

RELATIONSHIPS BETWEEN ZOOPLANKTON ABUNDANCE AND AGE-0  
BLACK CRAPPIE ABUNDANCE AND SIZE AT THREE PRODUCTIVE FLORIDA  
LAKES

By

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To my parents, Tom and Helen.

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Abstract of Thesis Presented to the Graduate School  
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Crappies Pomoxis spp. are valuable sportfish but are often difficult to manage due to highly variable recruitment. I investigated relations between zooplankton abundance and larval and juvenile black crappie Pomoxis nigromaculatus abundance and size at three Florida lakes. Age-0 black crappie were collected at Lakes Wauburg, Lochloosa, and Tarpon using surface and bottom trawls during spring, summer, and fall 2000 and 2001. Zooplankton abundance was measured concurrent with trawl sampling. In both fall seasons, juvenile crappie were larger at Lake Tarpon than at Lakes Lochloosa and Wauburg. However, age-0 black crappie abundance and summer crustacean zooplankton densities were higher at Lakes Lochloosa and Wauburg than at Lake Tarpon in both years. The lack of a relationship between crustacean zooplankton density and black crappie size across lakes suggests that age-0 black crappie abundance and size may not be related to zooplankton abundance in natural productive Florida lakes. In this study, fall

abundance of age-0 black crappie was highly correlated with early summer abundance, suggesting that year-class strength was set by early summer in the study lakes. Early summer juvenile abundance predicted age-0 black crappie fall abundance more effectively than larval fish density in the spring. Adult abundance and abiotic variables (e.g., water clarity) influenced age-0 black crappie abundance and size more than crustacean zooplankton abundance.

## INTRODUCTION

Recruitment can be defined as an addition of young individuals to an adult fish population (Everhart and Youngs 1981). Abundance of young fish is subject to environmental factors such as habitat variation and food availability, along with biotic interactions including predation and competition that may affect recruitment (Sigler and Sigler 1990). Due to highly variable recruitment and subsequent fishing quality, fisheries managers have found it difficult to manage crappies, Pomoxis spp. (Allen and Miranda 1995). Studies that reveal factors influencing recruitment may allow fishery managers to predict year-class strength and improve fisheries via harvest restrictions, particularly with important sport fish such as black crappie P. nigromaculatus and white crappie P. annularis (Maceina et al. 1991).

Previous investigations have evaluated variability of crappie recruitment due to abiotic factors such as water-level fluctuations, turbidity, wind, and temperature in lakes and reservoirs (Beam 1983; Guy and Willis 1995; Mitzner 1995). Maceina and Stimpert (1998) found that short winter (<10 days) and long post winter (> 11 days) retention times in Alabama reservoirs interacted to produce strong crappie year classes. High water level increased crappie year-class strength in a Kansas reservoir (Beam 1983). Coves may have provided shelter from the wind for larval crappies (Fisher 1997; Pope and Willis 1998), thus creating “nursery” areas. Wind and subsequent sediment resuspension increased turbidity (Bachmann et al. 2000), thereby reducing visibility and foraging success of many larval fish including crappie (Mitzner 1995; Claramunt and

Wahl 2000). Variable water temperatures may have also influenced recruitment. Cool water temperatures (~17 C) during spring reduced growth rates of early-hatched black crappie within a Florida lake (Pine and Allen 2001). Similarly, high water temperatures (>27 C) may constrain crappie growth during summer, likely due to increases in metabolic rates (Hayward and Arnold 1996).

Stock-recruitment dynamics may also explain recruitment variation among fish populations (Myers 1997). Generally, as adult stock abundance increases, the number of recruits produced increases and then may reach an asymptote (Beverton-Holt model) or begin to decline (Ricker model). Often, this relationship is subject to variability and not clearly defined (Royce 1996). Allen and Miranda (1998) found significant Ricker-type stock-recruit relations between the number of adult crappie and the number of juvenile crappie in four southern U.S. reservoirs. Adult yellow perch Perca flavescens abundance was related to the abundance of age-0 yellow perch, but no stock-recruit relationship was determined in Crystal Lake, WI (Sanderson et al. 1999).

Food availability, predation, and competition also influence recruitment (Garvey and Stein 1998). Foraging success of larval fish is dependent upon availability of zooplankton that are equal or less than larval gape for many fish including crappies (Miller et al. 1988; Schael et al. 1991; DeVries et al. 1998). Suitable prey availability for larval and juvenile fish can strongly influence growth and survival to adulthood (Welker et al. 1994). For example, greater condition was observed in larval striped bass Morone saxatilis reared in aquaria with high-prey densities than larvae reared in low-prey density containers (Chick and Van Den Avyle 2000). In general, larger larvae may catch more prey due to increases in swimming speed and gape size, thus contributing to survival and

subsequent growth (Miller et al. 1988). Therefore, a lack of adequate prey may directly lead to starvation of larval fish or may indirectly lead to mortality of larval fish subject to a longer exposure to predators (Partridge and DeVries 1999). Limited food resources may occur when larval and juvenile fish have high diet overlap in food selection, potentially reducing larval survival (Welker et al. 1994; Garvey and Stein 1998). Subtle differences in growth and survival, as a consequence of variations in food resources, can have potentially profound effects on fish recruitment (Houde 1989).

Early life history and diet habits of crappie have been previously documented. Black crappie and white crappie spawn in water temperatures ranging between 15 C and 20 C (Siefert 1968; Mitzner 1991), which generally occur from February to early May in Florida lakes (Hoyer and Canfield 1994; Pine and Allen 2001). Swim-up is initiated in the littoral region between 2 and 4 days post-hatch depending on water temperature (Siefert 1968). After swim-up, larval crappies move from the littoral region to the pelagic zone (O'Brien et al. 1984). Following absorption of the yolk sac, larval crappie up to 8-mm total length (TL) feed primarily on copepod nauplii, whereas crappie 8-14 mm TL consume both copepods and cladocerans (Siefert 1968; Pope and DeVries 1994). Larval crappie greater than 10 mm TL are usually not limited by gape, but selected prey size may be less than maximum gape width due to foraging and digestion efficiency (Schael et al. 1991; DeVries et al. 1998). Crappies primarily forage during daylight hours (Hanson and Qadri 1984) using a saltatory search method (i.e., swim and pause; Browman and O'Brien 1992). Juvenile black crappie (15-40 mm TL) feed primarily on large zooplankton such as Daphnia spp. and calanoid copepods (Pine and Allen 2001). Crappies between 60 and 160 mm TL continue to select for large zooplankton, but also

consume macroinvertebrates, such as dipteran larvae, ephemeropterans, and odonates (Siefert 1968; Tucker 1972). Crappies above 160 mm TL continue to forage on macroinvertebrates and may switch to small fish as prey (Siefert 1968; Ellison 1984).

Ontogenetic diet shifts often regulate fish survival through early life. For example, largemouth bass Micropterus salmoides with higher feeding efficiency on zooplankton and invertebrates exhibited faster growth rates and shifted to piscivory earlier than fish with poor feeding efficiency on zooplankton and invertebrates (Olson 1996).

Consequently, Olson (1996) suggested that an early shift to piscivory was important for juvenile largemouth bass growth and survival. Ludsin and DeVries (1997) described complex largemouth bass recruitment dynamics with factors such as hatching duration, ontogenetic shifts, lipid accumulation, and first winter survival interacting to influence survival. Ludsin and DeVries (1997) emphasized the importance of following a species throughout developmental stages to describe variables influencing recruitment.

Recently, trawls have been used in reservoirs and natural lakes to sample larval (Pope and Willis 1996; Sammons and Bettoli 1998) and juvenile and adult crappies (Pine 2000). Where applicable, trawls allow sampling crappies through larval and juvenile life stages, which until recently have not been evaluated (Pine and Allen 2001). In addition, no previous studies have compared multiple natural lakes to assess factors influencing black crappie recruitment.

I investigated the early life history of black crappie at three natural, productive Florida lakes and evaluated factors that potentially influence their recruitment. The objectives of this study were fourfold: 1) to compare the abundance and size distributions of larval and juvenile black crappie at each lake, 2) to assess the relationship between

adult stock abundance and juvenile black crappie catch rates, 3) to quantitatively assess and compare the abundance of potential zooplankton prey within each lake, and 4) to investigate the relationship between prey abundance and relative year-class strength among the three study lakes. I expected age-0 black crappie size and abundance to increase with density of preferred-size zooplankton and black crappie stock abundance to be related to age-0 black crappie abundance among lakes.

## METHODS

### **Study Lakes**

Lake location and physical and chemical parameters are shown in Figure 1 and Table 1, respectively. Lake Wauburg is a 150-ha natural, hypereutrophic lake that exhibits relatively stable and high black crappie recruitment (M. Allen, unpublished data). Lake Lochloosa is a 2,286-ha natural, hypereutrophic lake that had variable black crappie recruitment that was lower in the mid 1990's than later years (M. Allen, unpublished data). Lake Tarpon is a 1,030-ha natural, eutrophic lake and has historically sustained a quality black crappie fishery, yet abundance of recruits is often low (M. Allen, unpublished data). Lake trophic state was determined with criteria developed by Forsberg and Ryding (1980).

### **Age-0 Black Crappie Collection**

Larval ( $\leq 15$  mm TL) and juvenile (16 to 190 mm TL) black crappie were sampled at Lakes Wauburg, Lochloosa, and Tarpon from February to October in 2000 and 2001 to determine abundance and size structure. Five open-water sites were marked with a Garmin III GPS unit and used for each sampling event. On all three lakes, crappie larvae were collected with a neuston net (1x2-m<sup>2</sup> mouth, 4-m bag, 1-mm mesh; Sammons and Bettoli 1998) towed from a 6.7-m boat equipped with a 70-HP outboard motor. Neuston net samples were conducted between 0900 and 1400 hours three times per month (every 10 days) in 2000 and twice per month (every two weeks) in 2001. At each site, the neuston net was pulled once at a speed of  $\sim 1.0$  m/s for three minutes to minimize net

clogging. The trawl path was offset from the boat path in an attempt to reduce net avoidance by larval fish due to prop wash. A General Oceanics flowmeter was mounted in the net mouth to estimate the water volume sampled to determine larval crappie density (fish/1000 m<sup>3</sup>). At the end of each tow, samples were rinsed from the cod end, fixed in 10% formalin, and returned to the laboratory for analysis. Neuston netting for larval black crappie ( $\leq 15$  mm TL) was initiated in late February of each year and continued until black crappie larvae were no longer caught in the trawl for three consecutive sampling trips. Surface water temperature and dissolved oxygen were measured once at the first site on each sample date.

When black crappie  $> 15$  mm TL were collected in the neuston net, I used a small otter trawl to collect juvenile black crappie (3.7 m mouth, 4.6 m body, 8.4 mm bar mesh throat, 6.4 mm bar mesh bag; Pine and Allen 2001). At each fixed site, the small otter trawl was deployed from the same vessel and towed once for three minutes at 1.0 m/s. Sampling was conducted twice a month in April, May, and June of both years and once a month in August 2000 and July, August, and September 2001. Age-0 black crappie collected with the small otter trawl were preserved in 10% formalin and transported to the lab.

In October of both years, juvenile black crappie were sampled at the same sites using both the small trawl and also a larger otter trawl (4.6 m mouth, 4.9 m long, 38.1 mm bar mesh body, 31.8 mm bar mesh bag; Pine 2000) each pulled once at each site for three minutes. Both trawls were pulled because black crappie less than 100 mm TL may not be effectively collected with the large trawl (Pine 2000). The number of juvenile black crappie caught per minute (CPM) was used as an index of abundance for both

bottom trawls. In all lakes, the number of large trawls pulled was increased to obtain adequate samples for size structure in October of both years, especially at Lake Tarpon. Black crappie were placed on ice and brought to the lab to extract otoliths. Black crappie collected in October were verified as age-0 by examining otoliths for lack of annuli.

### **Lab Work-up**

At the laboratory, larval and juvenile black crappie were counted, measured to the nearest mm TL, and transferred to 95% alcohol for storage. Length-frequency distributions of age-0 black crappie across dates were used to describe size of black crappie through time at each lake. Up to 30 black crappie were subsampled in proportion to the length frequency distribution each month (Ludsin and DeVries 1997) and their stomachs were removed (O'Brien et al. 1984) and opened under a dissecting microscope. Cladocerans were identified to genus whereas copepods were identified as calanoid, cyclopoid, or nauplii according to Pennak (1987). Macroinvertebrates were identified to family (Merritt and Cummins 1996) and undigested fish identified to lowest possible taxon (Holland-Bartels et al. 1990). All organisms were counted and up to twenty individuals of each taxon from each stomach were measured to the nearest 0.01 mm using a standardized ocular micrometer.

### **Adult Abundance**

Adult black crappie ( $\geq 200$  mm TL) were collected with the large trawl at all three lakes in October 1999 and 2000 to relate to juvenile abundance in 2000 and 2001. Fall CPM of black crappie  $\geq 200$  mm TL in 1999 and 2000 was used as an index of stock fish abundance prior to the production of the 2000 and 2001 year classes.

### Zooplankton Density

Zooplankton were collected concurrent with each sampling event to assess potential prey abundance. Samples were taken using a Wisconsin-style plankton net (80- $\mu\text{m}$  mesh) raised vertically from the lake bottom to the surface at three of the five fixed trawl sites. Samples were concentrated and stored in 10% formalin. At the laboratory, samples were adjusted to a known volume and three 1-ml subsamples taken (Miranda and Gu 1998). Each 1-ml subsample was placed in a Sedgewick-Rafter counting cell and examined under a compound microscope equipped with an optical micrometer at 100X magnification (Pine and Allen 2001). All zooplankton were counted and up to 20 individuals of each taxon were measured to the nearest 0.01 mm. Cladocerans were identified to genus, copepods identified as calanoid, cyclopoid, or nauplii, and rotifers to genus using Pennak (1987). We determined zooplankton density ( $D$ ) for each sample by:

$$D = \frac{(n_s * v_s)}{(0.0113 * d)} \quad (1)$$

where  $n_s$  is the total number of organisms counted in the subsample,  $v_s$  is the total volume of that sample in ml,  $d$  is the station depth (m), and 0.0113 is the mouth area ( $\text{m}^2$ ) of the zooplankton net (Tugend and Allen 2000).

### Diet Analysis

Selectivity analysis was performed to provide insight on the relationships between zooplankton availability and diet composition in black crappie on each date. Chesson's alpha (Chesson 1978) was used to assess prey selectivity:

$$\alpha = \frac{(r_i / p_i)}{\sum_i^m (r_i / p_i)} \quad (2)$$

where  $r_i$  is the proportion of the prey type  $i$  in the diet sample (in proportion to the total number of prey types in the diet sample),  $p_i$  is the proportion of prey type  $i$  in the environment as determined from zooplankton counts,  $m$  is the number of prey types in the environment, and  $\alpha$  is the index of taxon selectivity. Alpha ranges from 0 to 1 where neutral selection is equal to  $1/m$ , positive selection is greater than  $1/m$ , and negative selection is less than  $1/m$ .

### **Analyses**

A repeated-measures analysis of variance (ANOVA) was used to test for differences between mean larval black crappie density (fish/1000 m<sup>3</sup>) in the neuston net and mean catch-per-minute (CPM) with small otter trawl across months and lakes in both years. Data were log<sub>10</sub>-transformed after adding 0.001 to all values to homogenize the variances. In the analyses, lakes were considered fixed factors, sample months were treated as a time variable, and sample sites were treated as subjects. A least-squares means procedure was used to separate means if the lake, month, or lake\*month interaction was significant in the repeated measures ANOVA. A one-way ANOVA was used to test for differences in mean CPM among lakes for age-0 black crappie sampled in October with the large otter trawl in both 2000 and 2001. The size structure of age-0 black crappie was described with length frequency histograms from bottom trawl collections made from April through October. In October, fish from the small and large trawls were combined to determine size structure of age-0 black crappie in the fall, because the large trawl may ineffectively sample juvenile black crappie less than 100 mm TL (Pine 2000). A Kolmogorov-Smirnov (KS) test was used to assess differences in the length frequencies of black crappie during October of each year. Correlations between larval density, early juvenile abundance, and fall age-0 abundance were determined for

each year across lakes. Regression analysis was used to assess relations between adult black crappie (fish greater than 200 mm TL) abundance in October 1999 – 2000 (i.e., the fall prior to production of the 2000 and 2001 year classes) and early summer (May) juvenile abundance in both years at each of the three study lakes.

To assess differences in prey abundance among lakes, repeated-measures ANOVA was used to test for differences in  $\log_{10}$ -transformed crustacean zooplankton density (org/L) using lakes and months as factors and the sites as subjects. Density of zooplankton taxa that were common in the diets of juvenile black crappie were also compared among lakes and sample months using repeated-measures ANOVA. An analysis of covariance (ANCOVA) was used to determine differences in the number of large zooplankton consumed by age-0 black crappie from each lake during May of both years. Most age-0 black crappie collected in the small trawl in May were zooplanktivorous in all lakes. Age-0 black crappie diets containing zooplankton, macroinvertebrates, and fish were analyzed using frequency of occurrence to assess potential diet shifts among lakes. All statistical analyses were conducted with SAS (1997) and statistical tests were considered significant when  $P < 0.05$ .

## RESULTS

The timing of larval black crappie (i.e.,  $\leq 15$  mm TL) first occurrence varied by lake and year. Larval black crappie were first collected at both Lakes Wauburg and Lochloosa on March 6, 2000. No larval black crappie were collected at Lake Tarpon in 2000. Catch of larval black crappie declined to zero by May 2000 at Lake Wauburg, but larval black crappie were collected with the neuston net at Lake Lochloosa through May of the same year (Figure 2a). In 2001, larval black crappie were first collected on February 19 at Lake Lochloosa, February 28 at Lake Wauburg, and only on March 2 at Lake Tarpon. Larval black crappie were collected until March 10 at Lake Wauburg, and until April 23 at Lake Lochloosa (Figure 2b). Thus, hatching duration may have been longer at Lake Lochloosa in both years as indicated by the extended catch of larval black crappie in the neuston net.

Larval black crappie abundance varied among lakes in both years. The lake\*month interaction on larval densities was significant in 2000 ( $F_{6,36} = 3.27$ ,  $\underline{P} = 0.008$ ) and 2001 ( $F_{4,24} = 3.27$ ,  $\underline{P} = 0.0114$ ). No larval black crappie were collected at Lake Tarpon in 2000. Larval densities were greater at Lake Lochloosa than Lake Wauburg in April 2000 (lsmeans  $\underline{P} < 0.001$ , Figure 2a). Larval densities were greater at Lake Lochloosa than Lakes Wauburg and Tarpon in February and March 2001 (lsmeans  $\underline{P} < 0.02$ , Figure 2b). Therefore, Lake Lochloosa generally had the highest larval density in the spring of both years, but differences were not consistent across months.

The small otter trawl was used at all lakes starting in early April 2000 and 2001. Repeated-measures ANOVA revealed a significant lake\*month interaction in CPM during 2000 ( $F_{7,34} = 2.82$ ,  $\underline{P} = 0.02$ ). Lake Wauburg generally had a greater mean CPM in the small otter trawl than Lakes Lochloosa and Tarpon in 2000 (Figure 2c). Lake Tarpon had the lowest black crappie abundance as only 4 fish were collected during summer 2000 with the small otter trawl ( $N = 2$  in April and May), resulting in mean CPM values below 0.2. Thus, summer abundance of juvenile black crappie was generally highest at Lake Wauburg and lowest at Lake Tarpon (Figure 2c). In 2001, juvenile black crappie were collected in all sample months beginning in April and continuing through October except at Lake Tarpon, where no fish were collected in June 2001. In 2001, the lake\*month interaction was significant ( $F_{11, 70} = 2.52$ ,  $\underline{P} = 0.0098$ ) indicating that differences existed but were not consistent through time. For example, in May 2001, mean CPM was highest at Lake Wauburg and lowest at Lake Tarpon (Figure 2d). Conversely, mean CPM was highest at Lake Lochloosa, intermediate at Lake Wauburg, and lowest at Lake Tarpon in June 2001 (Figure 2d).

Results from October sampling with the large otter trawl were indicative of the same differences in black crappie abundance among lakes as summer samples with the small otter trawl, i.e., Lake Wauburg exhibited a higher mean CPM than either Lake Lochloosa or Tarpon in both 2000 and 2001 (Figure 3). The one-way ANOVA revealed significant differences in mean black crappie CPM among all three lakes in both years (2000  $F_{2,64} = 159.8$ ,  $\underline{P} < 0.0001$ , 2001  $F_{2,83} = 69.21$ ,  $\underline{P} < 0.0001$ ). Least squares means showed significant differences among lakes in both years (2000  $\underline{P} < 0.032$ , 2001  $\underline{P} <$

0.001). Thus, fall abundance of age-0 black crappie was highest at Lake Wauburg and lowest at Lake Tarpon in both years (Figure 3).

Size of juvenile black crappie was generally largest at Lake Tarpon and smallest at Lake Lochloosa during 2000 and 2001. Size structure of age-0 black crappie at Lake Tarpon was not evident during summer 2000 due to low sample size (Figure 4). During June 2000, modal lengths were 7 and 5 cm at Lakes Wauburg and Lochloosa, respectively (Figure 4). This trend continued, and by October 2000, the modal lengths were 10 and 11 cm at Lake Wauburg and 9 cm at Lake Lochloosa (Figure 4). Thus, age-0 black crappie at Lake Wauburg appeared to be larger in fall 2000 than those at Lake Lochloosa (Figure 4). Size distribution was more variable in October at Lake Tarpon compared to the other two lakes, with age-0 black crappie ranging from 8 to 19 cm (Figure 4). Modal length of age-0 black crappie at Lake Tarpon was 13 cm. Thus, Lake Lochloosa had the smallest age-0 black crappie in the fall and Lake Tarpon the largest. In October 2000, age-0 black crappie were larger at Lake Tarpon ( $K-S = 4.16$ ,  $\underline{P} < 0.001$ ) than Lake Wauburg and age-0 black crappie at Lake Lochloosa were smaller than those at Lake Wauburg ( $K-S = 3.97$ ,  $\underline{P} < 0.001$ ).

Age-0 black crappie size structure in 2001 exhibited trends similar to those in 2000. In June 2001, Lake Wauburg modal lengths were 5 and 7 cm whereas Lake Lochloosa age-0 black crappie were mostly 5 cm. No age-0 black crappie were collected at Lake Tarpon during June 2001 (Figure 4). In October 2001, the modal lengths were 9 and 10 cm (range 8 to 12 cm) at Lake Wauburg and 8 cm (range 7 to 13 cm) at Lake Lochloosa (Figure 4). Lake Tarpon had a modal length of 10 cm with age-0 black crappie size ranging from 8 to 17 cm (Figure 4). In October 2001, age-0 black crappie were larger at

Lake Tarpon ( $K-S = 3.56$   $\underline{P} < 0.001$ ) than Lake Wauburg, and age-0 black crappie at Lake Wauburg were larger than Lake Lochloosa ( $K-S = 7.96$   $\underline{P} < 0.001$ ). Thus, age-0 black crappie size was generally largest at Lake Tarpon and smallest at Lake Lochloosa in both years.

Mean CPM of age-0 black crappie in May (calculated from small bottom trawl catches) effectively predicted fall age-0 black crappie abundance, but larval densities (as indicated in neuston samples) were not related with fall age-0 black crappie CPM. Juvenile black crappie CPM in May was highly correlated with fall age-0 black crappie CPM in both years (Table 2). However, larval densities were not correlated to fall abundance among lakes in either year (Table 2).

The relationship between adult black crappie ( $\geq 200$  mm TL) abundance prior to spawning and early juvenile abundance was marginally significant ( $\underline{P} = 0.0593$ ) among years. In both years, Lake Tarpon had low early summer juvenile CPM and low fall adult CPM whereas Lake Wauburg had relatively high early summer juvenile CPM and high fall adult CPM (Figure 5). Therefore, mean CPM of age-0 black crappie in early summer was positively related to CPM of adult black crappie the previous fall.

Crustacean zooplankton abundance varied among lakes and sample months in both years (Figure 6). There was a significant lake\*month interaction in 2000 ( $F_{11,34} = 9.65$ ,  $\underline{P} < 0.001$ ) and 2001 ( $F_{15,46} = 2.05$ ,  $\underline{P} = 0.032$ ) indicating that zooplankton abundance differed among lakes but differences were not consistent through time. For example, Lake Wauburg had the highest crustacean densities in February 2000 (331 org/L), whereas Lake Lochloosa had the highest crustacean zooplankton abundance during June 2000 (1,821 org/L) (Figure 6). Zooplankton data were not collected from Lake Tarpon

during August 2000 (Figure 6) because black crappie catches were nil during summer. In 2001, Lake Lochloosa patterns of crustacean zooplankton densities in April (310 org/L) were higher than the other two lakes, however, crustacean zooplankton abundance were generally similar across lakes across months (Figure 6). In general, Lake Lochloosa had the highest crustacean zooplankton densities, followed by Lake Wauburg, then by Lake Tarpon in both years.

Large crustacean zooplankton (copepods and cladocerans  $\geq 0.6$  mm) (LC zooplankton) density varied among lakes and sample months in both years (Figure 7). The lake\*month interaction was significant in 2000 ( $F_{9,28} = 7.67$ ,  $P < 0.001$ ). For example, Lake Wauburg had the highest LC zooplankton densities in February 2000 (62 org/L), whereas Lake Lochloosa had the highest LC zooplankton density during June 2000 (251 org/L) (Figure 7). In 2001, there was a significant lake\*month effect on LC zooplankton density ( $F_{14,30} = 3.08$ ,  $P = 0.0047$ ). Lake Lochloosa LC zooplankton densities in April 2001 (33 org/L) were higher than Lake Wauburg (10 org/L) and Lake Tarpon (6 org/L). However in August 2001, LC zooplankton densities were higher at Lake Wauburg (36 org/L) than Lake Lochloosa (7 org/L) and Lake Tarpon ( $< 1$  org/L) (Figure 7). In general, Lake Lochloosa had the highest LC zooplankton densities during summer, Lake Wauburg had intermediate LC zooplankton densities, and Lake Tarpon LC zooplankton densities were generally lower than the other two lakes, especially during summer.

Diet selection of zooplankton taxa by age-0 black crappie varied by season in both years. In 2000, age-0 black crappie diet selectivity was diverse in early summer compared to later summer months where LC zooplankton were highly selected (Figure

8). Lake Tarpon yielded few fish for diet analysis in 2000 (N=5), so selectivity indices could not be determined. In 2001, selection of zooplankton was similar to 2000 and by late summer, age-0 black crappie selection for LC zooplankton was pronounced in all three lakes. Thus, age-0 black crappie exhibited similar selection trends among lakes, with variable selection of zooplankton taxa in spring (e.g., March), followed by strong selection for large zooplankton by late summer and fall (i.e., August – October) in both years.

Consumption of LC zooplankton by age-0 black crappie in May varied among lakes. In May 2000, juvenile black crappie at Lake Wauburg were larger than those found at Lake Lochloosa, making comparisons of consumption invalid. However, in May 2001 the number of LC zooplankton consumed by age-0 black crappie differed among lakes (ANCOVA, test for difference in elevation,  $P < 0.001$ ). Age-0 black crappie at Lakes Wauburg and Tarpon consumed more LC zooplankton than similar-sized fish at Lake Lochloosa (Figure 9).

Most age-0 black crappie contained crustacean zooplankton in their diets in May and throughout the summer in all lakes in 2000 and 2001, but occurrence of macroinvertebrates and fish in the diets varied among lakes and years (Figure 10). In 2000, zooplankton was found in 100% of black crappie in May, but by August over 80% of fish in Lochloosa contained macroinvertebrates compared to about 20% of fish at Lake Wauburg. Low numbers of age-0 black crappie collected at Lake Tarpon precluded diet analysis for fish in this lake in summer 2000. In October 2000, fish were found in about 60% of Lake Tarpon black crappie diets whereas most fish at Lakes Lochloosa and Wauburg contained zooplankton and macroinvertebrates (Figure 10). In 2001, over 90%

of age-0 black crappie at Lake Lochloosa contained macroinvertebrates in May, whereas most age-0 black crappie in all lakes contained zooplankton and macroinvertebrates during August and October (Figure 10). Thus, most age-0 black crappie at Lake Lochloosa consumed macroinvertebrates earlier in summer than the other two lakes in both years (Figure 10), yet age-0 black crappie size was not larger by October (Figure 4). Occurrence of fish in diets of age-0 black crappie was higher at Lake Tarpon than the other two lakes in both years (Figure 10) and age-0 black crappie size was larger by October (Figure 4).

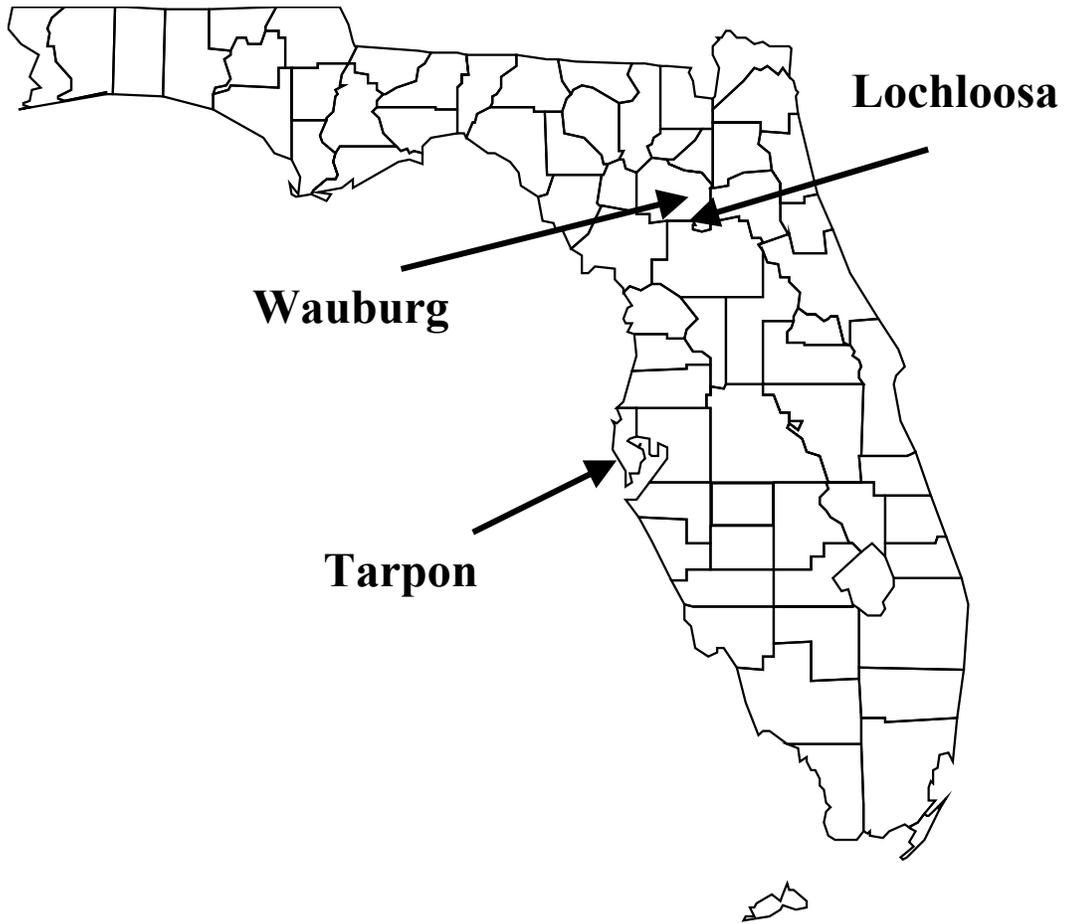


Figure 1. Location of study lakes in Florida.

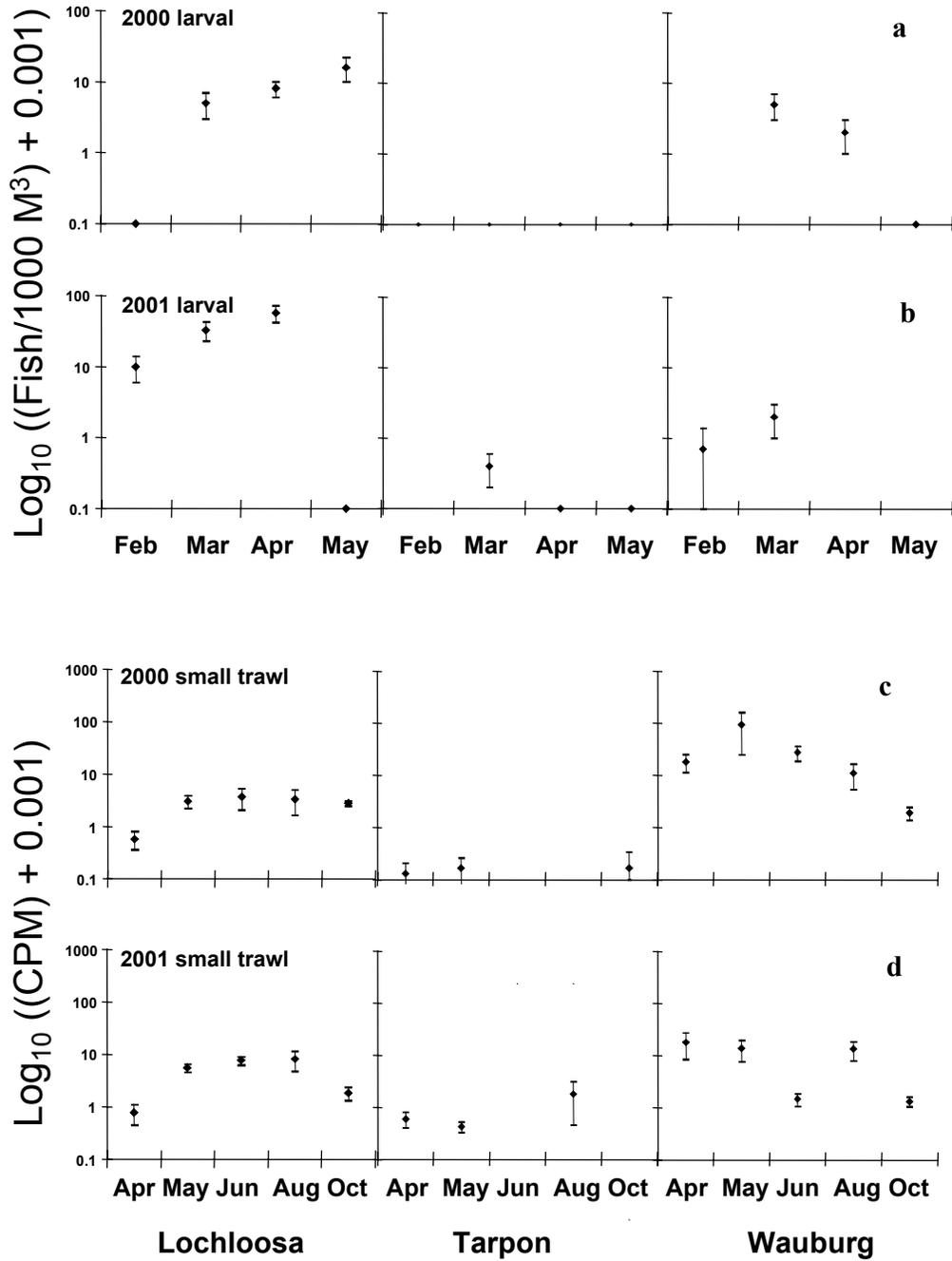


Figure 2. Mean ( $\pm 1$  SE) larval densities (a and b panels) as estimated from neuston net catches and small trawl catch per minute (CPM) (c and d panels) across sample months in 2000 and 2001 at Lakes Lochloosa, Tarpon, and Wauburg.

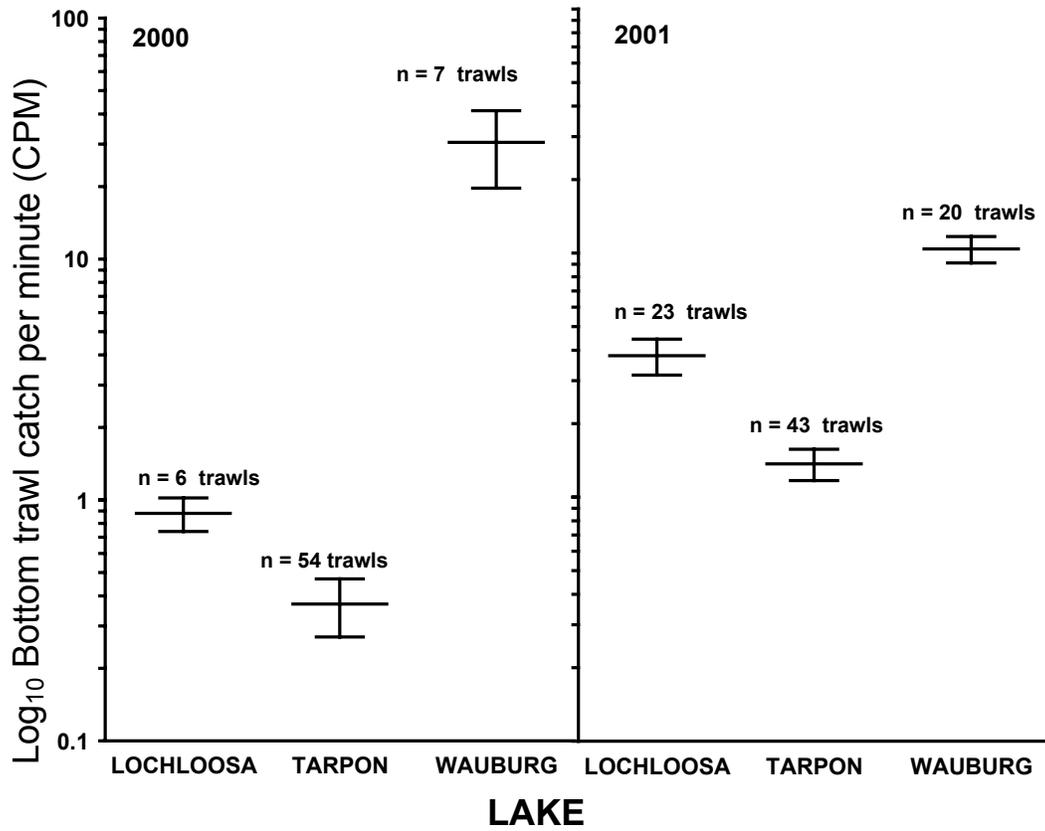


Figure 3. Large trawl catch per minute (mean  $\pm 1$  SE) of juvenile black crappie during fall of 2000 and 2001. Sample size (n = number of trawls) is indicated.

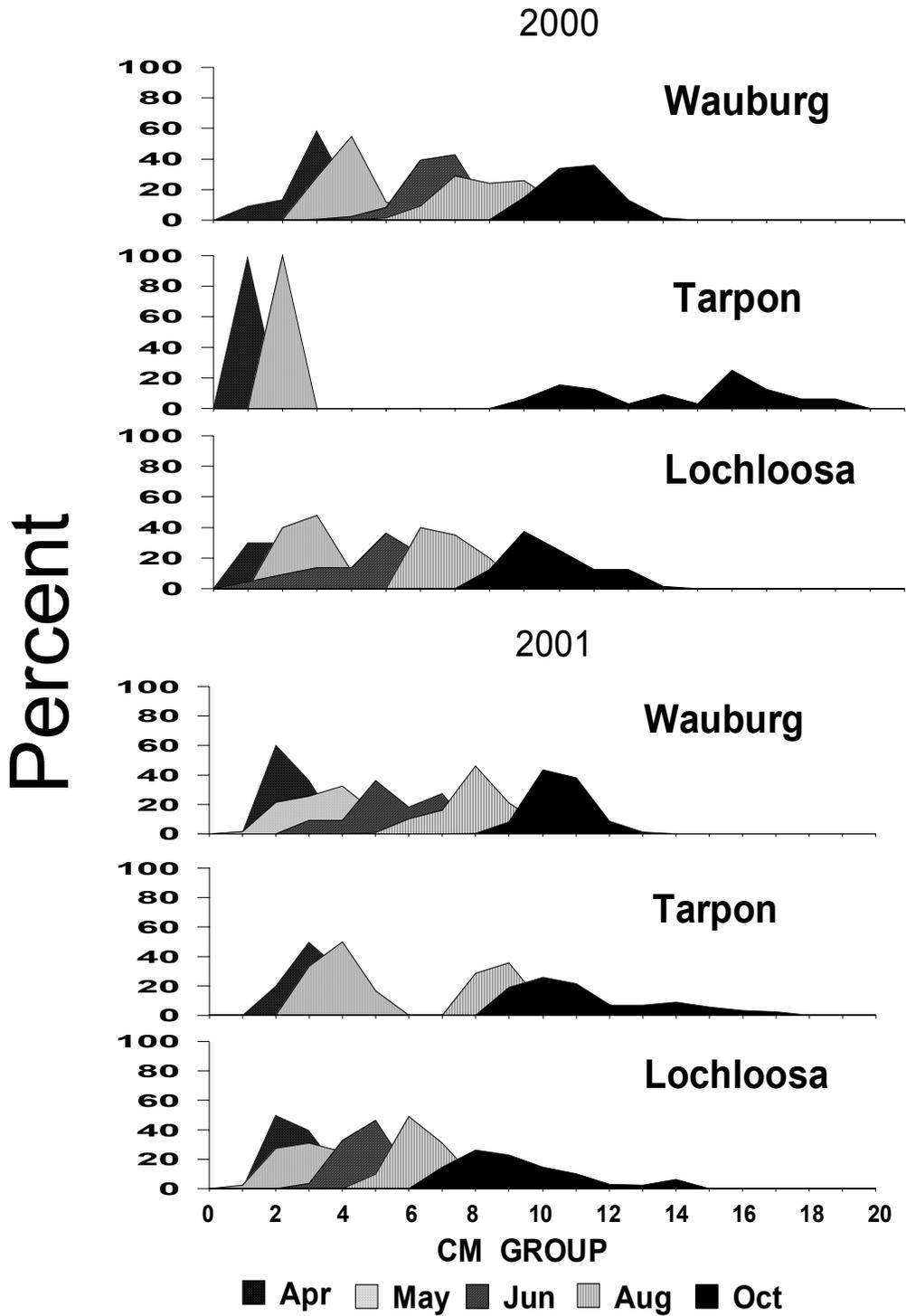


Figure 4. Relative length frequency distributions for age-0 black crappie in Lakes Wauburg, Tarpon, and Lochloosa in 2000 and 2001.

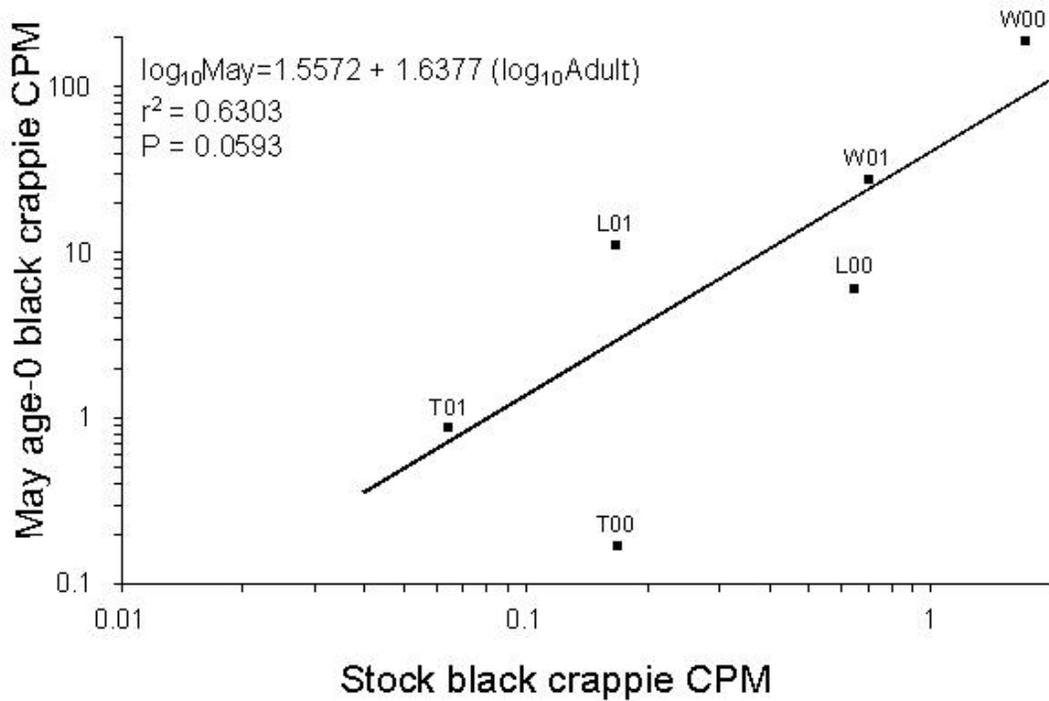


Figure 5. Regression between log<sub>10</sub> adult black crappie catch-per-minute (CPM) prior to spawning and log<sub>10</sub> juvenile black crappie CPM during May 2000 and 2001 in Lakes Lochloosa, Tarpon, and Wauburg. Symbols indicate lake (L=Lochloosa, T=Tarpon, W=Wauburg) and year (00=2000, 01=2001).

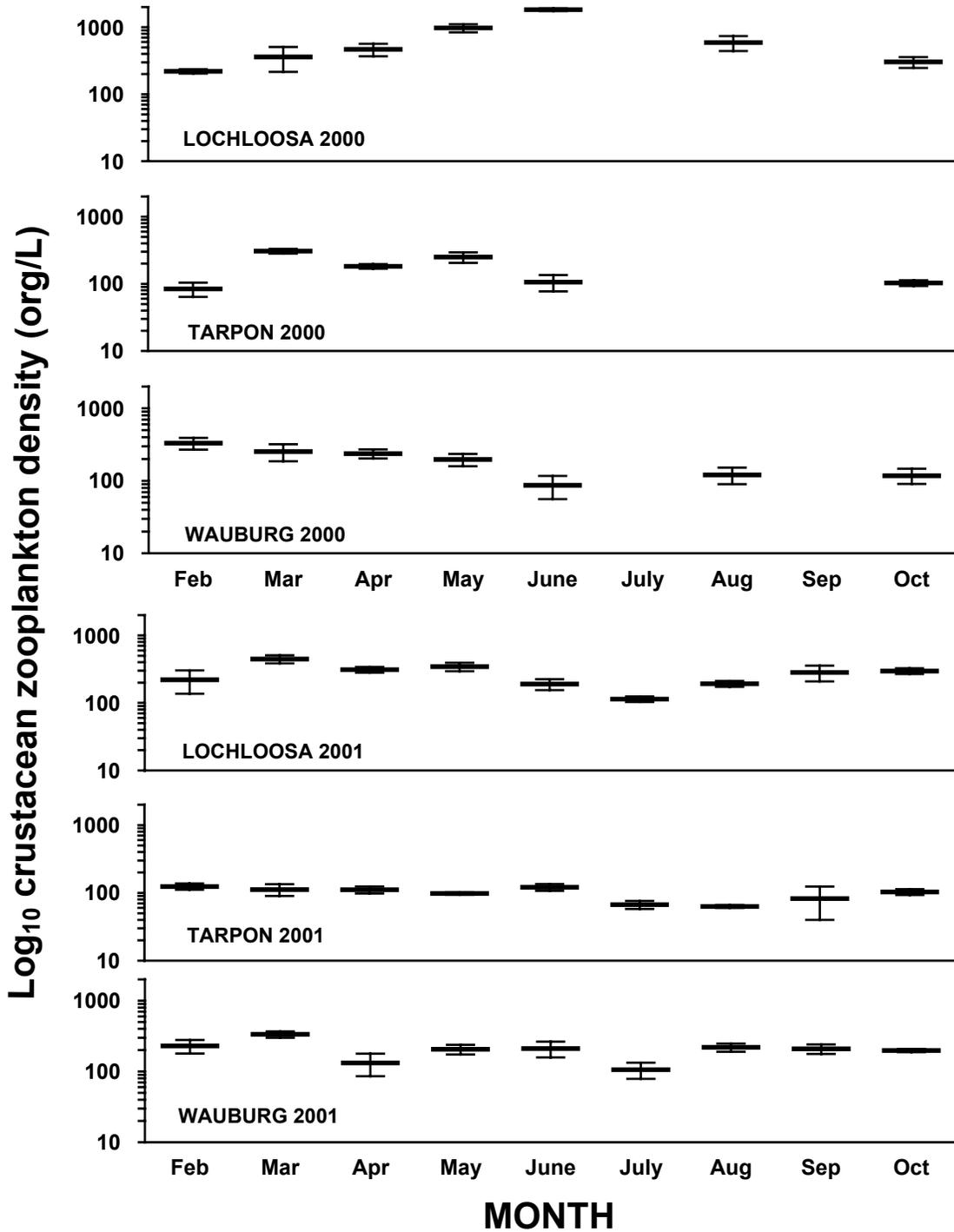


Figure 6.  $\text{Log}_{10}$  crustacean zooplankton (copepods and cladocerans) densities ( $\pm 1$  SE) in Lakes Lochloosa, Tarpon, and Wauburg for each sample month in 2000 and 2001. Mean densities with no error bars indicate low variance in those months. No samples were collected from any lakes in July 2000 or from Lake Tarpon in August 2000.

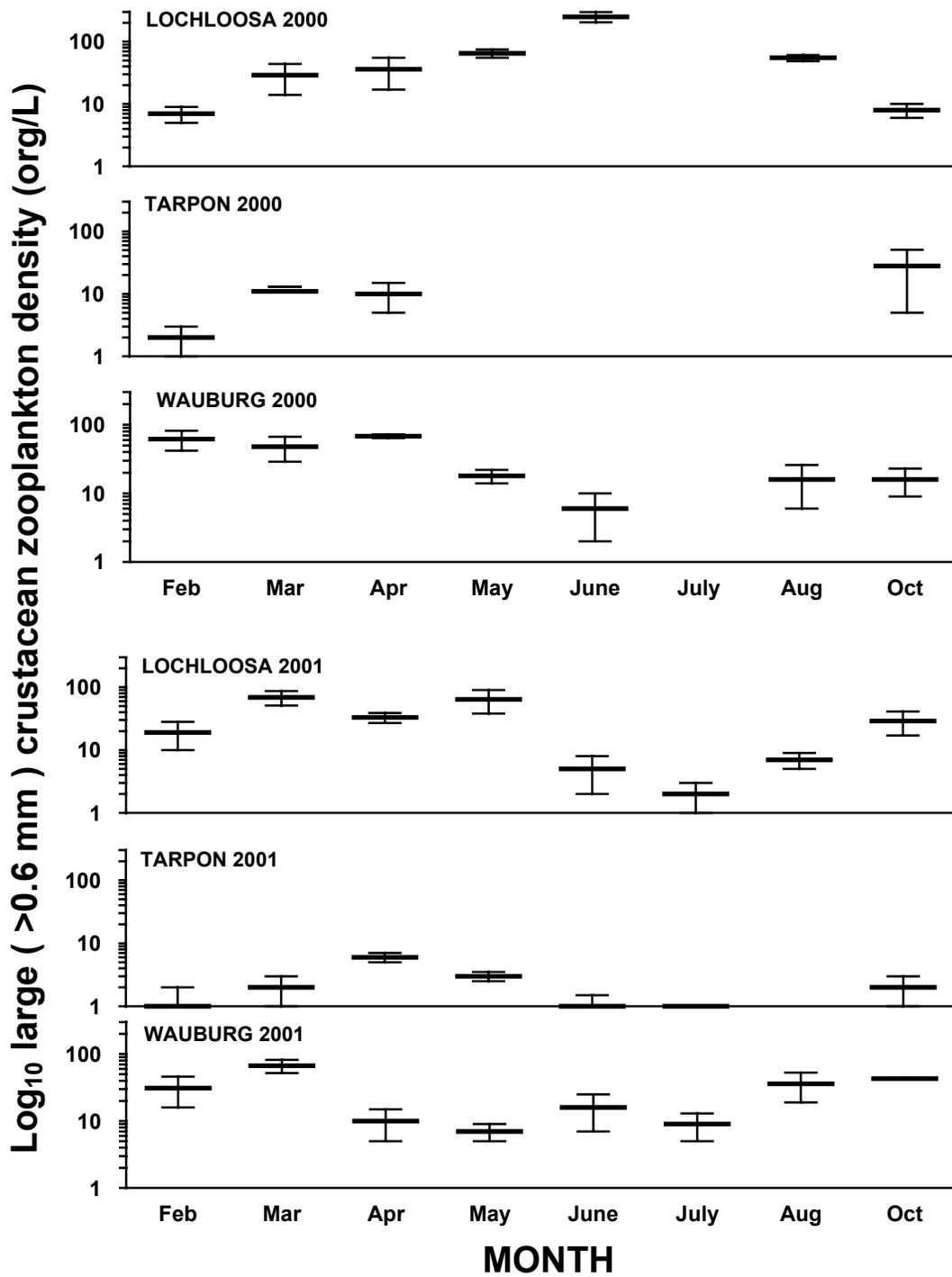


Figure 7.  $\text{Log}_{10}$  crustacean zooplankton ( $\geq 0.6$  mm) mean densities ( $\pm 1$  SE) in Lakes Lochloosa, Tarpon, and Wauburg during sample months in 2000 and 2001. Mean densities with no error bars indicate low variance in those months. No samples were collected from any lakes in July 2000 or from Lake Tarpon in August 2000.

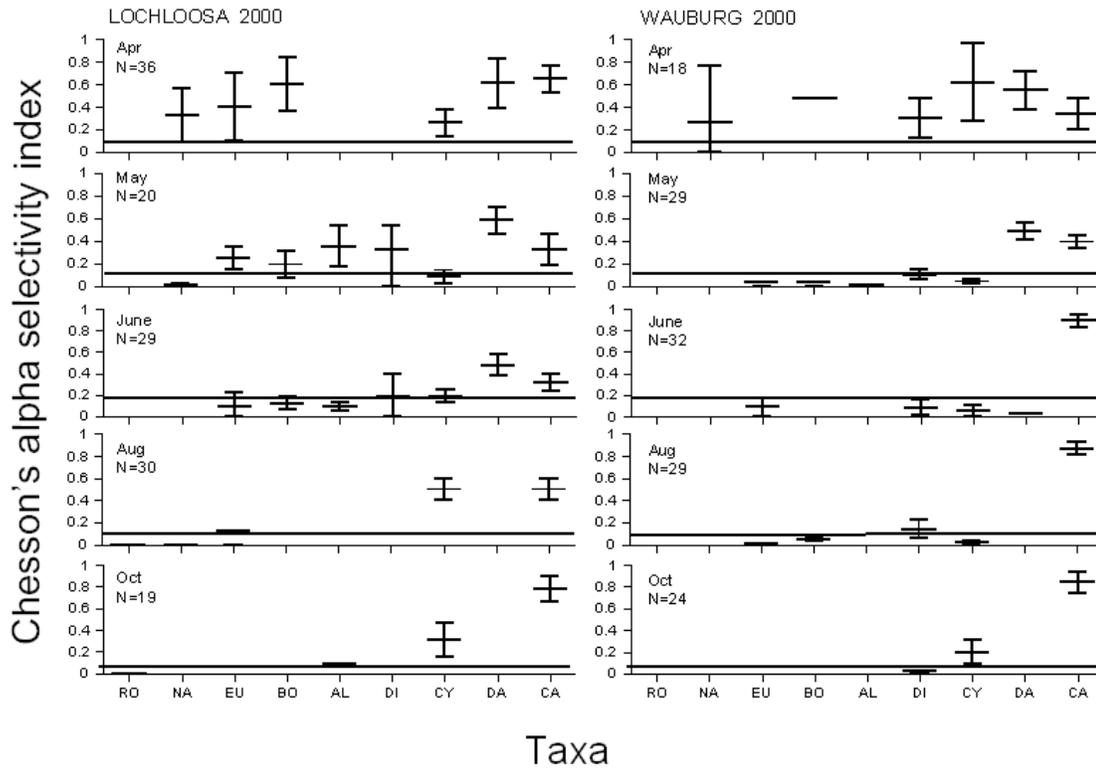


Figure 8. Age-0 black crappie selectivity (mean  $\pm$  1 SE; Chesson 1978) for zooplankton taxa in 2000 on Lakes Lochloosa and Wauburg. The solid line represents neutral selection. Taxa (RO - rotifers, NA - nauplii, EU - Eubosmina, BO - Bosmina, AL - Alona, DI - Diaphanosoma, CY - cyclopoid copepods, DA - Daphnia, and CA - calanoid copepods) are listed left to right from small to large. N equals the number of fish diets examined.

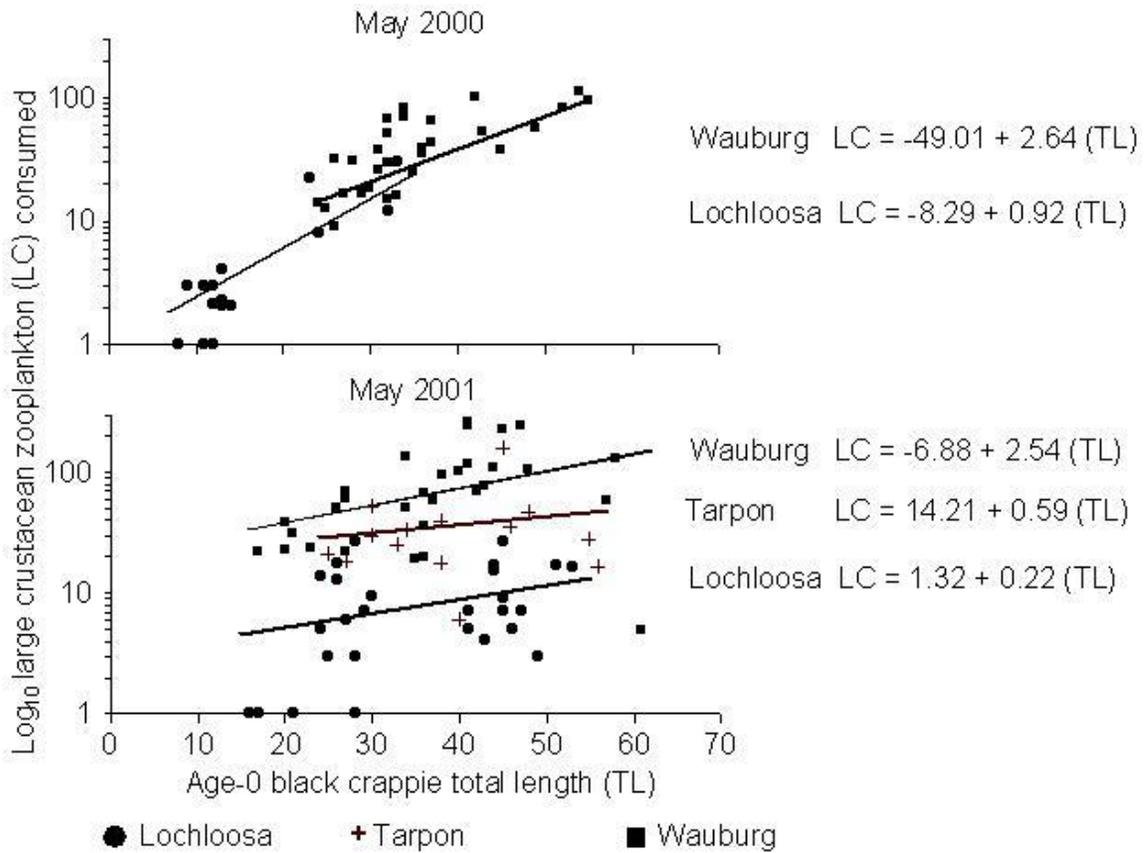


Figure 9. Log<sub>10</sub> number of large crustacean zooplankton (LC) in diets of age-0 black crappie in May 2000 (top panel) and 2001 (bottom panel). Points indicate individual fish. Lines represent regression equations and the fish size range for each lake.

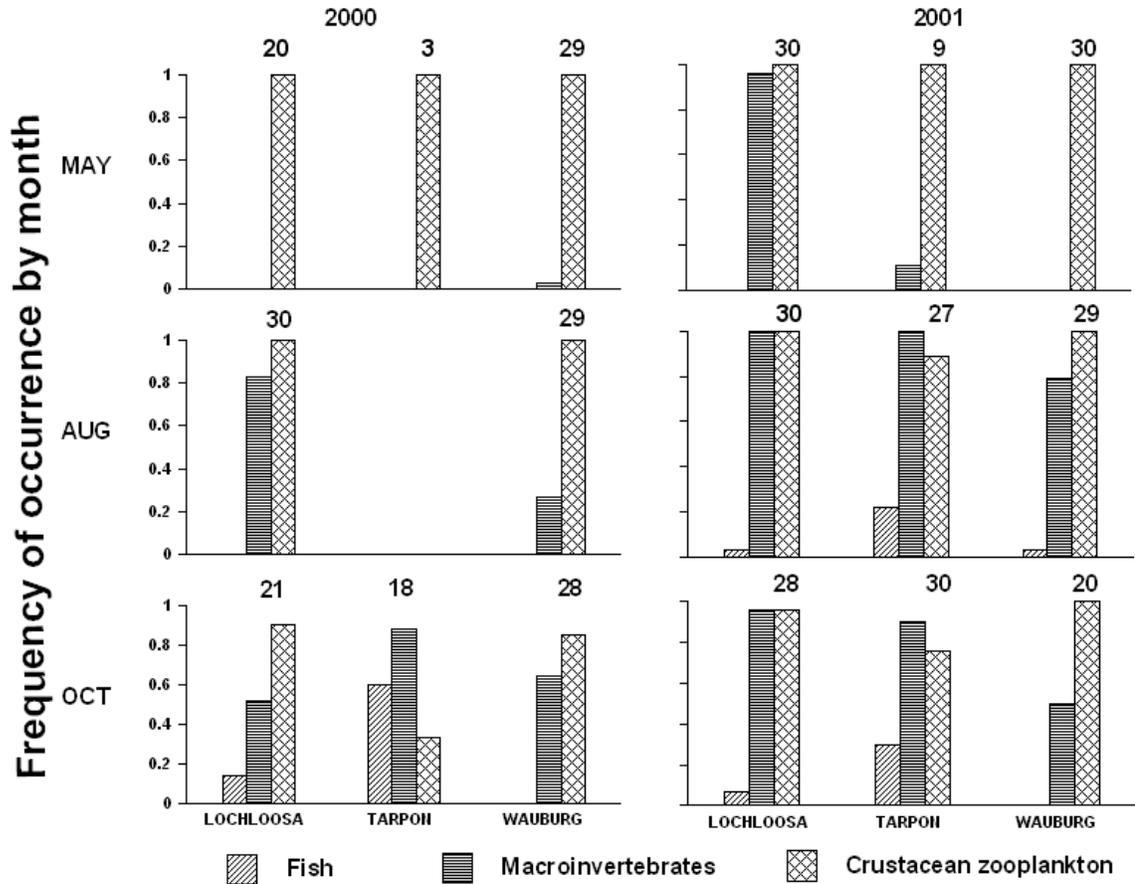


Figure 10. Proportion of age-0 black crappie diets containing crustacean zooplankton, macroinvertebrates, and fish during May, August, and October 2000 and 2001. No age-0 black crappie were sampled during August 2000 from Lake Tarpon. The number above the columns indicates the number of diets analyzed in each month.

Table 1. Annual mean levels of chlorophyll a (Chl a), total phosphorus (TP), total nitrogen (TN), and secchi depth (cm) of Lakes Lochloosa, Tarpon, and Wauburg for 2000 and 2001. Lakes Lochloosa and Wauburg data were from Florida Lakewatch (2001) and Lake Tarpon data were from Pinellas County Department of Environmental Management (unpublished data). Monthly samples (Jan-Dec) were collected from 3 sites at Lake Tarpon and 4 sites from Lake Wauburg in both years. In Lake Lochloosa, samples in 2000 were collected monthly at 4 sites except February secchi and November and December for all parameters. Due to low water levels in Lake Lochloosa in 2001, sampling protocol was reduced to two monthly water samples in February and August and one secchi depth reading in February. Percent of lake volume inhabited by macrophytes (PVI) was determined in Lochloosa, Tarpon, and Wauburg during May, October, and June of 2001, respectively. Dynamic ratio estimates are from Bachmann et al. (2000).

	Lochloosa	Tarpon	Wauburg
Surface area (ha)	2286	1030	150
Mean water depth (m)	2.0	2.5	3.0
Chl a ( $\mu\text{g/L}$ )			
2000	254	33	61
2001	138	29	83
TP ( $\mu\text{g/L}$ )			
2000	96	40	94
2001	90	43	115
TN ( $\mu\text{g/L}$ )			
2000	5275	1222	1445
2001	3824	1114	1793
Secchi Depth (cm)			
2000	26	82	72
2001	40	85	61
PVI (%)	5.0	4.3	0.6
Dynamic ratio (km/m)	2.39	1.26	0.41

Table 2. Pearson correlations between fall juvenile black crappie abundance (October age-0 CPM) and both larval density (fish/1000 m<sup>3</sup>) and juvenile abundance (May CPM) in the three study lakes (N).

Sample type Abundance parameter		Large bottom trawl October age-0 CPM	
		2000 N = 3	2001 N = 3
Surface trawl	r	0.122	-0.206
Larval fish/1000 m <sup>3</sup>	P	0.922	0.868
Small bottom trawl	r	0.999	0.992
May age-0 CPM	P	0.008	0.082

## DISCUSSION

Age-0 black crappie abundance and size during fall was not related to crustacean zooplankton abundance through summer among the three lakes. Age-0 black crappie at Lake Lochloosa were small compared to the other two lakes, but zooplankton density was highest at this lake in both years. Conversely, Lake Tarpon had the largest age-0 black crappie, but low zooplankton densities relative to the other two lakes. Lake Wauburg had higher abundances and intermediate size of age-0 black crappie and intermediate zooplankton abundance. Pope and Willis (1998) found no relation between crappie abundance and crustacean zooplankton size or abundance in two South Dakota systems over a three-year period. However, a weak correlation between zooplankton abundance and larval crappie density in Normandy Reservoir, Tennessee was reported by Sammons et al. (2001). Crustacean zooplankton densities (range 44 - 89 org/L) in Normandy Reservoir were lower than in South Dakota (50-700 org/L, Pope and Willis 1998). The lakes I evaluated were eutrophic/hypereutrophic and contained high crustacean zooplankton densities (50-1300 org/L). Thus, crustacean zooplankton densities did not appear to limit age-0 black crappie abundance or size in this study. Systems with greater crustacean zooplankton densities (i.e., more than 50 org/L) may not be zooplankton limited compared to systems that contain low abundance of crustacean zooplankton.

I found a correlation between abundance of age-0 black crappie in May and stock abundance the previous fall among the three lakes. Similarly, Allen and Miranda (1998) documented Ricker-type stock recruitment relations for crappies in four southeastern

reservoirs. Because my study only contained six lake-years of data (3 lakes and 2 years), I was unable to develop a stock-recruitment curve. However, a positive relation existed between stock and recruits in this study, and stock abundance during fall explained about 63% of the variation in early-summer age-0 black crappie abundance among lakes.

Population bottlenecks often regulate rates of mortality and growth in juvenile fish (Diana 1995). Although bottlenecks in survival may occur during summer in juvenile largemouth bass (Olson 1996; Ludsin and DeVries 1997) and bluegill Lepomis macrochirus (Cargnelli and Gross 1996), I found no evidence of a summer bottleneck for age-0 black crappie. Fall abundance of age-0 black crappie was strongly related to juvenile abundance during early summer among the study lakes. Because early summer catch rates were highly correlated to fall catch rates, zooplankton abundance during summer appeared adequate for high survival. Thus, age-0 black crappie fall abundance was set by early summer in both years.

Larval black crappie densities were not related to CPM of juvenile black crappie during early summer (May) or fall (October). Larval black crappie densities at Lake Lochloosa were higher than Lake Wauburg whereas juvenile black crappie were most abundant at Lake Wauburg. Higher larval black crappie catch rates at Lake Lochloosa may have resulted from the lake being shallow relative to Lake Wauburg (2 m vs 3 m) i.e., the neuston net sampled a larger portion of the water column relative to Lake Wauburg. Although I collected larval black crappie (7 to 15 mm) with the neuston net throughout the spring, I did not assess the survival of larval crappie to the juvenile stage. Therefore, mortality of larval black crappie may have occurred during spring of each year prior to recruitment of fish to the small bottom trawl sampling gear. Alternately, larval

sampling during daylight hours may have been less effective as compared to night sampling by Sammons and Bettoli (1998). It is possible that the neuston net may have ineffectively collected larval black crappie and confounded the relationship between larval and age-0 fall abundance at the three study lakes.

I detected differences in fall size structure of black crappie among lakes. However, fall size structure may not have been indicative of growth rates because differences in hatching duration may have contributed to the differences in size among age-0 black crappie. Black crappie began hatching at similar times, however, larval crappie ( $\leq 15$  mm) were present longer at Lake Lochloosa in both years. The extended occurrence of larval fish could have resulted from a protracted hatching period at Lake Lochloosa. This difference may be related to the resulting fall size structure of the study lakes (i.e., late-hatched fish may represent the smaller fish in the sample). At Lake Tarpon, no larval fish were caught in 2000, likely due to low abundance.

Age-0 black crappie size differences among lakes may be attributed to the amount of large zooplankton consumed. Juvenile black crappie at Lakes Tarpon and Wauburg consumed more large zooplankton in early summer and obtained a larger modal size by fall than juvenile black crappie at Lake Lochloosa. In comparison, juvenile bloater Coregonus hoyi that consumed large prey items achieved greater size than bloaters in aquaria without large prey available (Miller et al. 1990). Therefore, juvenile black crappie that consumed more large zooplankton in early summer may have had a size advantage by fall.

Growth of young and adult crappies has been shown to be density dependent in some lakes and reservoirs (Swingle and Swingle 1967; Allen et al. 1998). However, I

found little evidence of density-dependent growth due to zooplankton abundance among lakes. Lake Tarpon had the largest age-0 black crappie and the lowest zooplankton density in this study, but Lake Wauburg had higher zooplankton density and intermediate age-0 black crappie size among the three lakes. Zooplankton abundance was generally highest at Lake Lochloosa where age-0 black crappie were smallest in October. Thus, my expectation that age-0 black crappie size would be greater at lakes with higher zooplankton densities was not evident in this study.

Results of diet analysis of juvenile black crappie among the three lakes revealed similar prey composition as found in previous studies (Siefert 1968; Tucker 1972, Schael et al. 1991; DeVries et al. 1998, Pine and Allen 2001). Primarily large crustacean zooplankton, especially calanoid copepods, were positively selected by juvenile black crappie in the study lakes. However, preferred-size zooplankton densities were generally higher at Lake Lochloosa where juvenile black crappie size was smaller by fall when compared to the other two lakes. Pine and Allen (2001) found no significant differences in calanoid copepod densities through summer at Lake Wauburg, yet there were different growth rates between early and late age-0 black crappie cohorts, likely due to water temperature.

Differences in water clarity (i.e., secchi depth) may have contributed to the observed variation in age-0 black crappie sizes by fall among the study lakes. Reduced water clarity can be caused by phytoplankton production (Brown et al. 2000) and sediment resuspension (Bachmann et al. 2000) and may negatively influence foraging efficiency of larval fish, including black crappie (Mitzner 1991). Barefield and Ziebell (1986) demonstrated that the number of large zooplankton (Daphnia pulex 2.0-2.5 mm)

ingested by crappies (100-150 mm) was reduced as turbidity increased in a laboratory environment. Striped bass larvae ate fewer copepods as turbidity increased although the size of copepods consumed did not vary (Breitburg 1988). Miner and Stein (1993) suggested that larval bluegill growth may be negatively affected by turbidity. However, Miner and Stein (1993) also demonstrated the importance of contrast in the background to highlight transparent zooplankton. Thus, there may be a threshold in turbidity as suggested by Mitzner (1995) that provides optimum foraging for larval crappie.

The dynamic ratio (km/m) (Bachmann et al. 2000) indicates how likely shallow lakes are susceptible to turbulence and sediment resuspension due to wind. Bachmann et al. (2000) indicated that a lake with a dynamic ratio, (the square root of lake surface area in square kilometers divided by mean depth in meters), greater than 0.8 km/m may be prone to sediment resuspension. In addition, the percent of lake volume inhabited by macrophytes (PVI) may alter the dynamic ratio (e.g., high macrophyte abundance may buffer the turbulence generated by the wind, thereby overestimating the dynamic ratio)(Bachmann et al. 2000). Calculating the dynamic ratio for each study lake, Lake Wauburg had the lowest value at 0.41 km/m, Lake Tarpon was intermediate at 1.26 km/m, and Lake Lochloosa had the highest value at 2.39 km/m. Secchi depths were lower at Lake Lochloosa than at Lakes Tarpon and Wauburg in both years and PVI values in all lakes were relatively low. With low secchi depths and low PVI, it is possible that reduced water clarity at Lake Lochloosa may have resulted from a high dynamic ratio and associated sediment resuspension. In addition to potential wind resuspension of bottom sediments, chlorophyll values at Lake Lochloosa ( $> 100 \mu\text{g/L}$ ) were higher than Lakes Wauburg and Tarpon (70 and 30  $\mu\text{g/L}$ , respectively). Thus, both

physical (i.e., dynamic ratio) and biotic (i.e., chlorophyll) characteristics indicate that visibility and associated feeding efficiency of age-0 black crappie at Lake Lochloosa may have been lower than at Lakes Wauburg and Tarpon.

There is a need to determine the feeding success of age-0 black crappie on zooplankton prey in environments with varying water clarity (turbidity). Although Barefield and Ziebell (1986) evaluated feeding rates at different turbidities, the size of zooplankton prey (Daphnia pulex, 2.0-2.5 mm) they used was relatively large compared to prey types in my study lakes. Results of such a study would increase our understanding of the influence of turbidity on growth and survival of age-0 black crappie.

Many previous studies have shown that ontogenetic diet shifts can affect the growth and survival of age-0 fish. For example, dramatic increases in age-0 largemouth bass growth rates occur after a diet switch to macroinvertebrates whereas no diet shift causes poor fish growth and survival (Olson 1996, Ludsin and DeVries 1997). Northern pike Esox lucius require a shift from zooplankton prey to macroinvertebrates during early life prior to their shift to piscivory (Bry et al. 1995). Conversely, studies that observed a diet switch to macroinvertebrates by yellow perch Perca flavescens have shown conflicting results. Cobb and Watzin (1998) observed faster yellow perch growth rates when macroinvertebrates were consumed. However, juvenile yellow perch (> 30 mm TL) growth rates decreased when the proportion of benthic prey items increased at Lake Mendota, Wisconsin (Wu and Culver 1992). In this study, occurrence of macroinvertebrates in diets of black crappie size increased with fish size consistent with findings of previous studies (Tucker 1972; Ellison 1984). However, age-0 black crappie were smaller by fall at Lake Lochloosa than Lake Tarpon although macroinvertebrates

occurred commonly in the diets of fish from both lakes. Additionally, crustacean zooplankton occurred more often than macroinvertebrates in age-0 black crappie diets at Lake Wauburg, yet modal fish size was intermediate. Thus, a diet switch to macroinvertebrates by age-0 black crappie at all lakes did not translate to large size by fall as observed in studies of other predators (Bry et al. 1995; Olson 1996). However, macroinvertebrates and fish were present in age-0 black crappie diets at Lake Tarpon and crappie size by fall was greater than the other two lakes. Therefore, it appears that some age-0 black crappie at Lake Tarpon may have benefited from a diverse diet of zooplankton, macroinvertebrates, and fish by October. However, I did not assess macroinvertebrate or forage fish density among lakes and thus was unable to relate black crappie size and abundance to macroinvertebrate or forage fish abundance.

Age-0 black crappie abundance and size was not related to crustacean zooplankton density in highly productive natural lakes in Florida. Although crustacean zooplankton abundance was not related to age-0 black crappie abundance or size, I observed large differences in fall size and abundance of black crappie among the study lakes. Abiotic factors (e.g., reduced water clarity) may have reduced successful capture of crustacean zooplankton, especially at Lake Lochloosa, with negative consequences for growth of larval crappie in this lake. Juvenile black crappie abundances were also influenced by the abundance of adult black crappie the previous fall.

## MANAGEMENT IMPLICATIONS

Age-0 black crappie abundance and size was variable at productive lakes in Florida. For example, age-0 black crappie at Lake Tarpon exhibited larger size than Lakes Lochloosa and Wauburg during both study years, some reaching 18 cm by October. These sizes are more common in black crappie older than age-0 (Carlander 1977; Allen et al. 1998), thus crappie in Lake Tarpon may attain a harvestable size faster than other crappie populations. Harvest of these fish during a winter fishery at Lake Tarpon may reduce the potential number of spawning individuals the following year (Webb and Ott 1991). Age-0 black crappie at Lake Tarpon might be protected by imposing a length limit, potentially increasing their contribution to the reproductive population. Crappie populations with fast growth rates and low abundance, such as Lake Tarpon, may benefit from the implementation of harvest regulations. Conversely, implementing regulations on lakes or reservoirs with a high crappie abundance and/or small size, such as Lakes Wauburg and Lochloosa, may not be beneficial.

I found that mean CPM of age-0 black crappie in May was highly correlated with fall abundance among the three lakes in both years. Thus, year class strength of fish entering fall appeared to be set by May in both years. Larval fish densities, as determined from neuston net samples during spring, were not a reliable index of year class strength by fall as shown by Sammons and Bettoli (1998) in Tennessee. Thus, fishery managers might be better served by conducting bottom trawls in early summer to assess black crappie year class strength in Florida lakes.

Mean CPM of age-0 black crappie in May was strongly related to adult black crappie abundance in the previous fall. Thus, fall adult crappie stock abundance may depict juvenile crappie abundance the following summer. Hence, fall stock abundance may partially explain abundance of juvenile black crappie in Florida lakes. However, the interaction between stock densities and variable environmental conditions strongly influences crappie recruitment (Allen and Miranda 2001). Future studies that evaluate stock-recruitment relationships with abiotic effects are needed to further understand the mechanisms that result in variation in crappie recruitment.

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## BIOGRAPHICAL SKETCH

Kevin J. Dockendorf was born on February 15, 1973, in Iowa City, Iowa, the son of Tom and Helen Dockendorf. He was raised in the rural community of New Hampton, Iowa, with two brothers, Jeff and Brad. He graduated from Iowa State University with a B.S. in fisheries and wildlife biology in May 1996. He was a fisheries technician with the Iowa Department of Natural Resources and the Illinois Natural History Survey during 1996-2000. In February 2000, he began graduate work evaluating black crappie recruitment in the Department of Fisheries and Aquatic Sciences at the University of Florida. In December 2002, he will graduate with his Master of Science degree. His future plans include getting married in June 2003 and pursuing a career as a fisheries management biologist within a state agency.