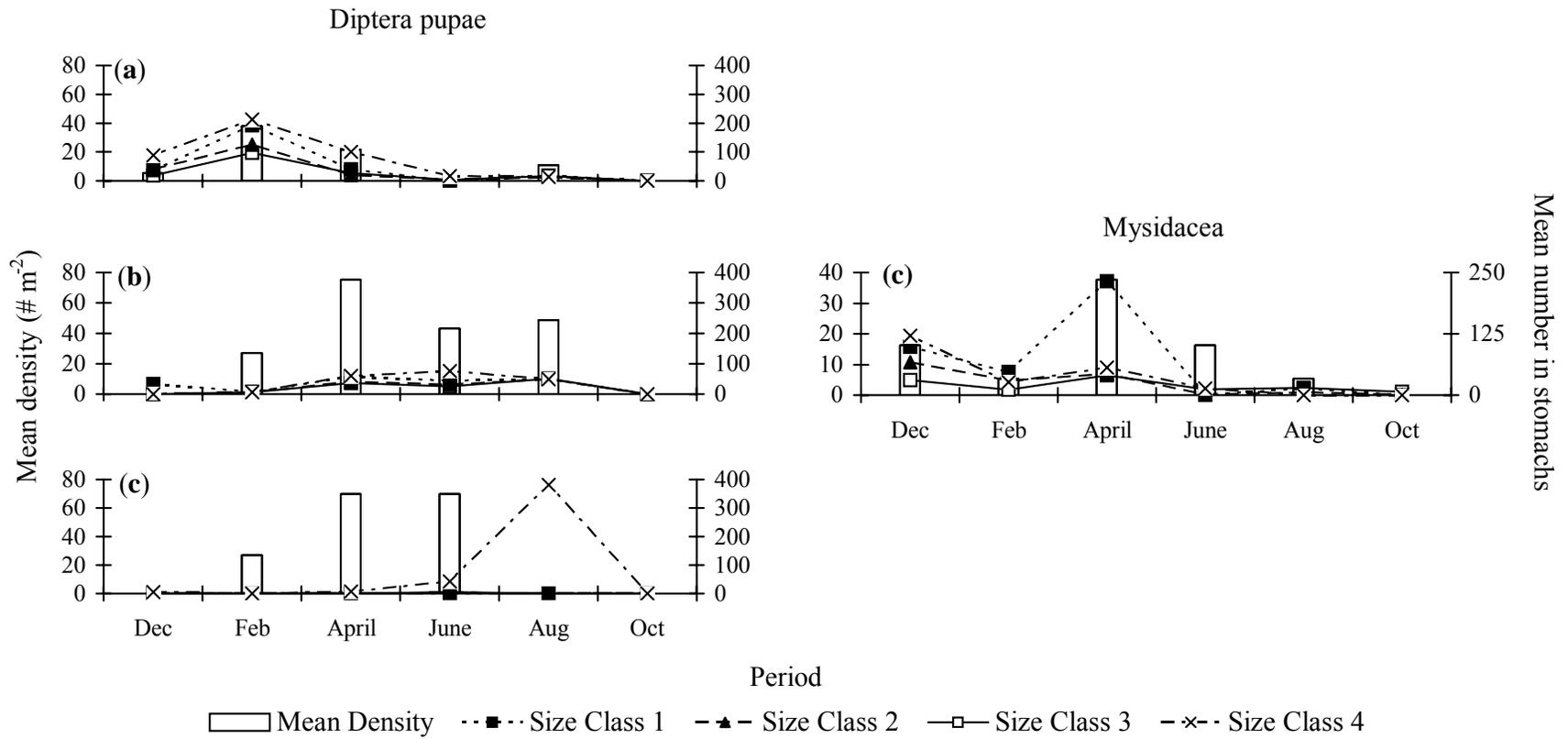


Figure 11. Continued.

DISCUSSION

The diet, prey availability, and population structure (i.e., abundance and size structure) differences among lakes likely contributed to the variation in population growth rates.

Lochloosa Lake had the lowest abundance of black crappie based on the otter trawl mean CPUE data and the least proportion of large fish based on the length frequency data. Lake Marian had the highest abundance of all sizes of black crappie and the greatest proportion of black crappie ≥ 190 mm TL. Lake Monroe had an intermediate abundance of black crappie, which obtained the largest size with Lochloosa Lake second and Lake Marian having the smallest length at age.

Benthic prey availability and prey selection caused differences in the diet composition and ontogenetic diet shifts of black crappie among the three study lakes. Black crappie at all three systems possessed similar ontogenetic diet shifts of microcrustaceans and fish. In general, the %Wt values of microcrustaceans in stomachs decreased as black crappie increased in size and the %Wt values of fish in stomachs increased as black crappie increased in size. Diet shifts of this nature have previously been found in black crappie food habit studies (Reid 1949; Keast 1968). However, differences occurred in the intermediate prey categories (i.e., insects and macrocrustaceans) due to the additional prey resource and prey selection of Mysidacea (i.e., *Americamysis almyra*) by black crappie at Lake Monroe. This substantially influenced diet composition of black crappie at Lake Monroe where fish of all sizes consumed high quantities of macrocrustaceans up to size class 3, then shifted to fish as prey at size class 4. Conversely, at Lakes Lochloosa and Marian, black crappie did not have Mysidacea as a prey option and fish were highly selective of Diptera pupae. Thus, black crappie at Lakes Lochloosa and Marian consumed high quantities of insects up to size class 3, then shifted to fish as prey at size class 4.

The availability and selection of a high energy Mysidacea prey by black crappie at Lake Monroe likely influenced the larger size at age attained at this system compared to Lakes

Lochloosa and Marian. Previous studies have recognized Mysidacea as an important prey item of black crappie at other Florida lakes (Chable 1947; Huish 1957; Ager 1975; Schramm et al. 1985). Ager (1975) found Mysidacea to comprise 53% of the dietary items in black crappie stomachs examined from Lake Okeechobee, Florida. Examples of other fish species that utilize mysid shrimp as a prey item, when it is available in fresh and brackish water, include striped bass *Morone saxatilis* (Cooper et al. 1998), pikeperch *Stizostedion lucioperca* (Hansson et al. 1997), alewives *Alosa pseudoharengus* (Madenjian et al. 2003; Pothoven and Vanderploeg 2004), yellow perch (Pothoven et al. 2000), and smelt *Osmerus eperlanus* (Vinni et al. 2004). Other studies have attributed Mysidacea as an important dietary item that can influence growth rates. Madenjian et al. (2003) credited the larger size of the non-piscivorous alewife at Lake Michigan to the availability and utilization of the larger, more energetic prey (i.e., Mysidacea and Amphipoda) in comparison to smaller alewives at Lake Ontario where these items were not available. Vinni et al. (2004) suggested that slow growth of age-1 and age-2 smelt at a Finnish lake was most likely due to an inconsistent supply of larger invertebrates (i.e., Mysidacea and Chaoboridae) during the intermediate stage of a diet shift before piscivory.

The availability of Mysidacea as an additional prey resource is also profitable when other prey resources are low. Huish (1957) found a lower number of Chironomidae larvae and pupae in black crappie stomachs at Lake George, Florida during July 1950 than in July 1949, which was replaced by the presence and volume of Mysidacea in the diets. Huish (1957) suggested that this was due to decreased abundance of Chironomidae larvae. This is similar to the tradeoff of utilized prey I found between Chironomidae larvae and Mysidacea in the diets of black crappie and their corresponding densities at Lake Monroe during April and June of 2003.

The optimal foraging theory suggests that a consumer should maximize the net energy gain by selectively preying on the most beneficial items (MacArthur and Pianka 1966; Emlen 1966). It takes into consideration prey densities, pursuit and capture costs, and energy return. A wide variety of fish diet studies have found selective predation of higher quality prey items, which maximized net energy returns (Mittelbach 1981; Galarowicz and Wahl 2005; Graeb et al. 2006). This in turn, can increase the growth of fish (Mittelbach 1983; Galarowicz and Wahl 2005).

In caloric studies conducted by Cummins and Wuycheck (1971), the crustacean class Malacostraca, which includes Mysidacea, resulted in 1,029 calories per gram wet weight, whereas the insect order Diptera (e.g., Chironomidae, Chaoboridae, etc.) had only 613 calories per gram wet weight. Furthermore, Gardner et al. (1985) found *Mysis relicta* to have a higher mean lipid value than Chironomidae at Lake Michigan. These results suggest that Mysidacea is a more energetically beneficial prey item when compared to insects, which makes the selection of Mysidacea by black crappie at Lake Monroe over Diptera pupae profitable.

Selective predation of more energy-rich prey items by crappie has been previously noted. Ball and Kilambi (1972) found that black crappie and white crappie fed on immature *Chaoborus* seven times more than the smaller cyclopoid copepod, although the copepods were more abundant in the water column. Pine and Allen (2001) and Dockendorf and Allen (2005) found that age-0 black crappie selected larger zooplankton taxa. Dockendorf and Allen (2005) associated size differences of age-0 black crappie among three Florida lakes with a higher consumption of large zooplankton. In an aquarium study, O'Brien et al. (1989) observed that when large and small prey were both present, the large prey were usually pursued. By pursuing the larger prey rather than the smaller prey, they found that the net energy gained by white

crappie was increased. This would improve the growth efficiency, which should improve their survival.

Various factors can influence selective predation by fish including prey characteristics, such as size (Werner and Hall 1974; Mayer and Wahl 1997; Robichaud-Leblanc et al. 1997), behavior (Buskey 1994), availability (Sanyanga 1998; Galarowicz et al. 2006), and visibility (Li et al. 1985; Buskey 1994); and predator characteristics, such as size (Mayer and Wahl 1997; Robichaud-Leblanc et al. 1997) and morphology (Graeb et al. 2005). Previous examples of selective predation by crappies were related to prey size (Ball and Kilambi 1972; O'Brien et al. 1989; Pine and Allen 2001; Dockendorf and Allen 2005). Measurements of individual Mysidacea and Diptera pupae found in black crappie diets and petite Ponar grabs at Lake Monroe were not made, and therefore it is unknown if prey size is a factor in the selectivity differences found at this system relative to Lakes Lochloosa and Marian. Size variation of these prey items could occur for several reasons (i.e., season, species, life stage), so it would be necessary to make individual measurements of available prey and consumed prey throughout sampling periods to determine if prey size (i.e., Mysidacea and Diptera pupae) is a factor in selection. While some specimens have been preserved in ethanol, this preservation treatment can cause significant biomass loss and size reduction (Howmiller 1972; Stanford 1973), and would not reflect the actual size and weight at the time of availability or consumption. Other differences (e.g., behavior, visibility, etc.) between Mysidacea and Diptera pupae may have also caused selectivity differences among systems.

Many studies have concluded that higher densities and availability of quality benthic prey items were instrumental in growth of various fish species. Fox (1989) found a positive relationship between the growth of juvenile walleye with the density and size of available

benthic prey (i.e., Chironomidae larvae) at experimental ponds. Similarly, Hayward and Margraf (1987) concluded that differences in availability of larger benthic prey at two basins of Lake Erie led to differences in the diets and growth of yellow perch in those basins. A low quality prey supply at the western basin of Lake Erie allowed smaller yellow perch to feed effectively, but the diets of larger yellow perch were inadequate, which caused slower growth. Contrarily, a high variety of larger benthic prey allowed all sizes of yellow perch to feed adequately at the central basin of Lake Erie, which allowed for higher growth rates (Hayward and Margraf 1987). In more recent years, Tyson and Knight (2001) attributed increased yellow perch growth at the western basin of Lake Erie to the increased availability and consumption of benthic prey. Lott et al. (1996) also attributed yellow perch populations with faster growth to the higher densities and availability of macroinvertebrates as prey.

Comparisons among lakes indicated that black crappie growth at Lochloosa Lake was not limited by benthic prey resources within that system. Black crappie at Lochloosa Lake attained a larger maximum size (L_{∞}) in comparison to Lake Marian and reached their maximum size at a faster rate (k) than black crappie at Lakes Marian and Monroe. Mysidacea was not available to black crappie at either Lakes Lochloosa or Marian. Instead, black crappie at these systems utilized Diptera pupae, Chironomidae larvae, and Chaoboridae larvae at higher levels. Benthic macroinvertebrate densities did not differ significantly between lakes except for higher densities of Chaoboridae larvae at Lake Marian during two sampling periods. Thus, I was unable to explain the growth rate differences between Lakes Lochloosa and Marian through differences in benthic prey availability alone.

Density dependent growth is commonly found in fish populations (Walters and Post 1993; Post et al. 1999; Boxrucker 2002; Buktenica et al. 2007). In general, increased densities of fish

can lead to low food availability, increased competition, and reduced growth. Swingle and Swingle (1967) observed density dependent growth of crappies at ponds and large reservoirs in Alabama. Schramm et al. (1985) and Miller et al. (1990) observed density dependent growth of black crappie at Lake Okeechobee, Florida. The high abundance of black crappie based on catch rates at Lake Marian, might suggest that slower growth is a result of higher density. The fast growth of black crappie at Lochloosa Lake could result from low abundance of black crappie at this system. However, based on results I obtained from index of fullness comparisons between lakes, black crappie at Lakes Lochloosa and Marian were not feeding differently between lakes in terms of total consumption. Nor were their diet shifts different, which suggests that energetic intake was comparable between systems. However, high densities of black crappie at Lake Marian could increase competition and cause greater energy to be applied in the search and capture of prey items. This is particularly true when prey densities (i.e., benthic macroinvertebrates) are not different between systems because prey per capita would be lower. This would result in less net energy gained and reduced growth rates in the high density system (i.e., Lake Marian) in comparison to the low density system (i.e., Lochloosa Lake). Thus, density dependent growth is a potential factor in the growth variation of black crappie at Lakes Lochloosa and Marian.

Many studies have found increased growth of various fish species exhibiting ontogenetic diet shifts after the onset of piscivory (Ellison 1984; Keast and Eadie 1985; Buijse and Houthuijzen 1992; Olson 1996; Madenjian et al. 1998; Vinni et al. 2004; Galarowicz and Wahl 2005). However, in this study, black crappie did not consume fish differently among lakes as they increased in size based on %*Wt* estimates. Therefore, initiation of fish as prey was not responsible for the growth differences of black crappie among systems.

Results of the simplified Morisita's index were variable for different taxa, but indicated that benthic prey availability can influence consumption rates of prey items by black crappie. In use here, a high C_H value for a benthic prey item indicates that consumption of that prey item by black crappie is proportionally similar to the density found in the environment throughout time. It does not necessarily mean that the prey item is being selected for. For example, Chironomidae had relatively high C_H values for all size classes and lakes, but were not found to be a highly selective item because of their large densities relative to the other taxa included in the comparisons. In addition to the simplified Morisita's index, comparisons of benthic densities and diets (i.e., %*Wt* and mean number) among lakes also suggest that benthic prey availability can influence consumption rates of prey items by black crappie.

Potential sources of error in the selectivity and similarity indices include inadequate habitat sampling, patchiness of prey, collection times of black crappie, and differential digestion rates of prey (Strauss 1979). The taxa included in these indices were chosen because they could be effectively sampled with a petite Ponar and would be readily available for black crappie consumption. Three taxa which could have exhibited biases were Chaoboridae larvae, Diptera pupae, and Mysidacea. Chaoboridae larvae and Mysidacea are known to have diel cycles of vertical migration in the water column, remaining close to the bottom during the day and moving up to feed at night (Pennak 1953; Cole 1994). Because I sampled with petite Ponars during the day, these taxa should have been readily available for collection. Also, the species of Mysidacea that was present in Lake Monroe, *Americamysis almyra*, appears not to have vertical migrations and remains close to the bottom during both day and night (Johnson and Allen 2005). The bulk of Diptera pupae found in this study (i.e., Chironomidae) are free swimming, but tend to remain at the bottom until time to emerge (Merritt et al. 1996; Coffman and Ferrington 1996).

Prey patchiness is another source of error through density estimates and prey consumption. For example, two individual black crappie consumed over 1,000 Diptera pupae each in August 2003 at Lake Monroe, whereas the other black crappie in the same size class had relatively small numbers. Consequently, the similarity values for that size class of black crappie were low. Estimates of prey densities can have high variability due to prey patchiness, particularly when there is a low sample size.

Collection times of fish for stomach analysis can impact diet results along with any index that uses diet as a variable when diel feeding patterns occur. For instance, if crappie feed at dusk and most fish are collected during morning and afternoon, stomach contents would not be representative of the true diet. This is particularly true when differential digestion rates of prey items occur. In this case, prey items with a higher rate of digestion would be underrepresented and vice versa (Strauss 1979). Past investigations have found black crappie to feed at various times of the day, including both day and night (Pearse 1918; Seaburg and Moyle 1964; Keast 1968; Ellison 1984). Differences in feeding times of crappies have been attributed to habits of their prey (Keast 1968; O'Brien et al. 1984). All black crappie collections for this project were made during the day, primarily in the mid-morning and early-afternoon hours at Lakes Marian and Monroe. However, catch rates of black crappie at Lochloosa Lake were low, making it necessary to sample from early-morning to late-afternoon, to obtain a representative sample. Diel investigations of black crappie diets were not conducted for this project, therefore differences or similarities in diel feeding patterns of black crappie among systems are unknown.

The increased consumption of fish in the diets of black crappie during the summer and fall months in this study is similar to previous studies (Dendy 1946; Reid 1949; Ball and Kilambi 1972). This is probably due to a higher availability of age-0 prey fish (i.e., shad, bluegill, etc.)

after spawning periods. This trend was more distinguished in the smaller size classes, which had low %*Wt* values before YOY prey fish would have been available. The %*Wt* values of fish in the smaller-size black crappie diets also leveled off or decreased by October 2003, which could be caused by prey fish outgrowing the smaller black crappie and becoming unavailable for consumption. The occurrence of potential prey fish outgrowing their smaller predators is common (Keast 1977; Keast and Eadie 1985; Storck 1986; Frankiewicz et al. 1996). As a result, this may cause smaller black crappie to return to a less energetic diet of smaller prey items. This could explain the increase in microcrustaceans present in the diets during the winter period. The larger size classes had higher %*Wt* values of fish in their diets throughout the year, which was most likely a result of having the ability to consume the larger prey fish throughout the year. However, I did not obtain prey abundance estimates of fish, and therefore did not quantify how fish prey abundance and size was related to black crappie diets.

When considering all sampling periods, empty stomachs made up a relatively low percentage of the total stomachs examined for each lake (all < 7 %) when compared to previous diet studies of black crappie in Florida (Chable 1947; Reid 1949; Huish 1957; Ager 1975). Previous studies all found empty stomachs to be > 14 % of the total stomachs examined. There were individual periods, which had percentages of empty stomachs that were similar to what previous studies found, particularly the August and October periods in Lake Monroe for 2002 and 2003.

These results suggest that black crappie are both opportunistic and selective in their benthic macroinvertebrate feeding habits. Black crappie appeared to utilize various resources at a greater extent when their densities were up, but consistently selected for certain taxa within a lake throughout the study. Differences in diet shifts of black crappie among lakes existed

because of an additional resource and selection for that resource in Lake Monroe. This, in turn, likely allowed Lake Monroe black crappie to obtain a larger size at age than black crappie at Lakes Lochloosa and Marian. Contrarily, diet shifts and total prey consumption by black crappie at Lakes Lochloosa and Marian were not different, although there were differences in growth between systems. This was probably a result of density dependence, where Lake Marian had a large population with slow growth and Lochloosa Lake had a small population with fast growth.

MANAGEMENT IMPLICATIONS

Stocking of black crappie at Florida water bodies is not a current management tool, but there is potential for its use in the future. A factor which can influence the stocking success of other fish is an adequate forage base, including zooplankton (Fielder 1992; Hoxmeier et al. 2004), macroinvertebrates, and prey fish (Axon and Whitehurst 1985; Stahl and Stein 1994; Donovan et al. 1997; Pierce et al. 2001). Each forage group could play an important role in the success of stocking programs, depending on the species, size, and diets of fish being stocked (Hoxmeier and Wahl 2002). The results of this study show that prey availability can influence the diet and growth of black crappie, and therefore future stocking programs of black crappie should consider the prey base before initiating a program. For example, Lake Monroe may have greater potential for stocking success of black crappie due to the additional prey taxa and fast growth of black crappie at this system.

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BIOGRAPHICAL SKETCH

Travis Tuten is a second generation Floridian born in Orlando, FL on October 30, 1975. He graduated from Colonial High School in 1993 and received an Associate of Arts degree from Valencia Community College in April 1996. He started coursework at University of Florida in 1996 and graduated with a Bachelor of Science degree in wildlife ecology and conservation in December 1998. Work took him to South Florida in April 1999, where he stayed 3 years as a biological technician working in the Florida Everglades. He returned to Gainesville in January 2002 and began working on non-indigenous fish projects with the United States Geological Survey (USGS). He started coursework towards his Master of Science degree in August 2002 and was hired by the Florida Fish and Wildlife Conservation Commission (FWC) in November 2002. His masters research on black crappie *Pomoxis nigromaculatus* diets and benthic food availability was an opportunity to further his education while employed with FWC. After graduation, he plans to continue conducting fisheries research in the state of Florida.