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FACTORS AFFECTING BLACK CRAPPIE RECRUITMENT IN FOUR WEST-CENTRAL MINNESOTA LAKES[1]

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Abstract.--We evaluated the factors affecting recruitment of black crappie *Pomoxis nigromaculatus* in four small lakes in west-central Minnesota. Recruitment to age 2+ was relatively consistent across years (1992-2001) in Brophy and Louise lakes, but was much more variable in Blackwell and Freeborn lakes. The only year with a very weak year class in all four lakes was 1992, which was characterized by unusually cold June and July air temperatures. Strong year classes were very lake specific. Only in 1996, 1997, and 1998 did two lakes produce a strong black crappie year class. Larval sampling of black crappie (1998-2000) was not related to future year class strength in Brophy and Louise lakes, likely due to supplemental recruitment caused by emigration from other lakes in the chain. Larval sampling was more closely related to future year class strength in Blackwell and Freeborn lakes in that the year with highest larval catch subsequently produced a stronger year class. For the four lakes evaluated in 1998-2000, adjusted annual rate of exploitation of black crappie ranged from 13-50%, but 9 of 12 lake-years were between 19-29%. We found little evidence to suggest that yellow perch *Perca flavescens* or zooplankton dynamics had an effect on black crappie recruitment.

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Understanding recruitment and population dynamics of a species is crucial to fisheries management. This is particularly true when the species of interest demonstrates highly variable recruitment. Black crappie *Pomoxis nigromaculatus* are a very popular sport fish in the midwestern United States (Boxrucker and Irwin 2002). In Minnesota, there has been an increasing trend towards active black crappie management, particularly in regard to restrictive experimental angling regulations. To fully evaluate management activities for black crappie in Minnesota, we need a more thorough understanding of their population and recruitment dynamics.

Population characteristics of both black crappie and white crappie *P. annularis* and the factors that influence them have been well documented in reservoirs throughout the midwestern and southern United States (Mitzner 1984; Hooe 1991; Boxrucker and Irwin 2002). Various environmental variables including water level (Groen and Schroeder 1978; McDonough and Buchanan 1991; Sammons et al. 2002), turbidity (Mitzner 1991), water temperature (McDonough and Buchanan 1991; McInerny and Degan 1991), and wind (Mitzner 1991), and biological variables including zooplankton populations (Bunnell et al. 2003), competitor density (Stein et al. 1995), and predator densities (Galinat et al. 2002), have been related to crappie recruitment and growth in midwestern and southern reservoirs. Many of these studies focused on a single water body, and focused on white crappie or included both black and white crappie, and the two species are not directly comparable (Ellison 1984; McInerny et al. 1993). However, information for black crappie in reservoirs, and particularly natural lakes, in the upper Midwest and Great Plains is sparse (Guy and Willis 1995). While Guy and Willis (1995) studied black crappie recruitment in 22 South Dakota lakes, 16 of the 22 were impoundments, and only 6 were natural lakes. Furthermore, the natural lakes were relatively large (390-6,600 ha).

While the body of literature on black crappie is large, very little of it is directly applicable to small lakes in central Minnesota. Minnesota has thousands of smaller (<400 ha) lakes in which black crappie are an important component of the fishery. Parsons and Reed (1998) found up to 28% of angling effort in small west-central Minnesota lakes was directed at black crappie. The Minnesota summer lake survey program of gill netting and trap netting has created a database that has provided information necessary to understand recruitment processes for numerous fish species. However, the summer gill nets and trap nets used in this program do not effectively sample black crappie (McInerny et al. 1993), and thus we know very little about the recruitment or population dynamics of this species in Minnesota waters. However, Grant et al. (2004), utilizing this database, did detect a significant decreasing trend in catch per unit effort (CPUE) in gill net catch of black crappie from 1983-1997.

Anglers in Minnesota have become accustomed to variability in crappie angling success, and fisheries managers have attributed this to cyclic variations in recruitment. Allen and Miranda (2001) suggested that crappie do not show true cycles, but rather what they called "quasi-cycles", resulting from random fluctuations in environmental conditions combined with density-dependent mechanisms.

Questions remain as to when the critical period for black crappie recruitment occurs. McDonough and Buchanan (1991) and Sammons and Bettoli (1998) found that peak larval crappie density accurately predicted recruitment to age 0+ or age 1+ in Tennessee reservoirs. However, Dubuc and Devries (2002) did not find evidence of such a relationship in three Alabama reservoirs, nor did Dockendorf and Allen (in press) in three Florida lakes. Pope (1996) also reported that larval black crappie abundance did not correspond with fall trap net catch-per-unit-effort (CPUE) of age-0 fish in two South Dakota waters.

Interspecific relationships in lakes may also affect black crappie recruitment. In Brant Lake, South Dakota, age-0 black crappie abundance was high only in years when age-0 yellow perch *Perca flavescens* abundance was extremely low (Pope et al. 1996). The authors, however, attributed this to differential relations with weather variables rather than interspecific competition. Nevertheless, predation by age-0 yellow perch can substantially affect zooplankton density and size structure in lakes (Mills and Forney 1983), although Anderson et al. (1997) found no significant relationships between larval yellow perch abundance and various measures of zooplankton abundance. Yellow perch hatch before black crappie, and larval yellow perch and black crappie have been reported to use similar zooplankton resources, primarily adult and immature stages of copepods (Bulkley et al. 1976; Post et al. 1994). Thus, yellow perch recruitment and zooplankton dynamics must be considered.

The objective of this study was to identify factors influencing year class strength of black crappie. To accomplish this, we sought, to monitor the adult population to determine population density, mortality and growth, and for three years to attempt to quantify abundance, growth and diet of age-0 black crappie and yellow perch, and relate these results to biotic and abiotic factors.

Methods

We sampled four small (<125 ha) lakes in west-central Minnesota (Table 1) representing Minnesota Lake Classes 31 and 34 (Schupp 1992). The lakes were selected to cover a range of black crappie population characteristics. Historical lake survey data indicated that Blackwell Lake generally contained an abundant, slow growing population of black crappie, while Freeborn Lake black crappie were low in abundance and fast growing. Brophy and Louise lakes were intermediate in these characteristics.

All four lakes contain northern pike *Esox lucius*, largemouth bass *Micropterus salmoides*, and walleye *Sander vitreus* as predators, and yellow perch, bluegill *Lepomis macrochirus*, and pumpkinseed *L. gibbosus* in addition to black crappie as panfish. Bullhead *Ameirus* spp., several cyprinids, and white sucker *Catostomus commersoni* are also common. All four lakes are managed under statewide angling regulations, and the only active fisheries management activity is walleye stocking in each lake except Blackwell Lake. Freeborn Lake has experienced partial winterkill on rare occasion. Freeborn and Blackwell lakes are essentially isolated from other water bodies, but Brophy and Louise lakes are located in a chain of 16 lakes (Parsons and Reed, in press).

Black crappie were sampled with double-frame (0.9 x 1.8 m) trap nets with 19 mm mesh and a 15 m lead. Nets were set and lifted daily at six sites in each lake during spring and fall 1998-2003. Net sites were fixed among years, but differed between spring and fall. Due to variation in ice-out date and weather, and occasional net toppling due to wind or tampering, dates and total effort varied among years and lakes (Table 2). All black crappie were measured, and scales were taken from five fish per cm length group for aging. Black crappie ≥ 180 mm total length (hereafter referred to as adult) were marked with individually numbered Hallprint[2] TBF-1 fine anchor t-bar tags in spring and fall 1998-2000. Tags were inserted with a Dennison fine-fabric gun diagonally forward and laterally through the pterygiophores of the spinous dorsal fin. Total tag length was 39 mm, including 23 mm of white tubing that contained the tag number. Anchor length was 8 mm. Adult black crappie were marked with a left pelvic fin clip in spring 2001 and with a right pelvic fin clip in spring 2002. No adult marking occurred in fall 2001-2002 or spring 2003, and black crappie < 180 mm (hereafter referred to as juvenile) were not marked.

Using spring trap net data, we fit the following linear model with JMP software (SAS Institute, Cary, North Carolina) to estimate black crappie year class strength in each lake: $\text{Log}_e(\text{CPUE}_{ij}) = \mu + \alpha_i \bullet \text{Age}(i) + \beta_i \bullet \text{Year Class}(j) + \varepsilon_{ij}$, where CPUE_{ij} is the number of fish age *i* from year class *j* caught divided by the number of nets, plus 1 to allow log of zero values, and Age (*i*) and YearClass (*j*) were model main effects. We used the least-square means from the year-class main effect as an age-adjusted index of year class abundance (YCLSM). Only fish ages 2-6 were used because age 2 is when fish begin to recruit to spring trap nets, and our confidence

[2] Use of trade names does not imply endorsement of products

Table 1. Characteristics of the four study lakes including lake class, area (ha), percent littoral zone (< 5 m deep), maximum depth (m), and shoreline development factor (SDF).

Lake	Class	Area	Littoral	Depth	SDF
Blackwell	34	124	65	12.8	2.08
Brophy	31	117	52	13.4	1.34
Freeborn	34	98	71	5.5	1.52
Louise	31	87	45	10.1	1.16

Table 2. Trap net sampling dates and total net nights of effort for Blackwell, Brophy, Freeborn, and Louise lakes.

Year	Dates	Blackwell	Brophy	Freeborn	Louise
		Spring			
1998	14 April – 22 April	54	46	48	46
1999	12 April – 22 April	54	54	53	54
2000	5 April – 26 April	63	68	63	68
2001	27 April – 4 May	36	45	44	39
2002	23 April – 3 May	42	46	51	52
2003	22 April – 29 April	37	48	40	44
		Fall			
1998	29 September – 16 October	56	57	68	34
1999	27 September – 14 October	47	66	70	66
2000	2 October – 18 October	48	47	44	50
2001	25 September – 10 October	40	30	48	34
2002	1 October – 9 October	39	48	32	35

in aging with scales declined dramatically after age 6. Also, Kruse et al. (1993) found scales to be as precise as otoliths for aging black crappie from both fast and slow growing populations in South Dakota up to age 7. This method allowed comparison of the 1992-2001 cohorts. The 1992 and 2001 cohorts, however, were only represented in one spring, and thus have large standard errors and should be interpreted with caution. A year class was considered strong if its YCLSM exceeded the 10-year lake mean LSM plus two standard errors. Similarly, a year class was considered weak if its YCLSM was below the 10-year lake mean LSM minus two standard errors.

Yellow perch were also sampled during spring trap netting from 1999-2003. All yellow perch were measured and sexed through extrusion of gametes. In 1999, scales were taken from five fish per cm group for age and growth analysis (Fullhart et al. 2002).

Population estimates were calculated for adult black crappie with the Chapman modification of the Peterson method (Ricker 1975). The subsequent sampling with the voluntary tag returns over a three year period similar to the method used by Parsons and highest number of recaptures, usually the next spring, was used for the recapture period. The catch examined for marks was adjusted to account for growth if necessary. Estimates were calculated only if we found more than three recaptures.

Exploitation of tagged fish was estimated from voluntary tag returns by anglers. No incentives were used, but the presence of tagged fish was advertised. Therefore, we used a reporting rate of 50%, which was midway between an altruistic rate of 33% reported by Zale and Bain (1994) and the incentive rate calculated for Alexandria area lakes (69%, Parsons and Reed 1998). We made no adjustments for tag loss or tagging mortality, thereby making our estimate of exploitation conservative.

We also calculated mortality rates for adult black crappie. Standard catch curve analysis was impossible due to high fluctuations among years in spring trap net CPUE. Therefore we used two alternative methods to calculate instantaneous total mortality (Z). First, we used the annual decline in angler Reed (1998). Numbers of annual tag returns were transformed by natural log, and regression analysis yielded a line similar to the descending limb of a catch curve. The slope of the line was the estimate of Z, and total annual mortality (A) was computed as ($A = 1\text{-}e^{-Z}$). This method was used for fish tagged in spring and fall combined in 1999 for Blackwell and Louise lakes and in 1998 for Brophy Lake. This method requires that we assume equal angling effort and equal angler tag return rates among years. We also calculated an adjusted A for Brophy and Louise lakes to account for emigration. Since our method depended upon tag returns from the lakes, emigration would appear to be mortality. Therefore, we lowered our estimate of A by 15% in Brophy Lake and 23% in Louise Lake based on emigration rates reported by Parsons and Reed (in press). Freeborn Lake had no tag returns after year two, so we calculated A as ($1\text{-}(N_1/N_0)$) where N_1 = the population estimate in spring 2002 and N_0 = the population estimate in spring 2001. This requires no recruitment to the adult population within that year, which did prove to be the case. Since recruitment was negligible in Blackwell Lake during this period, we also calculated mortality with this method to compare the two methods. For all four lakes, we then subtracted average rate of exploitation from A to yield an estimate of natural mortality.

Weather data was obtained for west-central Minnesota from the Divisional Climate Data Time Series on the website of the Western Regional Climate Center (www.wrcc.dri.edu/spi/divplot1map.html). We used correlation analysis for YCLSM with mean monthly and multi-month combination air temperature and monthly rainfall data for April, May, June, and July 1992-2001. We averaged the YCLSM across the four lakes to provide an overall annual year class strength, and we also looked for correlations in individual lakes. We set alpha = 0.05, but applying the Bonferroni correction (Miller 1981) for 10 comparisons, correlations were considered significant if $P < 0.005$.

Larval fish sampling began in early May and continued weekly until late June or early July. Each lake was sampled eight times each year, except Blackwell Lake in 1998 (9 samples). Two nets were mounted in an aluminum frame attached to the booms of an electrofishing boat and fished just below the surface. Sampling nets were 0.75 m in diameter and 3.75 m long with 800 µm mesh. On each lake, nine areas were randomly selected in the limnetic zone as sampling stations. Five of the nine stations were randomly selected each sampling day for a total of ten samples per day. A General Oceanics[3] mechanical flowmeter was mounted in the center of one net to determine water volume sampled. A second flowmeter was mounted between the nets to determine sampling speed and filtering efficiency of the nets. We attempted to maintain a speed of approximately 0.75 m/s for 1-5 minutes, depending on conditions. Samples were preserved in ethanol and were identified to species (except cyprinidae) using the keys of Auer (1982). All black crappie and subsamples of yellow perch larvae were measured to the nearest 0.1 mm total length using optical imaging software (Simple PCI). Mean daily growth of yellow perch larvae was estimated by subtracting mean length at first catch from mean length in the last sample yellow perch were caught, divided by number of days. Due to apparent nonsynchronous hatching, we were unable to calculate mean daily growth rate for black crappie.

Peak density for black crappie and yellow perch was compared among years using the Kruskal-Wallis nonparametric one-way analysis of variance (Zar 1984). We also estimated the number of larval black crappie and yellow perch present in the lake at peak density. We multiplied the peak density (number/m^3) by the volume of water in the top 1 m of the lake area (m^2). Since our samples were pelagic, we must assume that equal numbers of larvae are in the pelagic and littoral zones. Claramunt et al. (in press) had a mean crappie catch of 0.05/m^3 in the pelagic zone and 0.11/m^3 in the littoral zone of 21 Illinois reservoirs. For yellow perch, Fisher et al. (1999) caught more larval yellow perch offshore than nearshore zones, but the differences were not significant. This method also assumes that all larvae are in the top 1 m of the

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water column, which is not the case (Faber 1967; Whiteside and Hatch 1997). Therefore, we suggest that our estimates of larval numbers be considered minimum values.

Limnetic zooplankton was sampled weekly in May and June, and during purse seining in August and September. Duplicate vertical hauls were taken and combined at 3 stations per lake with a 12 cm diameter Wisconsin plankton net with 153 µm mesh. Tows were 5 m deep except at one station on Blackwell Lake and all stations on Freeborn Lake, where tows were 3 m deep. Samples were preserved in ethanol for processing. In the laboratory, each sample was filtered through 80 µm mesh netting to drain ethanol. The sample was then poured into an appropriate size beaker and diluted with water to a volume that provided at least 100-150 organisms per 5 ml aliquot. The sample was then mixed and one 5ml aliquot was withdrawn with a bulb pipette and placed on a counting wheel. All crustacean zooplankton in the 5 ml aliquot were then identified, counted, and measured under a dissecting microscope with the use of an image analysis system and the "ZCOUNT" zooplankton analysis software program. When necessary, individual specimens were placed on slides and viewed under a compound microscope for further identification. Cladocerans were identified to the lowest taxonomic level possible (either genus or species), and copepods were split into the following four major groups: calanoid; cyclopoid; copepodite; and nauplii. For each sample, a second replicate 5 ml aliquot was withdrawn, placed on counting wheel, and counted. Zooplankton densities (number/l), biomass (µg/l), percent composition by number and weight, mean weight (µg), mean length (mm), and total count for each taxonomic group were calculated. Biomass was estimated from length-weight regression coefficients based on dry weight (Culver et al. 1985).

Purse seining was conducted in early and late August and in mid- September to collect age-0 black crappie and yellow perch. On each lake, seven to nine stations were set at randomly selected sites in the littoral zone. On each sampling day, 4-6 stations were randomly selected for sampling. The seine was 24.4 m long and 2.4 m deep with 6 mm mesh. Age-0 and age-1 black crappie, yellow perch, bluegill, and largemouth bass were counted. Subsamples of age-0 black crappie and yellow perch were preserved in formalin for diet analysis and lengths.

In the laboratory, stomachs were removed from age-0 black crappie and yellow perch, diet items were identified to selected taxonomic groups and counted. Depending on the number of diet items, all or a representative subsample of each taxonomic group were measured with computer imaging software (Simple PCI). Biomass for diet items was estimated from length-dry weight equations for specific taxa (Dumont et al. 1975; Smock 1980; McCauley 1984; Culver et al. 1985; Traina and Von Ende 1992; Breck 1993). Schoener's Index (Schoener 1970) was used to calculate diet overlap for black crappie and yellow perch. We calculated the index using samples from dates where at least 10 of each species were caught. Diet items were grouped into 12 categories: *Daphnia* (including *D. pulex, D. galeata, D. retrocurva*); small cladocerans (including *Ceriodaphnia, Latonopsis, Bosmina, Chydorus, Diphanasoma*); *Leptodora kindti*; Calanoid copepods; Cyclopoid copepods; Ostracods; Chironomids; *Chaoborus*; other insects (including Ephemeroptera, Trichoptera, and Odonata); amphipods; fish; and other.

To describe the fish communities of the study lakes, we used standard Minnesota summer lake survey information collected by fisheries management personnel with gill nets and trap nets. Experimental multifilament gill nets were 76 m long with five 15.2 X 1.8 m panels of graded bar mesh sizes of 19, 25, 32, 38 and 51 mm. Trap nets were identical to those used for spring netting operations. Six gill nets and nine trap nets were set overnight at the same locations in each survey. Surveys were conducted in 1996 and 2002 in Brophy and Louise lakes, and in 1999 and 2004 in Blackwell and Freeborn lakes.

Results

Adult Black Crappie and Recruitment

Blackwell Lake - Black crappie recruitment was quite variable in Blackwell

Lake. Year class analysis showed that the 1996 and 1997 year classes were strong, and the 1992, 1993 and 1999 cohorts were weak (Figure 1). The YCLSM ranged from -0.16 to 2.28, with a high coefficient of variation (CV) (86%). The strong 1996 and 1997 year classes strongly influenced CPUE, density, and growth of black crappie in Blackwell Lake.

Spring adult trap net CPUE and population density increased from 4.1/net and 14.4/ha in 1998 to a peak of 24.1/net and 197.4/ha in 2001 (Figure 2). Although adult trap net CPUE generally reflected population density, very low CPUE occurred in spring 2000 despite an increasing population. Fall trap net CPUE of juveniles exceeded 30/net in both 1998 and 1999 (Figure 3). Low subsequent recruitment from the 1998-2001 year classes was also apparent as fall juvenile CPUE in 2000-2002 was much lower.

Growth of black crappie was slow in Blackwell Lake, and worsened considerably due to the two strong cohorts (Figure 4). Mean length at age declined during the study for all age classes. Mean length at age 3 was 179 mm for the 1995 cohort and declined to 148 mm for the 1998 cohort. There was some evidence that growth was beginning to improve in 2003 (Figure 4).

Brophy Lake - Black crappie recruitment was more consistent in Brophy Lake. According to our criteria, the 1994 and 1998 year classes were strong while 1992 and 1993 were relatively weak (Figure 1). YCLSM values ranged from –0.07 to 1.16, and CV was only 57%. Estimated spring population density was consistent among years, ranging only from 63-75/ha, and spring trap net CPUE ranged from 4.0 to 9.4/net (Figure 2). Growth was consistent across ages with mean length at age 3 ranging from 194-219 mm (Figure 4). Fall trap netting captured very few adult (Figure 2) or juvenile (Figure 3) black crappie.

Freeborn Lake - Black crappie recruitment was highly variable in Freeborn Lake. Year class analysis showed that the 1997 and 2000 year classes were strong, while the 1992 through 1995 were weak (Figure 1). Although the range of YCLSM was only 0.06 to 1.15, CV was quite high (103%).

The four weak or missing year classes led to an extremely low adult population density when the study began in 1998. Despite 48 net nights of effort, only 8 black crappie > 180 mm were caught. However, recruitment of moderate (1996) and strong (1997) year classes in spring 1999 increased adult population density to an estimated 33.7/ha (Figure 2). Both cohorts recruited to adult size in the same year due to unusually good growth rates exhibited by all year classes in 1998. Spring adult population density declined to 12.4 in 2001 and 4.4 in 2002 as recruitment from the moderate 1998 and 1999 year classes failed to offset the decline of the 1997 year class. Spring adult trap net CPE generally did not reflect population density. CPE from 1999-2002 was always between 2.6 and 4.0, yet population density varied from 4-37/ha (Figure 2).

We observed a large decline in length at age 2 for the 2000 (141 mm) and 2001 (133 mm) year classes compared to previous cohorts (158-188 mm) (Figure 4). The mean length of the 2000 year class at age 3 was at least 50 mm lower than the 1995-1999 year classes. While the 2000 year class was considered strong, it was still weaker than the 1997 year class, which grew at a high rate. It is possible that the 2001 year class caused much of the decline in growth rate. Fall trap net juvenile CPUE was extremely high (39.1) due to the 2001 year class (Figure 3). However, this cohort did not recruit to the trap nets in large numbers in 2003 leading to a low YCLSM (Figure 1). It is unlikely that a large mortality event greatly reduced the 2001 year class between ages 1 and 2. Rather, we feel that slow growth by the 2001 year class lowered their catchability in the spring trap nets, and since our methodology only sampled this year class one year, our YCLSM value was biased low for 2001.

Louise Lake – All aspects of the black crappie population were consistent in Louise Lake. YCLSM values ranged only from 0.08-0.97 (Figure 1), and CV was 43%. The 1996 and 1998 year classes were strongest, while only 1992 was very weak. Estimated spring population density ranged from 55.9 to 97.2/ha (Figure 2). The lowest estimate was in 2002, apparently reflecting relatively lower recruitment of the 1999-2001 year classes.

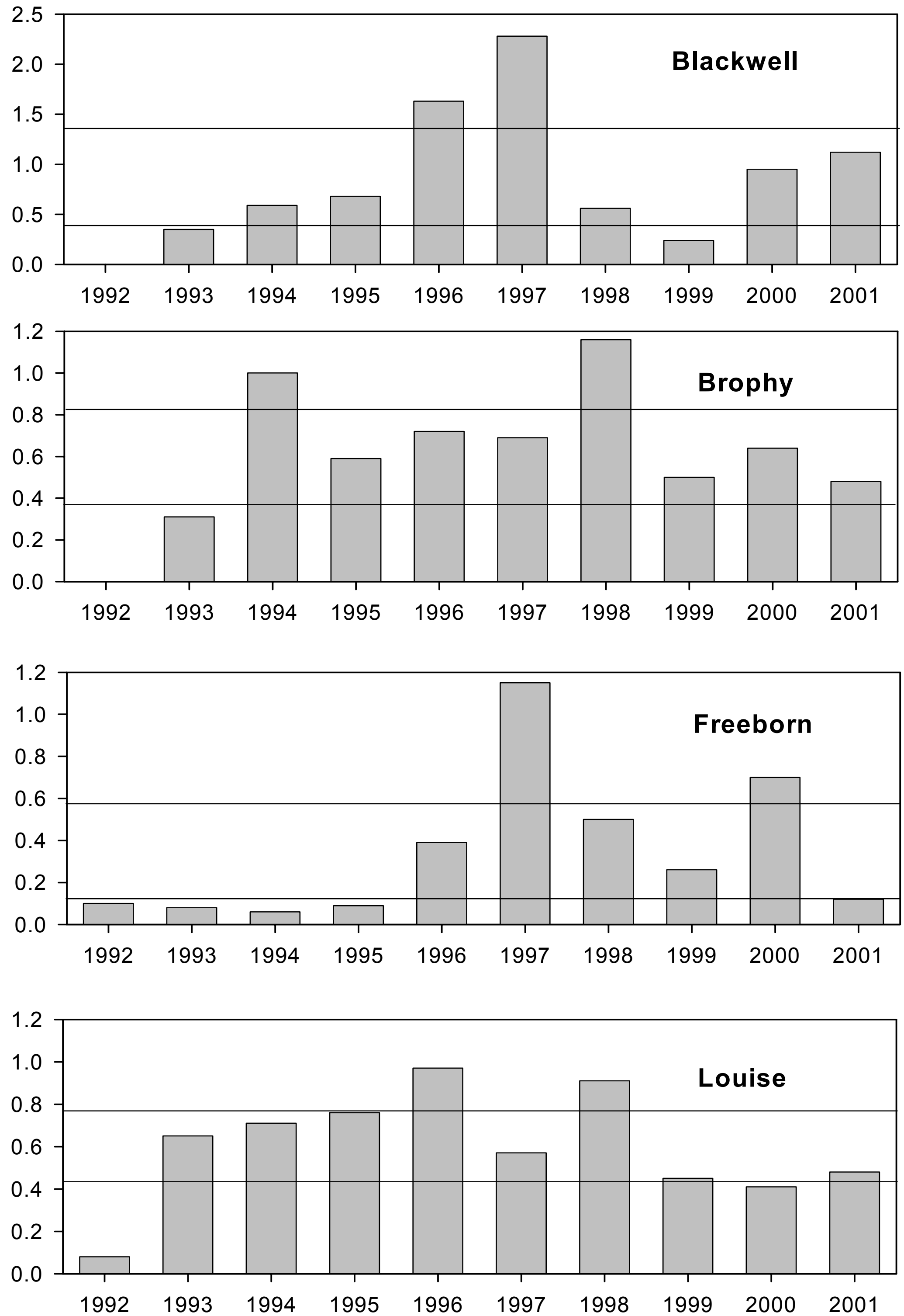

Figure 1. Year class strength of black crappie (1992-2001) as estimated by the linear model year class least squares mean (YCLSM) for Blackwell, Brophy, Freeborn, and Louise lakes. Horizontal lines indicate the lake mean ± two standard errors.

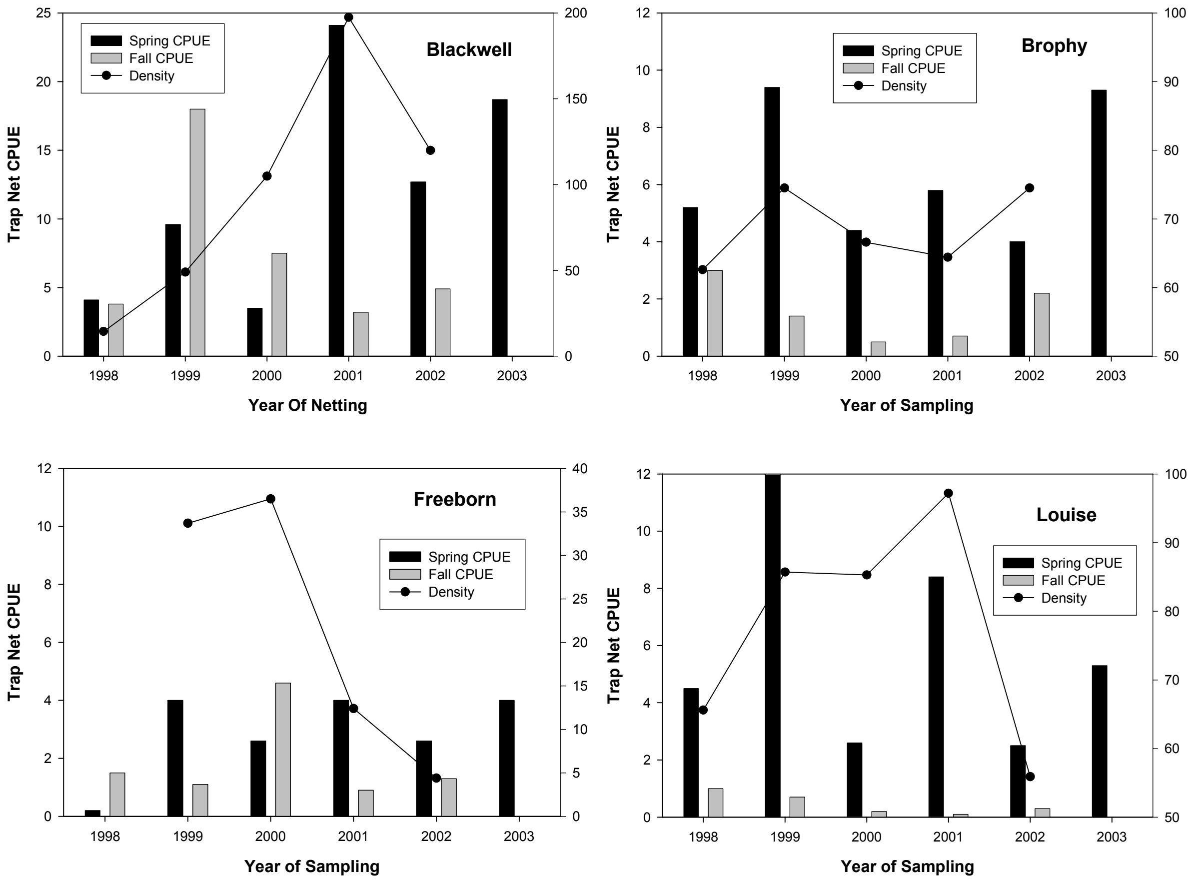

Figure 2. Spring and fall trap net catch per unit effort (CPUE), and estimated adult density (number/ha, right Y axis in each plot) of black crappie in Blackwell, Brophy, Freeborn, and Louise lakes, 1998-2003. No fall trap netting or population estimates were conducted in 2003.

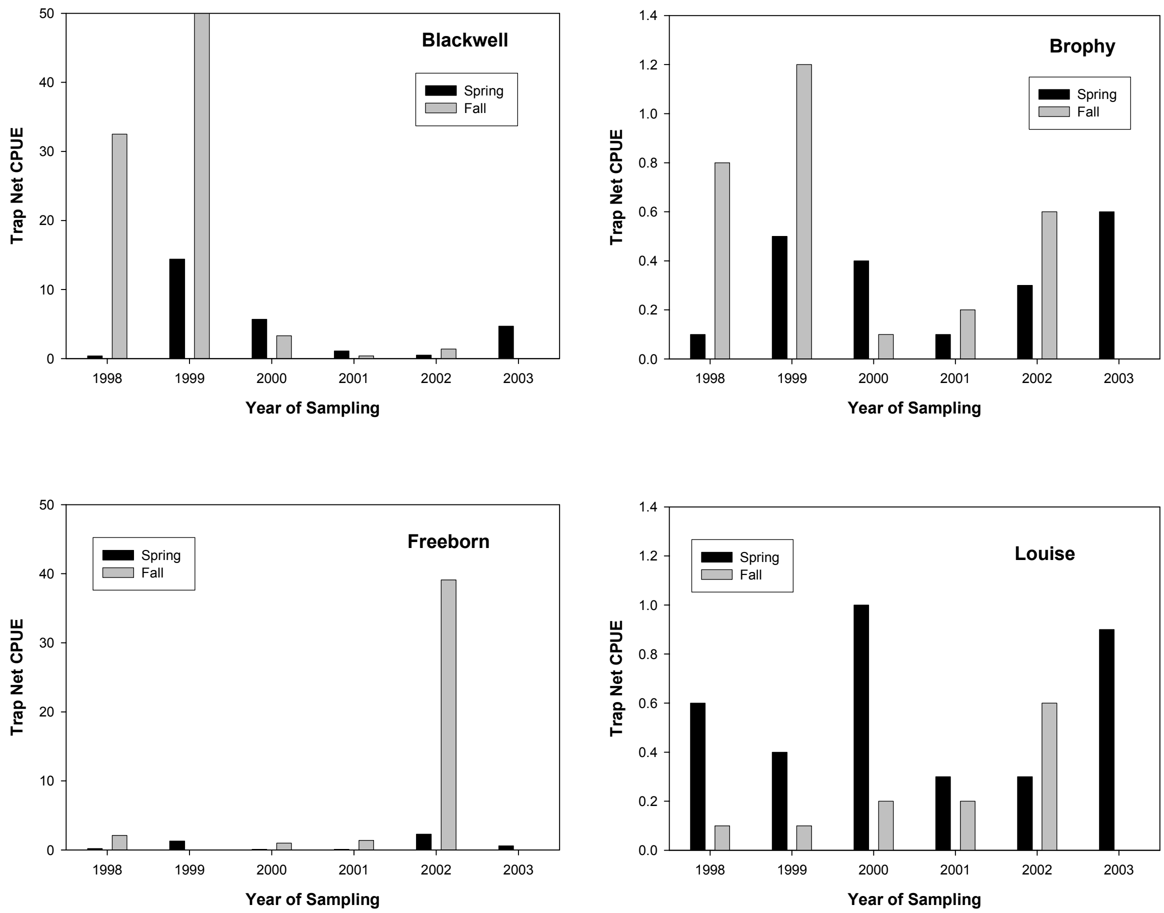

Figure 3. Trap net catch per unit effort (CPUE) of juvenile black crappie during spring and fall sampling, 1998-2003, in Blackwell, Brophy, Freeborn, and Louise lakes. No trap netting was conducted in fall 2003.

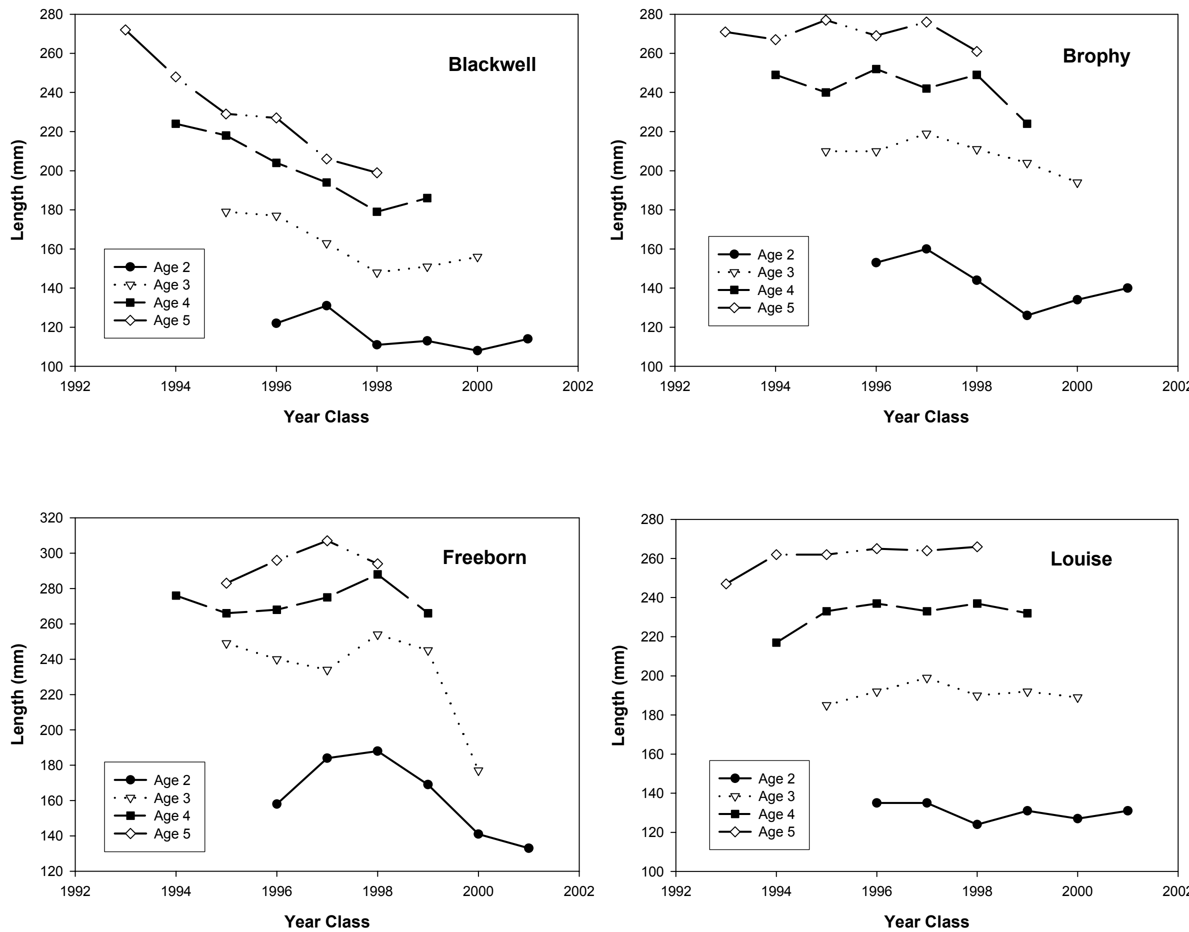

Figure 4. Mean length (mm) by age at capture in spring trap nets for the 1993-2001 black crappie year classes in Blackwell, Brophy, Freeborn, and Louise Lakes.

Spring trap net CPUE was more variable despite relatively stable population density estimates, ranging from 12.6/net in 1999 down to 2.5/net in 2002. Growth was very consistent among years for all ages (Figure 4). Mean length in spring at age 3 ranged only from 185-199 mm (Figure 4). Juvenile CPUE was very low in both spring and fall (Figure 3).

Weather and Recruitment

Weather variables (Tables 3 and 4) were generally poor predictors of eventual black crappie year class strength. With the exception of 1992 (and perhaps 1993), there was little consistency among lakes regarding year class strength. The 1992 year class was virtually nonexistent in all four lakes, and 1993 was weak in all but Louise Lake (Figure 1). June and July air temperatures in 1992 were the coldest observed (Table 3). Only in 1996 (Blackwell and Brophy lakes), 1997 (Blackwell and Freeborn lakes), and 1998 (Brophy and Louise lakes) did more than one lake produce a strong year class.

A closer examination of weather during staging, spawning, and the larval period in these three years shows many contradictions. In 1996 and 1997, April and May were unusually cool, but those months in 1998 were the warmest in our study (Table 3). June temperatures were warm in 1996 and 1997, but unusually cool in 1998. Similar contradictions occurred using rainfall. In 1996, rainfall was very low in April and June, but high in May (Table 4). May and June were very dry in 1997, whereas April was dry in 1998, but May and June were near normal. However, we did find a significant negative correlation between overall year class strength for the four lakes combined and June rainfall (r = -0.783) (Table 5). There were no significant correlations between black crappie year class strength in individual lakes and any of our weather variables.

Exploitation and Mortality

Angler rate of exploitation of black crappie adjusted for non-reporting ranged from 16% to 28% among the study lakes for all three tagging years and spring and fall combined (Figure 5). We combined tagging seasons because exploitation rate for fish tagged in the spring was very similar to that for fish tagged in the fall in Freeborn and Louise lakes, and only about 7% higher in Blackwell and Brophy lakes. Open water angling accounted for the great majority of tag

Table 3. Mean air temperatures (˚F) by month and multi-month combination, and the 12-year averages for west-central Minnesota, 1992-2003. Ranking of years in parentheses.

Year	April	May	June	July	May-June	May-July	June-July
1992	40.9 (9)	59.6 (3)	63.7(11)	63.6(12)	61.4 (6)	62.1(11)	63.4(12)
1993	42.3 (7)	55.8 (7)	62.2(12)	67.5(11)	59.0(12)	61.8(12)	64.9(11)
1994	44.1 (4)	60.1 (2)	67.8 (5)	68.1(10)	63.9 (1)	65.3 (5)	68.0 (8)
1995	38.6(12)	54.6 (9)	69.8 (1)	70.7 (6)	62.2 (5)	65.0 (6)	70.3 (2)
1996	39.1(11)	53.5(10)	68.3 (4)	69.0 (9)	61.1(9)	63.6(10)	68.7 (6)
1997	40.0(10)	52.8(11)	69.8 (1)	70.1 (8)	61.3 (7)	64.2 (8)	70.0 (3)
1998	48.2 (1)	62.1 (1)	63.8(10)	71.4 (4)	63.0 (2)	65.8 (3)	67.6 (9)
1999	45.7 (3)	58.4 (6)	66.5 (7)	73.2 (2)	62.5 (4)	66.0 (2)	69.9 (4)
2000	43.8 (5)	58.5 (4)	64.1 (9)	70.5 (7)	61.3 (7)	64.4 (7)	67.3(10)
2001	43.5 (6)	58.5 (4)	67.0 (6)	72.7 (3)	62.8 (3)	66.1 (1)	69.9 (4)
2002	41.2 (8)	52.2(12)	69.8 (1)	74.1 (1)	61.0(10)	65.4 (4)	72.0 (1)
2003	46.5 (2)	55.6 (8)	65.5 (8)	71.4 (4)	60.6(11)	64.2 (8)	68.5 (7)
Average	42.8	56.8	66.5	70.2	61.7	64.5	68.4

Table 4. Total rainfall (mm) by month and multi-month combination, and the 12-year averages for west-central Minnesota, 1992-2003. Ranking of years in parentheses.

Year	April	May	June	July	April-May	May-June	June-July
1992	43 (9)	42(11)	137 (3)	90 (8)	85(12)	179 (5)	227 (2)
1993	53 (7)	126 (1)	144 (1)	164 (1)	179 (2)	270 (1)	308 (1)
1994	94 (2)	44(10)	73 (9)	121 (4)	138 (6)	117(11)	194 (8)
1995	63 (4)	83 (7)	67(10)	159 (2)	146 (4)	150 (9)	226 (3)
1996	15(12)	100 (3)	57(11)	66(11)	115(10)	157 (8)	123(12)
1997	64 (3)	38(12)	56(12)	116 (6)	102(11)	94(12)	172(11)
1998	40(10)	87 (5)	106 (4)	80(10	127 (8)	193 (4)	186(10)
1999	40(10)	104 (2)	105 (5)	92 (7)	144 (5)	209 (3)	197 (7)
2000	42 (8)	91 (4)	85 (7)	120 (5)	133 (7)	176 (6)	205 (6)
2001	144 (1)	69 (8)	103 (6)	90 (8)	213 (1)	172 (7)	193 (9)
2002	56 (6)	64 (9)	74 (8)	144 (3)	120 (9)	138(10)	218 (4)
2003	61 (5)	87 (5)	143 (2)	63(12)	148 (3)	230 (2)	206 (5)
Average	60	78	96	109	138	174	205

Table 5. Pearson correlation coefficients (r) between black crappie year class strength as measured by the linear model least-square mean and monthly and multi-month combination air temperature (Temp) and rainfall (Rain) variables by lake for Blackwell, Brophy, Freeborn, and Louise lakes. Initial significant correlations are shown in bold (alpha = 0.05). Significant correlation after Bonferroni adjustment for 10 comparisons (*P* < 0.005) is indicated with an asterisk.

Lake	May Temp	June Temp	July Temp	May-June Temp	May-July Temp	June-July Temp	May Rain	June Rain	July Rain	June-July Rain
Blackwell	**-0.644**	**0.625**	0.337	-0.059	0.165	0.589	-0.213	**-0.744**	-0.150	-0.593
Brophy	0.177	0.294	0.495	0.539	**0.622**	0.495	-0.004	-0.575	-0.159	-0.484
Freeborn	-0.333	0.227	0.237	-0.132	0.069	0.282	-0.219	-0.475	-0.173	-0.432
Louise	-0.241	0.317	0.328	0.107	0.252	0.410	0.354	-0.494	-0.015	-0.336
All Lakes	-0.443	0.542	0.442	0.094	0.321	**0.609**	-0.106	**-0.783***	-0.173	**-0.635**

returns in Brophy (88%) and Louise (92%) lakes. Ice angling was more important in Blackwell Lake (34%) and particularly Freeborn Lake (66%). A further breakdown by angling season (Table 6, Figure 6) shows that early and late summer accounted for most exploitation on Brophy and Louise lakes. However, seasonal distribution of tag returns was much more consistent in Blackwell Lake, including substantial contributions from the open water panfish-only and the fall open water seasons. Black crappie tagged at lengths < 200 mm experienced lower exploitation except on Louise Lake (Figure 7). For fish > 200, mm there was little evidence to suggest that rate of exploitation increased as fish were larger. This comparison is difficult due to small sample sizes (< 20) of fish > 300 mm tagged in each lake.

Our estimates of total annual mortality (A) of black crappie ranged from 59% to 68% on Blackwell, Brophy, and Freeborn lakes (Table 7). Our estimate was considerably higher for Louise Lake (84%). However, after adjusting for emigration, we estimated A to be 58% in Brophy Lake and 65% on Louise Lake. After accounting for exploitation, natural mortality estimates were fairly similar among lakes, ranging from 30% in Brophy Lake to 43% on Blackwell and Freeborn lakes. Our comparison of mortality methods in Blackwell Lake showed both methods yielded similar results. The tag return method A was 59%, while the population estimate method A was 61%.

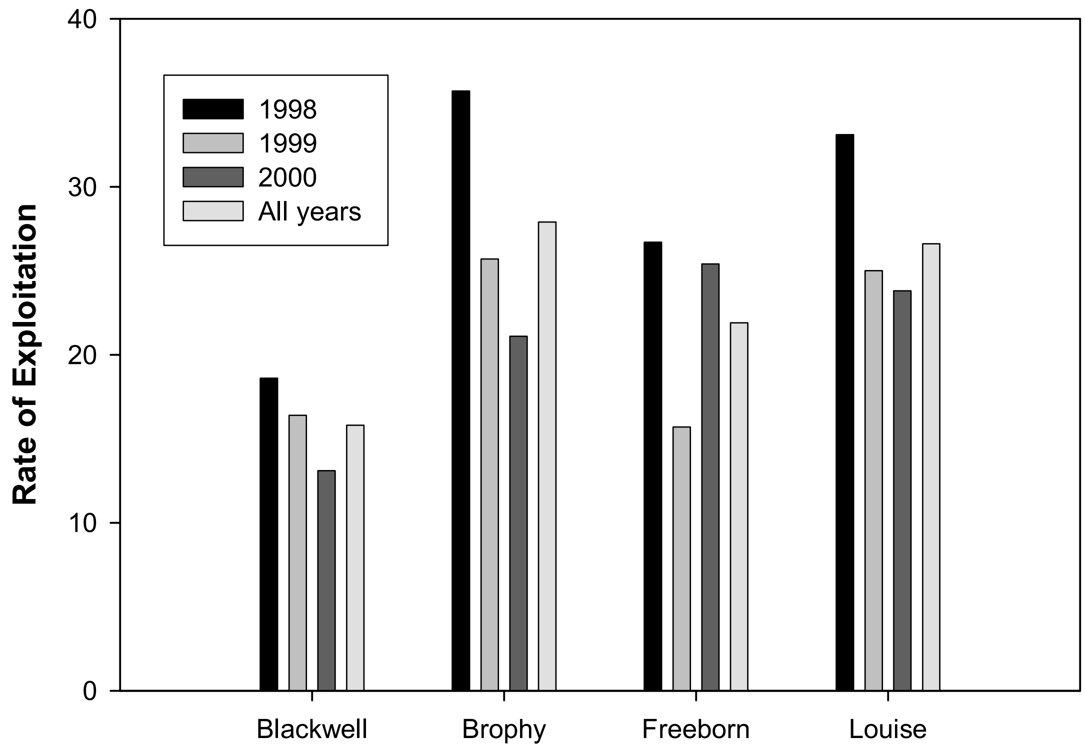

Figure 5. Annual rate of angler exploitation from the four study lakes, 1998-2000, and for all years combined, for spring and fall fish combined.

Table 6. Angling seasons used to evaluate seasonal exploitation patterns.

Fall open water	FOW	Labor day to ice (late November)
Early winter walleye	EWW	Ice formation to mid-January
Late winter walleye	LWW	Mid-January to late February
Late winter panfish	LWP	Late February to ice-out (mid-April)
Early open water panfish	EOP	Ice-out to walleye season open (mid-May)
Early open water walleye	EOW	Walleye season to July 4
Late open water walleye	LOW	July 4 to Labor Day

Table 7. Estimated rate of instantaneous mortality (Z), total annual mortality (A), total annual mortality adjusted for emigration (A(adj)), exploitation (µ) (from Figure 5), and natural mortality (v) for black crappie.

Lake	Z	A	A(adj)	µ	v
Blackwell	-0.896	0.592		0.158	0.434
Brophy	-1.151	0.684	0.581	0.279	0.302
Freeborn	-1.056	0.652		0.219	0.433
Louise	-1.851	0.843	0.649	0.266	0.383

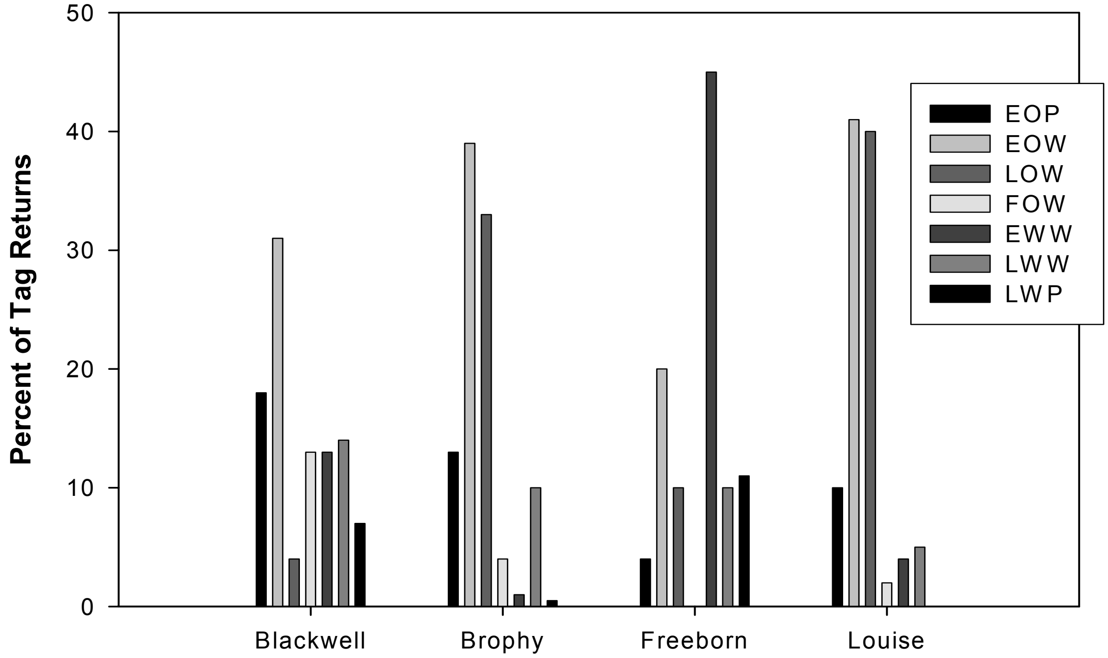

Figure 6. Percent of all angler tag returns by angling season (as defined in Table 6) for the four study lakes.

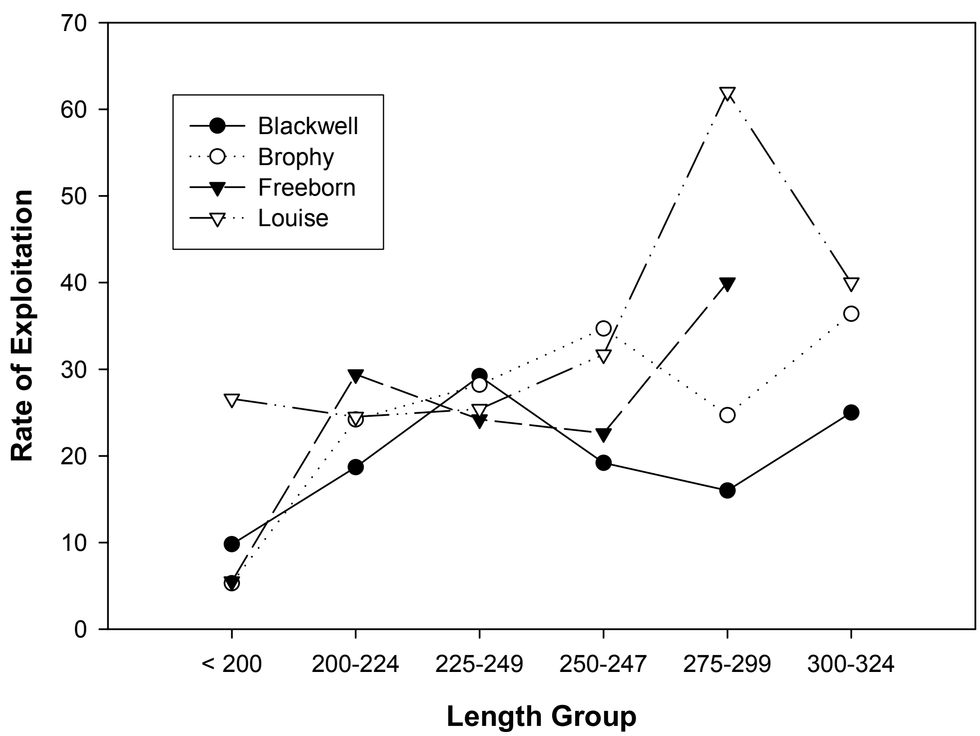

Figure 7. Estimated rate of angler exploitation adjusted for non-reporting by length group at tagging for the four study lakes.

Larval Sampling

Our larval sampling gear worked appropriately. The design of the push net apparatus allowed us to monitor for excessive zooplankton clogging because the catch buckets could be easily reached for inspection during hauls. High densities of *Daphnia pulex* in Freeborn Lake in 1998 and 2000, and *Leptodora kindti* in all years in Blackwell Lake occasionally led to shorter tow duration. Sampling speed over all tows conducted in the 4 lakes averaged 0.73 m/s, and filtering efficiency averaged 94%. Mean sampling time was just under 3 minutes, and the average net filtered 61 m^3 of water.

Black Crappie - Larval black crappie catch varied among years and lakes (Figure 8). There was no temporal similarity among lakes. For example, highest density occurred in Louise Lake in 1999, but 1999 was the lowest density year in Blackwell Lake. Although 2000 was the year of highest density in Freeborn and Blackwell lakes, density was very low in Louise Lake in 2000. There was also variability in date of peak density.

In Blackwell Lake, peak density of larval black crappie was $0.31/m^3$ in 1998 and $0.17/m^3$ in 1999, but increased to $2.61/m^3$ in 2000 (Figure 8). This led to a significant difference in peak catch among years ($H = 13.36$; $P = 0.0013$). Peak catch occurred on 26 May in 1998, 11 June in 1999, and not until 23 June in 2000 (Figure 8). A secondary peak occurred on 6 June in 2000. Analysis of the catch and lengths of fish by station clearly showed that spawning occurred about 2 weeks later in the north basin in 2000, yielding the bimodal catch by date. Each year, larval black crappie were first caught at stations in the southern basin of Blackwell Lake. Though less pronounced in 1998 and 1999, the graph of larval length over time shows a decline coinciding with hatch from the north basin (Figure 9). Mean length at peak density was rather similar among years, ranging from 7.2 mm in 1998 to 8.5 mm in 2000. Estimated number at peak density exceeded 3.2 million larvae in 2000 (Figure 10).

Catch of larval black crappie was consistently low in Brophy Lake. Peak density ranged only from $0.04/m^3$ in 1998 to $0.08/m^3$ in 1999 (Figure 8), and there was no significant difference among years ($H = 2.73$, $P = 0.2557$). Date of peak density was also consistent, ranging from 3 June in 1998 to 12 June in 2000. Mean length at peak was small each year, from 6.0 mm in 2000 to 7.8 mm in 1998 (Figure 9). Density and mean length by date suggests there may have been two separate spawning bouts in 2000 in Brophy Lake as well. Estimated total number of larvae at peak catch only ranged from 43,000-94,000 (Figure 10).

Larval black crappie catch was significantly different among years ($H = 13.38$, $P = 0.0003$) in Freeborn Lake. No larvae were caught in 1998 and only 16 larvae were caught in 1999. However, a large catch occurred in 2000 (Figure 8), yielding a peak estimate of 356,000 larvae (Figure 10). A bimodal distribution in catch was observed in 2000 with peak catch on 5 June and a secondary peak on 28 June (Figure 8). Unlike Blackwell and Brophy lakes, the second peak did not consist of small fish, presumably from a separate spawning bout, but rather larger (mean = 17.6 mm) larvae (Figure 9).

Larval black crappie density was low in 1998 and 2000 in Louise Lake (Figure 8), but higher density in 1999 lead to a significant difference among years ($H = 8.03$, $P = 0.0180$). Although the peak was very low, it did occur 14-17 days earlier in 1998 (Figure 8). Mean length at peak was very small each year (6.3-7.1 mm; Figure 9). Although only 8 were caught, larger (> 10 mm) larvae were observed in June of 1998. Estimated number of larvae at peak varied by an order of magnitude from 1998 (15,000) to 1999 (152,000) (Figure 10).

Larval black crappie density was at least partially related to year class strength in Blackwell and Freeborn lakes. In Blackwell Lake, peak larval catch was significantly higher in 2000, and the 2000 year class, while not strong, had an YCLSM of 0.95 compared to 0.56 in 1998 and 0.24 in 1999. Similarly, in Freeborn Lake, larval catch was significantly higher in 2000 and a strong year class at age 2+ (YCLSM = 0.70) did result. Larval sampling was not entirely effective in Freeborn Lake, however. We caught no larval black

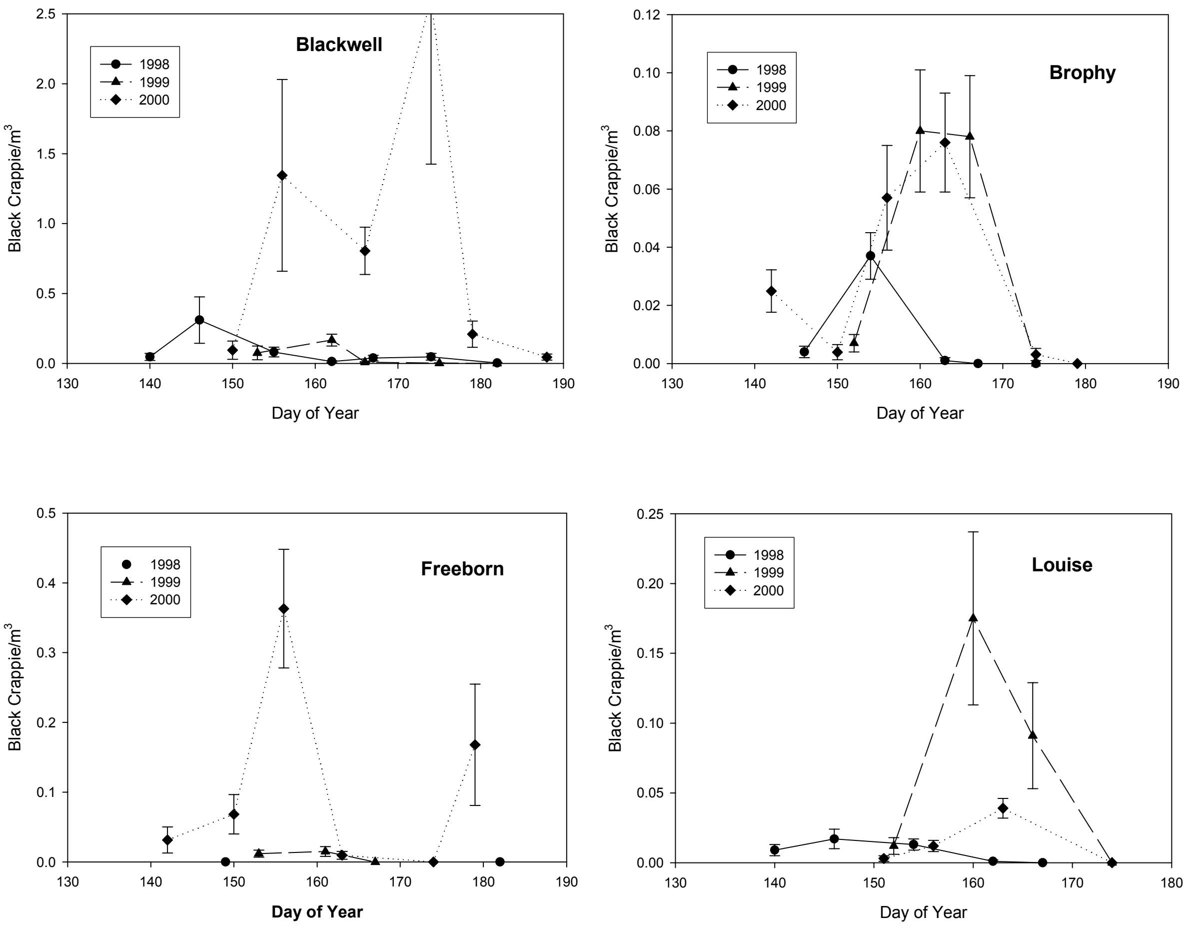

Figure 8. Mean catch (number/m^3) ± one standard error of black crappie larvae by sampling date, 1998-2000 from the four study lakes.

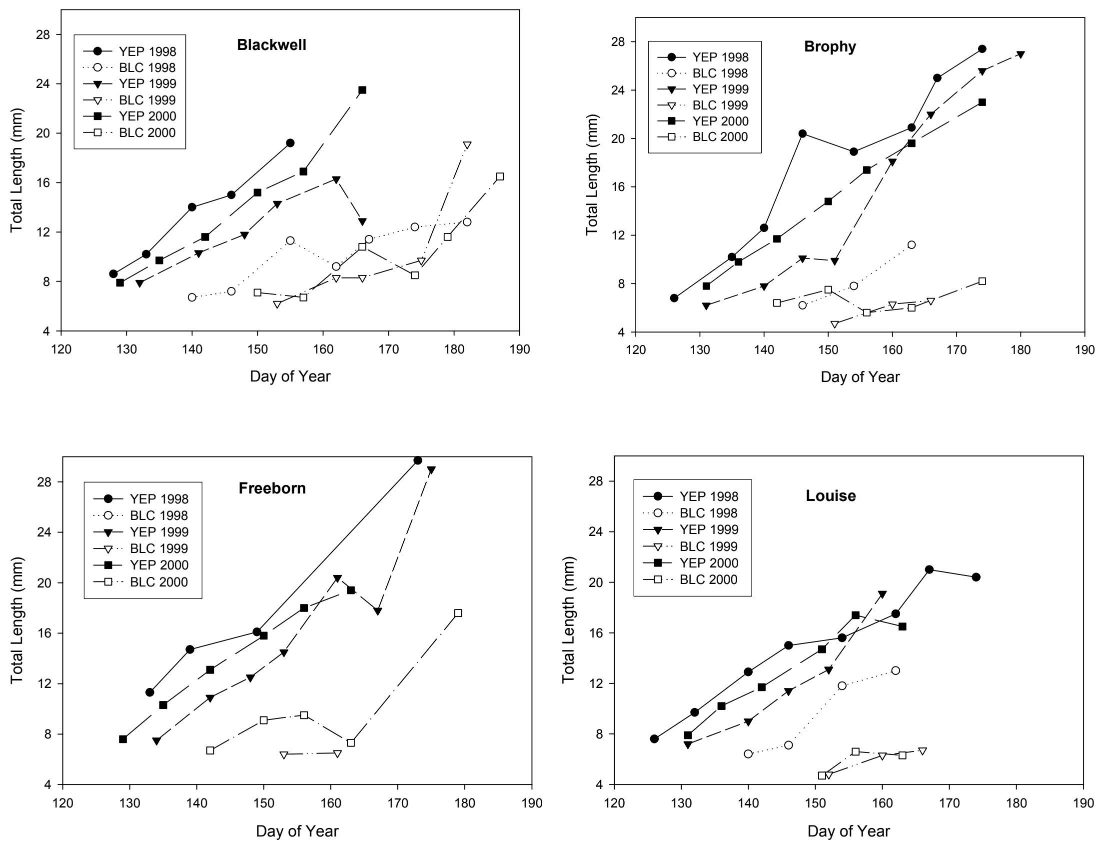

Figure 9. Mean length of larval black crappie (BLC) and yellow perch (YEP) by day of year, 1998-2000 for the four study lakes.

crappie in 1998, but a moderate year class (YCLSM = 0.50) was produced.

Conversely, larval black crappie density was not related to future year class strength on Brophy or Louise lakes. In Louise Lake, 1998 was a strong year class, but larval catch was lower than 2000, and significantly lower than 1999. A similar situation was observed on Brophy Lake. Although not significant, larval catch in 1998 was lower than the other two years, but year class strength was strong.

Yellow Perch - Larval yellow perch density varied among years and lakes (Figure 11). There was no similarity among lakes for which year had a high or low density. For example, highest density occurred in Brophy Lake in 2000, but 2000 was the lowest density year in Blackwell Lake. Similarly, 1998 was the year of highest density in Louise Lake, but lowest in Freeborn Lake. Peak density occurred in Blackwell, Brophy, and Louise lakes on the second sampling date in 1998 and 1999 and on the third sampling date in 2000, but on the third sampling date all three years in Freeborn Lake.

In Blackwell Lake, peak density of larval yellow perch was much higher in 1998 and 1999 than in 2000 (H = 19.38; P = 0.0001) (Figure 11). Peak density occurred about 1 week earlier in 1998 than in other years. Mean length at peak density was similar between 1998 and 1999 (10.2 mm and 10.3 mm), but larger (11.6 mm) in 2000 (Figure 9).

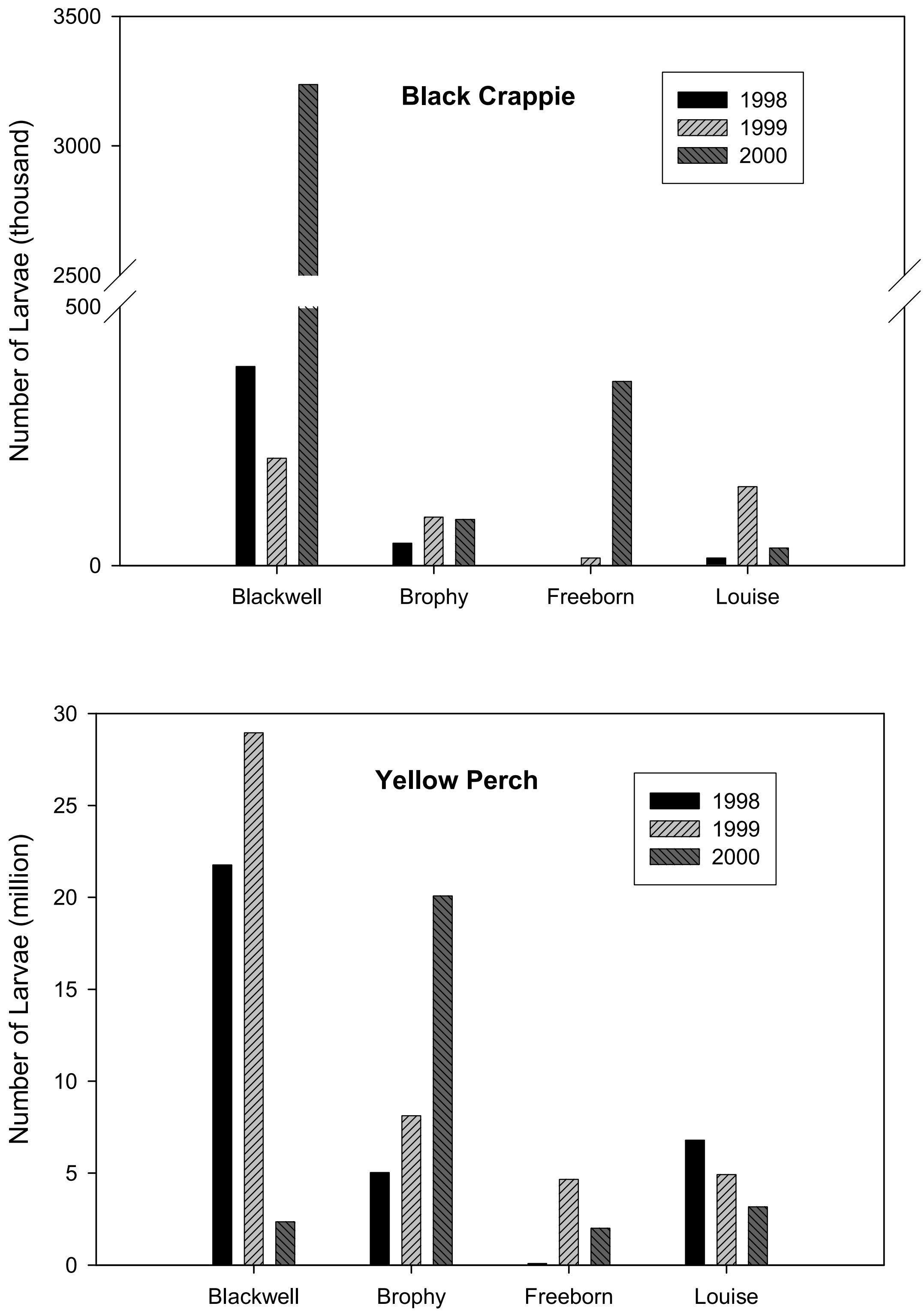

Figure 10. Estimated number of larval black crappie and yellow perch in the study lakes on day of peak catch in 1998-2000 for the four study lakes.

Estimated number of perch larvae exceeded 20 million in 1998 and reached nearly 30 million in 1999, but was just over 2 million in 2000 (Figure 10). Daily growth rate may have been related to density of larval yellow perch, ranging from 0.39 mm/day in 1998 to 0.28 mm/day in 1999, and increasing to 0.42 mm/day in 2000 (Figure 9).

In Brophy Lake, peak density differed significantly among years (H = 9.32, P = 0.0095), reaching 17.2/m^3 in 2000 (Figure 11). Date of peak density was consistent, ranging only from 15 May in 1998 to 22 May in 2000. Mean length at peak density did vary considerably among years, ranging from only 7.8 mm in 1999 to 11.7 mm in 2000 (Figure 9). Estimated number of larvae at peak also varied greatly, from 5 million in 1998 to 20 million in 2000 (Figure 10). Daily growth of yellow perch larvae was 0.43 and 0.42 mm/day in 1998 and 1999 and 0.35 mm/day in 2000 (Figure 9).

In Freeborn Lake, density of larval yellow perch was very low in 1998, but higher in 1999 and 2000 (Figure 11) (H = 21.84, $P <$ 0.0001). Date of peak density was consistently later than the other study lakes, and ranged from 19 May in 1998 to 28 May in 1999. Mean length at peak was larger than the other study lakes, ranging from 12.5 mm in 1999 to 14.7 mm in 1998 (Figure 9). Estimated number of larvae at peak did not exceed 5 million in any year (Figure 10). Growth of catch and larval catch of black crappie (Figure 13). The extremely high larval catch in Blackwell Lake in 2000 was reflected in a higher purse seine catch, but this was not the case in the other lakes. Larval catch was highest in Freeborn Lake in 2000, but purse seine catch, while very high in 2000, was still higher in 1999. In Brophy and Louise lakes, larval catch was highest in 1999, but purse seine catch was highest in 2000. Conversely, 1998 was the strongest black crappie year class in these lakes.

Purse seine catch of age-0 yellow perch was generally very low across all years and lakes (Table 8). Only Brophy and Louise lakes had high catches, both in 1998, but these were heavily influenced by one haul, leading to high standard errors. The high catch in yellow perch larvae was generally faster but more variable in Freeborn Lake (0.46, 0.52, 0.35 mm/day in 1998, 1999, and 2000, respectively; Figure 9).

In Louise Lake, peak density ranged from 3.6/m^3 in 2000 to 7.8/m^3 in 1998 (Figure 11) but did not differ significantly among years (H = 4.76, P = 0.0927). Date of peak density was consistent between 12 and 22 May, and, as in Brophy Lake, mean length at peak was smaller in 1998 (9.7 mm) and 1999 (9.0 mm) than in 2000 (11.7 mm) (Figure 9). There was little variation in peak abundance between years, with estimates ranging from 3.2 million in 2000 to 6.8 million in 1998 (Figure 10). Daily growth rates were 0.33, 0.41, 0.38 mm/day in 1998-2000, respectively (Figure 9).

With data from all four lakes combined, we found a relatively weak but significant correlation between peak estimated number of yellow perch larvae and daily larval growth (Figure 12) (r^2 = 0.28, P = 0.0435). One zooplankton variable, mean June density of small cladocerans, significantly improved the relationship (adjusted r^2 = 0.59, P = 0.0073).

Juvenile Sampling

Purse seine catch of age-0 black crappie was highest in 2000 in each lake except Freeborn (Table 8). However, there was not a consistent relationship between purse seine 1998 in Louise Lake did coincide with the highest larval catch, but this was not the case for Brophy Lake. Also, larval yellow perch catch was 12-15 times higher in Blackwell Lake in 1998 and 1999 than in 2000, but purse seine catch was very low each year.

Age-0 black crappie and yellow perch ate a wide variety of diet items in late summer, and there was overlap in these items (Appendix 1). However, consistent differences were noted. Black crappie consistently ate *Chaoborus* spp. in all four lakes and fish in Freeborn and Brophy lakes, while yellow perch did not. Schoener's diet overlap index was generally between 0.4 and 0.6 in all lakes and years, with four notable exceptions (Figure 14). Diet overlap was nearly complete in Blackwell Lake in 1999 as both species ate

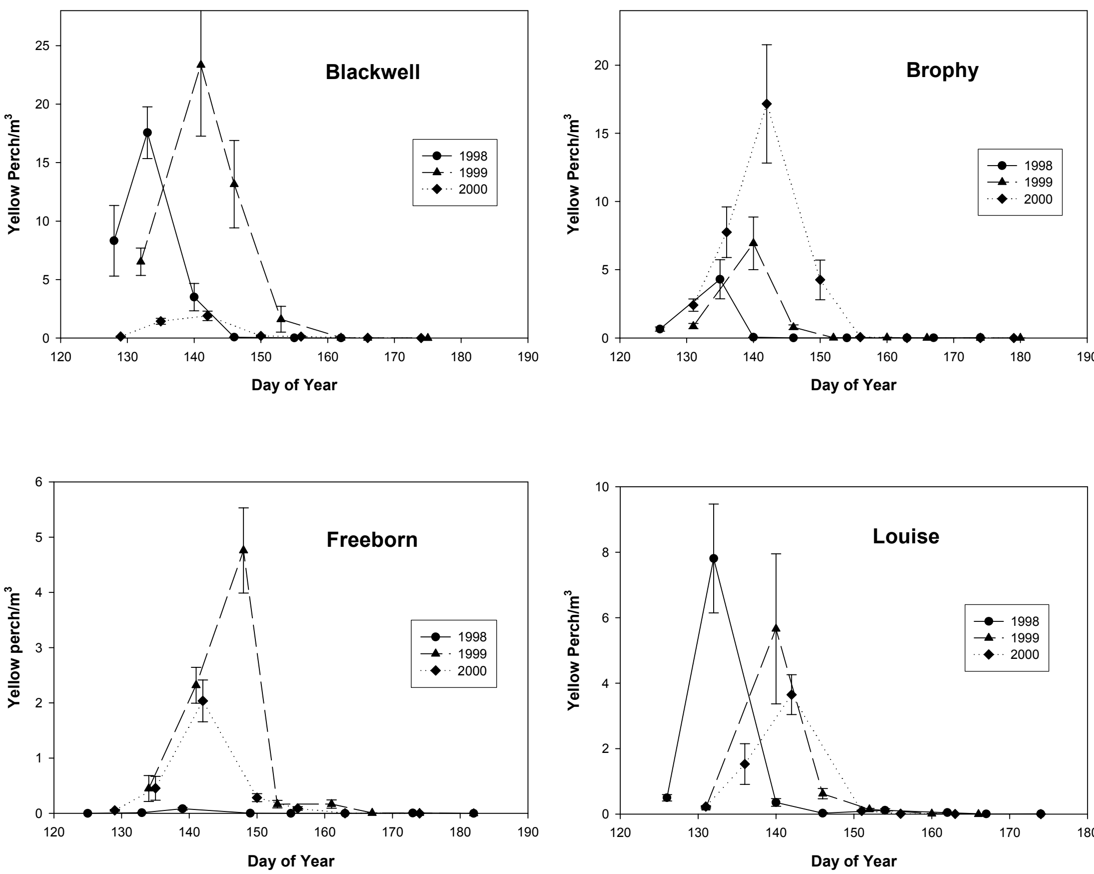

Figure 11. Mean catch (number/m^3) $\pm$ one standard error of yellow perch larvae by sampling date, 1998-2000 for the four study lakes.

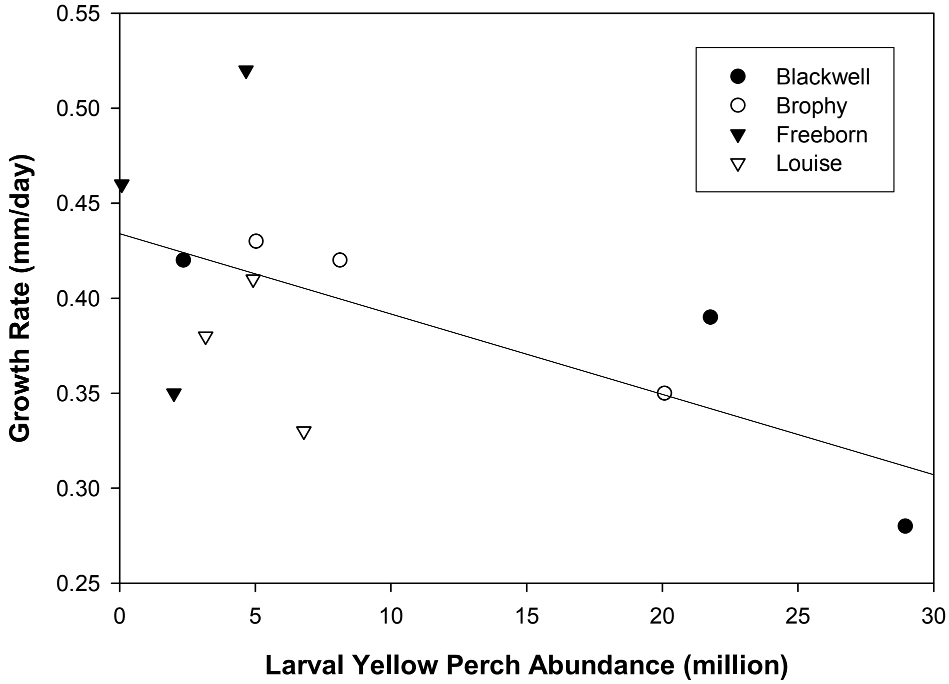

Figure 12. Relationship between abundance (millions) and growth rate (mm/day) of larval yellow perch in the four study lakes, combined. The regression line is shown (r^2 = 0.28, P = 0.0435).

Table 8. Mean purse seine catch and standard error of age-0 black crappie and yellow perch for all sampling periods combined on Blackwell, Brophy, Freeborn, and Louise lakes, 1998-2000. Mean length (mm) is from the final sample that fish were caught.

	Black Crappie			Yellow Perch		
Lake and Year	Mean	SE	mm	Mean	SE	mm
Blackwell 1998	0.8	0.6	46	1.7	1.3	64
Blackwell 1999	1.2	0.6	52	1.4	1.0	58
Blackwell 2000	9.7	4.1	47	1.5	1.1	60
Brophy 1998	3.2	1.0	60	32.4	28.3	57
Brophy 1999	0.6	0.4	59	4.8	2.0	49
Brophy 2000	7.6	2.6	48	2.5	0.9	57
Freeborn 1998	1.1	0.3	89	0.4	0.2	78
Freeborn 1999	38.8	13.3	52	2.1	0.8	47
Freeborn 2000	29.2	10.9	63	1.3	0.5	62
Louise 1998	6.7	4.0	56	47.6	28.3	55
Louise 1999	6.2	3.1	49	5.6	3.1	59
Louise 2000	10.2	6.2	54	9.7	7.3	56

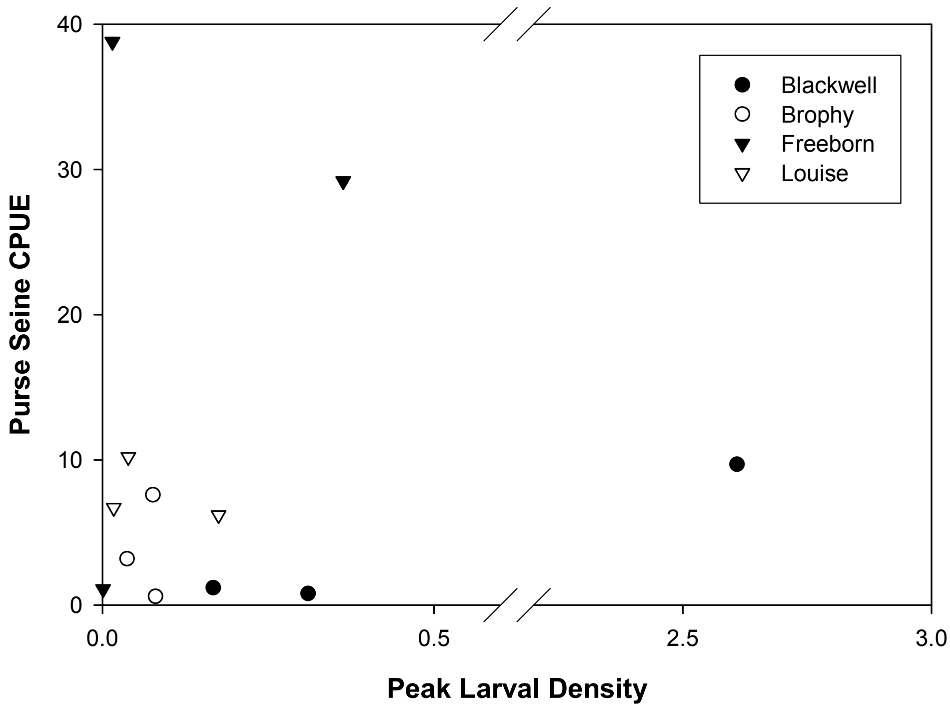

Figure 13. Plot of peak larval density (number/m^3) and mean purse seine CPUE (number/haul) by study lake, 1998-2000.

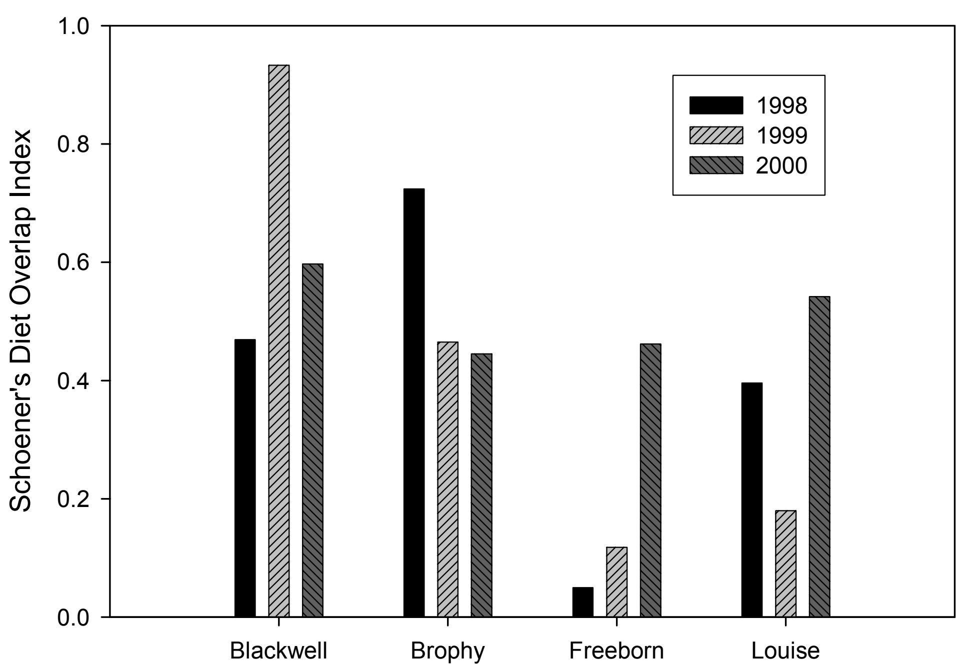

Figure 14. Schoener's diet overlap index in late summer between age-0 black crappie and yellow perch, 1998-2000 for the four study lakes.

almost exclusively Calanoid copepods. Conversely, overlap was very low (<0.2) in Freeborn Lake in 1998 and 1999. Yellow perch sample size was very low in 1998 (4), and those fish ate *Daphnia* spp. and *Leptodora kindti*. Black crappie ate age-0 bluegill, some cyclopoid copepods, and small cladocerans. In 1999 in Freeborn Lake, black crappie ate mostly Calanoid and Cyclopoid copepods and *Chaoborus* spp., while yellow perch ate *Daphnia* spp. and small cladocerans. The very low index in Louise Lake in 1999 was due to a black crappie diet dominated by copepods, while yellow perch diet was dominated by *Daphnia* spp.

Adult yellow perch

Lake surveys indicated very low adult yellow perch abundance in three of the four lakes (Tables 9-12). Only Freeborn Lake had a gill net catch above the first quartile for its lake class when surveyed in 1999 and 2004. We also caught 382 yellow perch in spring 1999 in Freeborn Lake (Table 13), most of which appeared to be from the 1995 year class. Catch was much lower in 2000-2001, apparently due to poor recruitment of the 1996-1998 year classes. Catch increased somewhat in 2002 and more so in 2003, as the 1999 and especially 2000 year classes recruited. These results do correspond with peak larval catch, which was significantly higher in 1999 and 2000 than in 1998.

Adult yellow perch catch was low in Blackwell Lake in 1999 and 2000, and fell to virtually nothing in 2001-2003 (Table 13). Evaluating the length distributions suggests that the 1996 year class was the last to produce an appreciable number of recruits. This is in spite of very high larval catch in 1998 and 1999. No fish > 190 mm were caught in any gear. The extremely low abundance of yellow perch > 120 mm was confirmed by the summer gill net and trap net surveys in 1999 and 2004, neither of which caught any yellow perch (Table 9).

Yellow perch catch was low but consistent in spring trap nets in Brophy Lake from 1999-2002, ranging from 36 to 43 fish (Table 13). Length frequencies further suggest that recruitment to age-3 was consistent for the 1996-1999 year classes. The 2000 year class appeared to be less abundant. These results conflict with larval catch, which was significantly higher in 2000. Fish > 200 mm, while rare, were caught each year.

Adult yellow perch catch was highest in 2000 in Louise Lake, but fell to very low levels in 2001-2003 (Table 13). The length frequencies indicate very little recruitment to age-3 since the 1997 year class. This is despite consistently high larval catches in 1998-2000. Summer lake surveys conducted in 1996 and 2002 support these results (Table 12). Yellow perch gill net CPUE was 5.8/net in 1996, but 0 in 2002. Louise Lake was unique in the presence of large yellow perch as fish > 270 mm were caught in 4 of the 5 spring samples.

Zooplankton and Larval Diets

The study lakes generally showed the classic seasonal zooplankton density pattern. High numbers were found in early May followed by a rapid decline to lows in late June, with a slight rebound in late summer. There was considerable annual and among lake variability in the zooplankton populations. In all four lakes, abundance in the first sample of the year was highest in 1998, which had the warmest April and May during the 1992-2003 period (Table 3).

In Blackwell Lake, the peak early May abundance in 1998 (Figure 15) was due to high numbers (>200/l) of the small cladoceran *Bosmina longirostrus*. Early copepod densities were also highest in 1998. Only *Daphnia galeata* were more abundant in a different year (2000). We observed a slight late summer increase in *Daphnia* in 1998 and 2000 caused by *Daphnia retrocurva*. The decline in small cladocerans and copepods occurred between samples 2 and 4 in 1998, corresponding with the peak density of 22 million larval yellow perch. A similar pattern occurred with copepods in 1999 corresponding with nearly 30 million larval yellow perch. *Daphnia galeata* were more abundant early in 2000, the year of highest larval crappie density, but peak abundance of larval black crappie occurred at sample 7, when *Daphnia galeata* densities were similar to prior years.

Table 9. Gill and trap net catch per unit effort (number/net-night) from lake surveys on Blackwell Lake. Effort was six gill and nine trap nets each year.

Species	1999 Gill	1999 Trap	2004 Gill	2004 Trap
Northern Pike	5.7	0.3	3.5	0.2
Common Carp	0.8	0.3	0	0.2
White Sucker	0.3	0.1	0	0
Black Bullhead	12.3	0.3	18.3	0.3
Yellow Bullhead	0.7	2.9	0.2	3.0
Brown Bullhead	0	0.1	0.2	0.3
Hybrid Sunfish	0	0.3	0	0.1
Green Sunfish	0	0.1	0	0
Pumpkinseed	0	0.9	0.2	0.6
Bluegill	2.7	42.1	9.8	25.8
Largemouth Bass	2.5	0.6	1.2	1.2
Black Crappie	3.7	5.3	1	1.1
Yellow Perch	0	0	0	0
Walleye	1.5	0	3.8	0.7

Table 10. Gill and trap net catch per unit effort (number/net-night) from lake surveys on Brophy Lake. Effort was six gill and nine trap nets each year.

Species	1997 Gill	1997 Trap	2002 Gill	2002 Trap
Bowfin	0	0.7	0	0.6
Tulibee	1.7	0	0.2	0
Northern Pike	14.2	0.4	11.2	1.1
White Sucker	0.5	0	1.7	0.1
Black Bullhead	2.3	0.2	2.5	0
Yellow Bullhead	10.5	2.7	30.7	5.3
Brown Bullhead	0	0.2	1.8	0.1
Rock Bass	0	0	0.3	0.1
Hybrid Sunfish	0	1.7	0	1.2
Green Sunfish	0	0	0	0.1
Pumpkinseed	1.0	0.7	2.5	7.3
Bluegill	0.2	7.0	11.5	21.0
Largemouth Bass	0.3	0.6	1.7	0.1
Black Crappie	0	1.0	0.2	0.6
Yellow Perch	0.7	0	0	0.4
Walleye	3.0	0.4	3.0	1.0

Table 11. Gill and trap net catch per unit effort (number/net-night) from lake surveys on Freeborn Lake. Effort was six gill and nine trap nets each year.

Species	1999 Gill	1999 Trap	2004 Gill	2004 Trap
Northern Pike	8.2	1.8	6.3	3.3
White Sucker	0	0	0.2	0
Black Bullhead	2.8	0.4	6.7	0.9
Yellow Bullhead	6.2	0	15.8	13.0
Brown Bullhead	0.5	0	0.7	0
Pumpkinseed	1.0	3.8	0	0.2
Bluegill	1.3	14.8	0.5	5.8
Largemouth Bass	0.5	0.2	0	0.3
Black Crappie	0.8	3.3	1.3	0.3
Yellow Perch	4.8	0.6	12.0	0.2
Walleye	13.8	0.7	4.2	0.7

Table 12. Gill and trap net catch per unit effort (number/net-night) from lake surveys on Louise Lake. Effort was six gill and nine trap nets in 2002 and six gill and six trap nets in 1996.

Species	1996 Gill	1996 Trap	2002 Gill	2002 Trap
Bowfin	0.7	0.7	0.2	0.8
Tulibee	5.2	0	1.2	0
Northern Pike	15.5	0.6	25.2	0.7
White Sucker	4.5	0.4	1.7	0.1
Black Bullhead	8.2	0.2	0.8	0
Yellow Bullhead	2.0	1.0	8.2	2.0
Brown Bullhead	2.0	2.0	0.7	0.1
Rock Bass	0	0.2	0	2.3
Hybrid Sunfish	0	1.1	0	1.8
Pumpkinseed	0.3	2.7	0.3	5.9
Bluegill	1.5	41.4	1.8	32.7
Largemouth Bass	0.2	0.6	0.2	0.4
Black Crappie	0.7	0.1	0.3	0.3
Yellow Perch	5.8	0.1	0	0.1
Walleye	2.2	0.6	0.8	0.1

Table 13. Length distribution (cm group) of yellow perch caught in spring trap nets in the four study lakes 1999-2003.

Year	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27+
Blackwell																					
1999			3	5	5	8	2			1											
2000			1	2	7	10	11	6	1	3											
2001				1			4	1		1		1									
2002					1																
2003						1	2			1											
Brophy																					
1999			2	7	9	5	4	3	3	3	4	1							1	1	
2000				1	1	9	5	9	4	5	1	2	1	1							
2001					2	6	7	8	2	5	1	2		2	1						
2002				1	1	1	8	13	4	2	2	2	2		3	1	1				
2003				2	1	4	5	1	1		1	1			1						
Freeborn																					
1999		2	2	2	6	26	62	98	91	33	28	18	7	3	3	1					
2000			1	1	5	23	52	33	15	7	5	6	7	5	3	2	4			1	
2001	1		1	7	31	18	4	4	6	3	2										
2002	1			3	34	65	17	10	24	9	4	6	4								
2003			15	80	49	33	36	7	4	2	1			2							
Louise																					
1999		1	5	4	1		2	2		1		1	1	1	2					1	1
2000		1		2	7	5	9	5	6	3	4	1		2	2	2				1	2
2001							2	1	1		2							1			
2002					2	1	3	2	3	1		2						1			2
2003				1	1	3	6					1	1								1

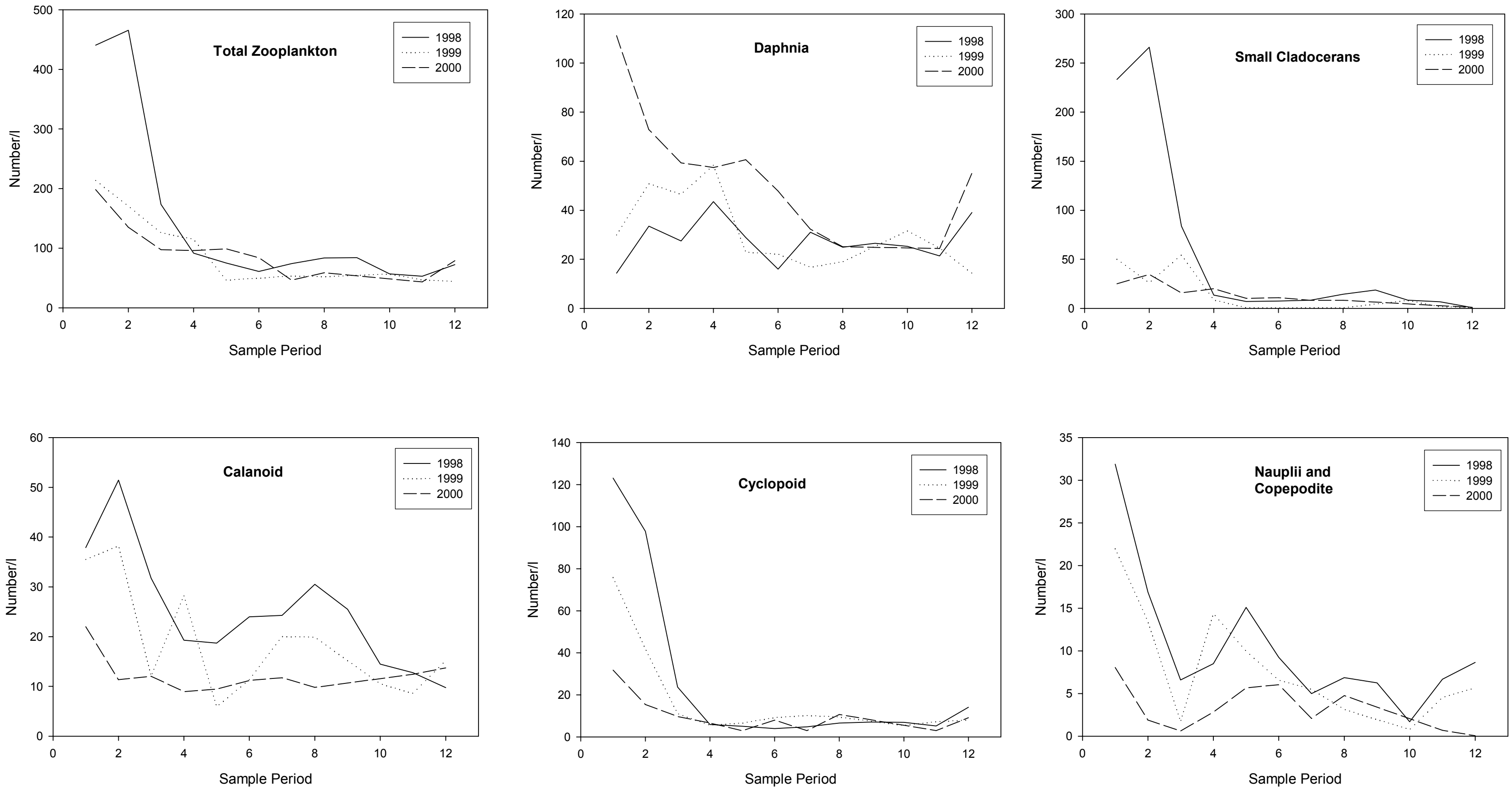

Figure 15. Densities (number/l) of all zooplankton and zooplankton groups by sample period for Blackwell Lake, 1998-2000. Sample periods correspond to larval and purse seine sample dates. Samples 1-4 are May, 5-8 are June, 9 is early July (1998 only), 10 is early August, 11 is late August, and 12 is mid-September.

In Brophy Lake, the peak early May abundance in 1998 was due primarily to copepod densities (Figure 16). While peak numbers of *Daphnia galeata* were highest in May of 1998, they also fell to very low levels by the end of June 1998. However, *Daphnia retrocurva* densities exceeded 40/l in August 1998, unlike 1999 and 2000. Both black crappie and yellow perch preyed heavily on *Daphnia retrocurva* in late August of 1998 (Appendix 1B).

Zooplankton dynamics were unique in Freeborn Lake (Figure 17). The highest total zooplankton density we observed occurred in early August 1998, and was due primarily to a huge pulse in small cladocerans. While *Bosmina longirostrus* accounted for the bulk of this peak (154/l), *Chydorus sphaericus* (24/l) and *Diphanasoma birgei* (19/l) were also present in levels not found in any other sample in any lake or year. Densities of copepods were also higher in August 1998 than other years. Diets of age-0 black crappie and yellow perch did not reflect these unusually high densities (Appendix 1C). Although sample size was small, due to low recruitment of both species in 1998, samples from 26 August 1998 showed black crappie ate fish (primarily larval *Lepomis* spp.), Trichoptera, and some *Chydorus sphaericus*, while yellow perch ate primarily *Leptodora kindti*.

Daphnia dynamics were also unique in Freeborn Lake. In the other three lakes, May *Daphnia* were almost exclusively *Daphnia galeata*. In Freeborn Lake, the *Daphnia* community was dominated by *Daphnia pulex* in 1998 and 2000, and *Daphnia galeata* in 1999. The *Daphnia pulex* population also remained stable or increased in numbers in late June in 1998 and 2000 in Freeborn Lake, while all other lakes and years, *Daphnia* spp. declined in June. Also unlike the other three lakes, no late summer *Daphnia* spp. pulse occurred in Freeborn Lake.

In Louise Lake, zooplankton dynamics were generally consistent among years. The peak May density in 1998 was due to a pulse of *Bosmina longirostrus* and higher numbers of cyclopoid copepods (Figure 18). The late summer increase was also consistent among years and was due to *Daphnia retrocurva*.

Black crappie larvae < 10 mm long ate almost exclusively nauplii and rotifers in all four lakes (Table 14). Four calanoid copepods in Blackwell Lake and three *Bosmina longirostrus* in Louise Lake were also eaten by small black crappie. In contrast, larger black crappie larvae (10-14.6 mm) ate a variety of zooplankton (Table 14). Over one-half (51%) of the diet items in these fish in Blackwell Lake were calanoid copepods, followed by *Diphanasoma birgei* (22%), *Bosmina longirostrus* (11%), and nauplii (10%). In Louise Lake, however, 44% of the diet items were *Daphnia galeata*, followed by calanoid copepods (28%), *Chydorus sphaericus* (22%) and *Bosmina longirostrus* (6%). Diets of the largest black crappie larvae (>15 mm) were relatively simple, consisting of calanoid copepods and *Diphanasoma birgei* in Blackwell Lake, and *Daphnia pulex* and calanoid copepods in Freeborn Lake.

We only have diet data for small (< 12 mm) yellow perch from Blackwell Lake (Table 14), and they ate the same items, nauplii (75%) and calanoid copepods (24%), as small black crappie larvae. Although their diets were similar, they were separated in time. Small yellow perch were caught on 8 and 13 May 1998, while the small black crappie were caught from 26 May to 23 June 1998. Diets of larger yellow perch larvae were generally similar among lakes, with *Daphnia galeata* and calanoid copepods dominating. *Bosmina longirostrus* were generally the third most frequent diet item, but in Blackwell Lake they were about equal in number to *Daphnia galeata* and calanoid copepods.

Because larval logperch *Percina caprodes* were the most common larvae caught with black crappie, we also examined a small subsample of stomachs for their diets (Table 14). As with black crappie, calanoid copepods were an important item (20-38%), except in Louise Lake (5%). In Freeborn Lake, 54% of diet items were *Daphnia pulex*, while *Bosmina longirostrus* were over half the diet items in Blackwell (57%) and Louise (59%) lakes. Although sample size was small, *Chydorus sphaericus* (38%) were an important item for logperch in Brophy Lake.

Since sufficient sample sizes for large black crappie, large yellow perch, and log

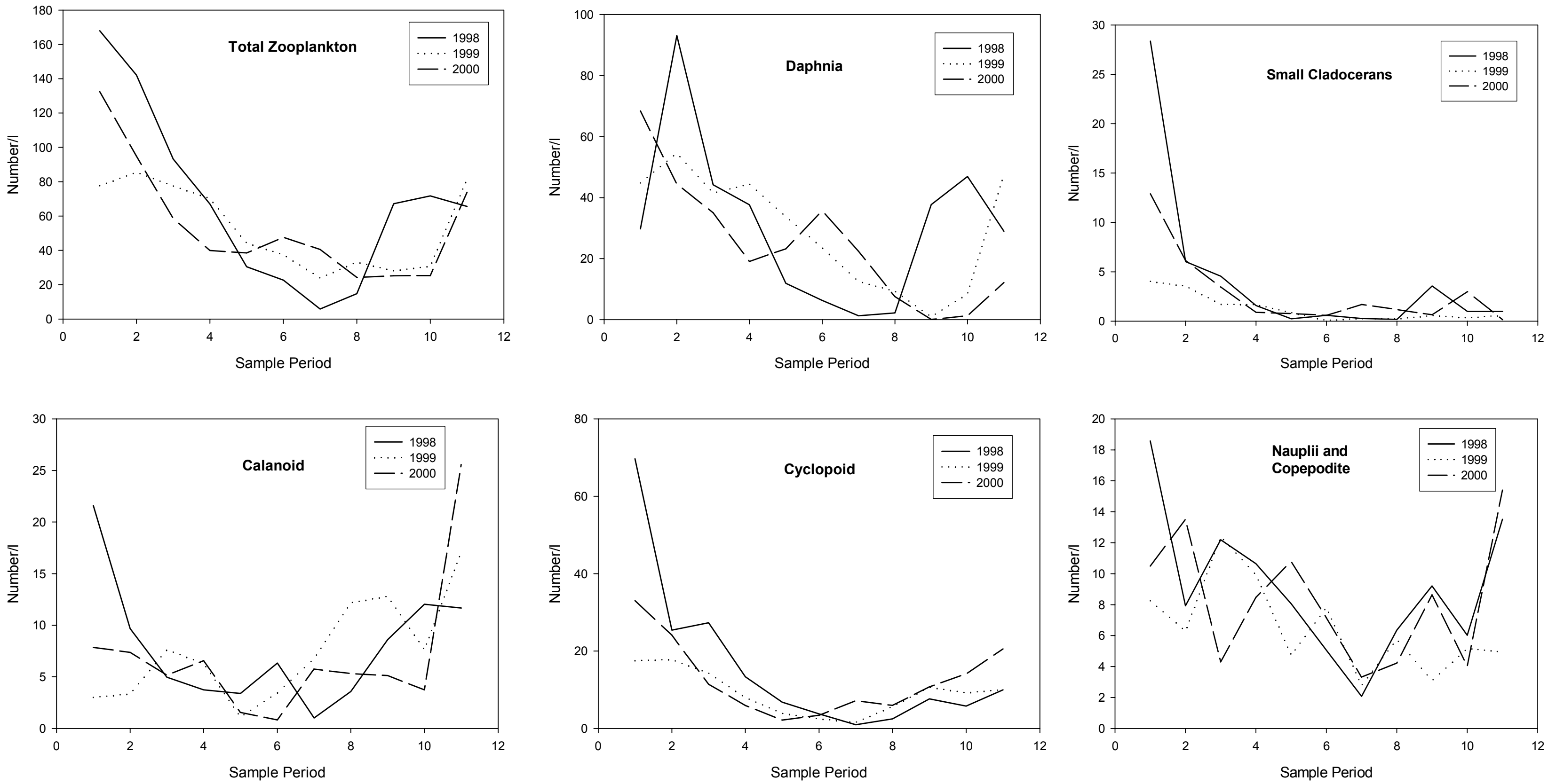

Figure 16. Densities (number/l) of all zooplankton and zooplankton groups by sample period for Brophy Lake, 1998-2000. Sample periods correspond to larval and purse seine sample dates. Samples 1-4 are May, 5-8 are June, 9 is early August, 10 is late August, and 11 is mid-September.

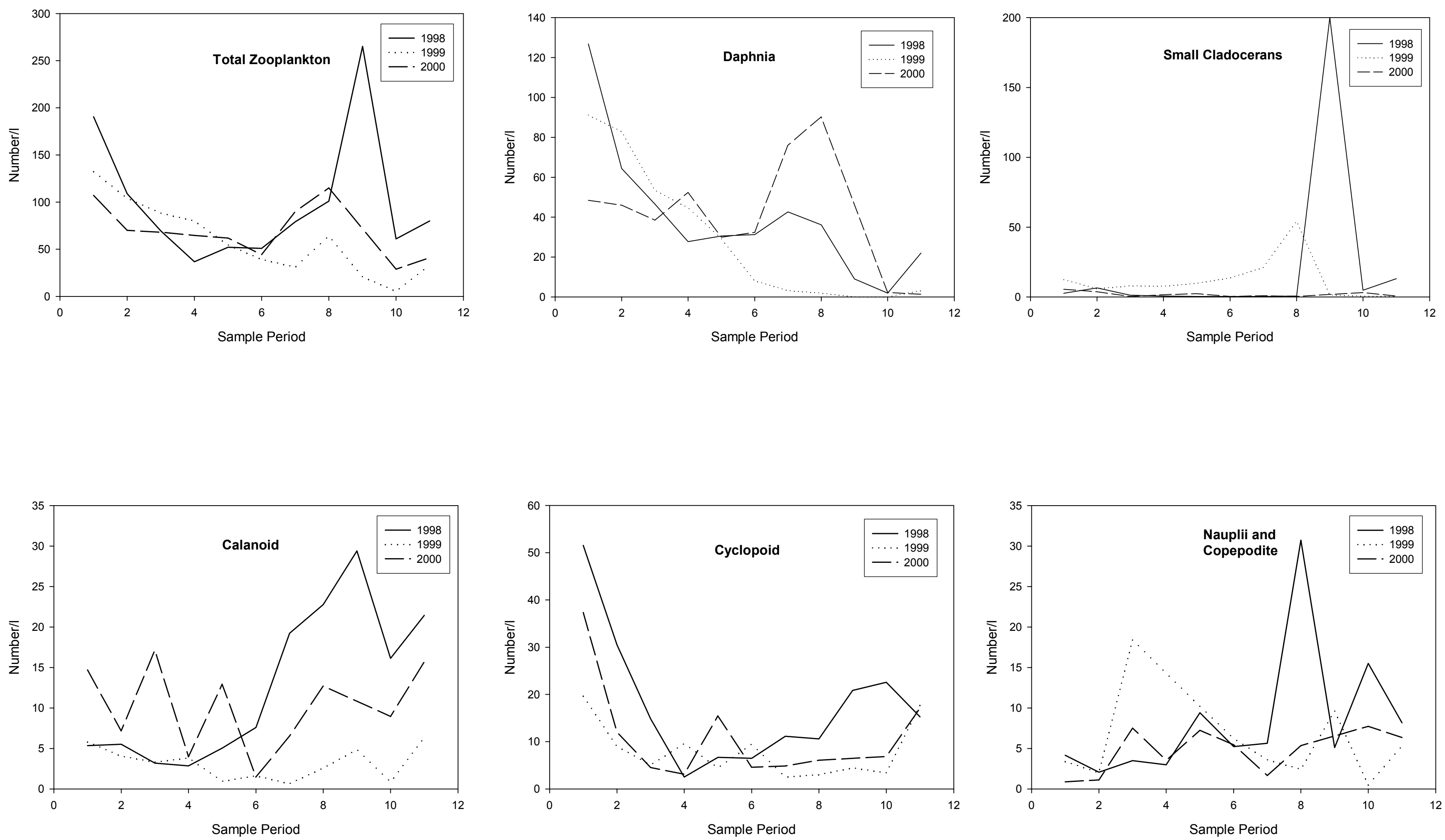

Figure17. Densities (number/l) of all zooplankton and zooplankton groups by sample period for Freeborn Lake, 1998-2000. Sample periods correspond to larval and purse seine sample dates. Samples 1-4 are May, 5-8 are June, 9 is early August, 10 is late August, and 11 is mid-September.

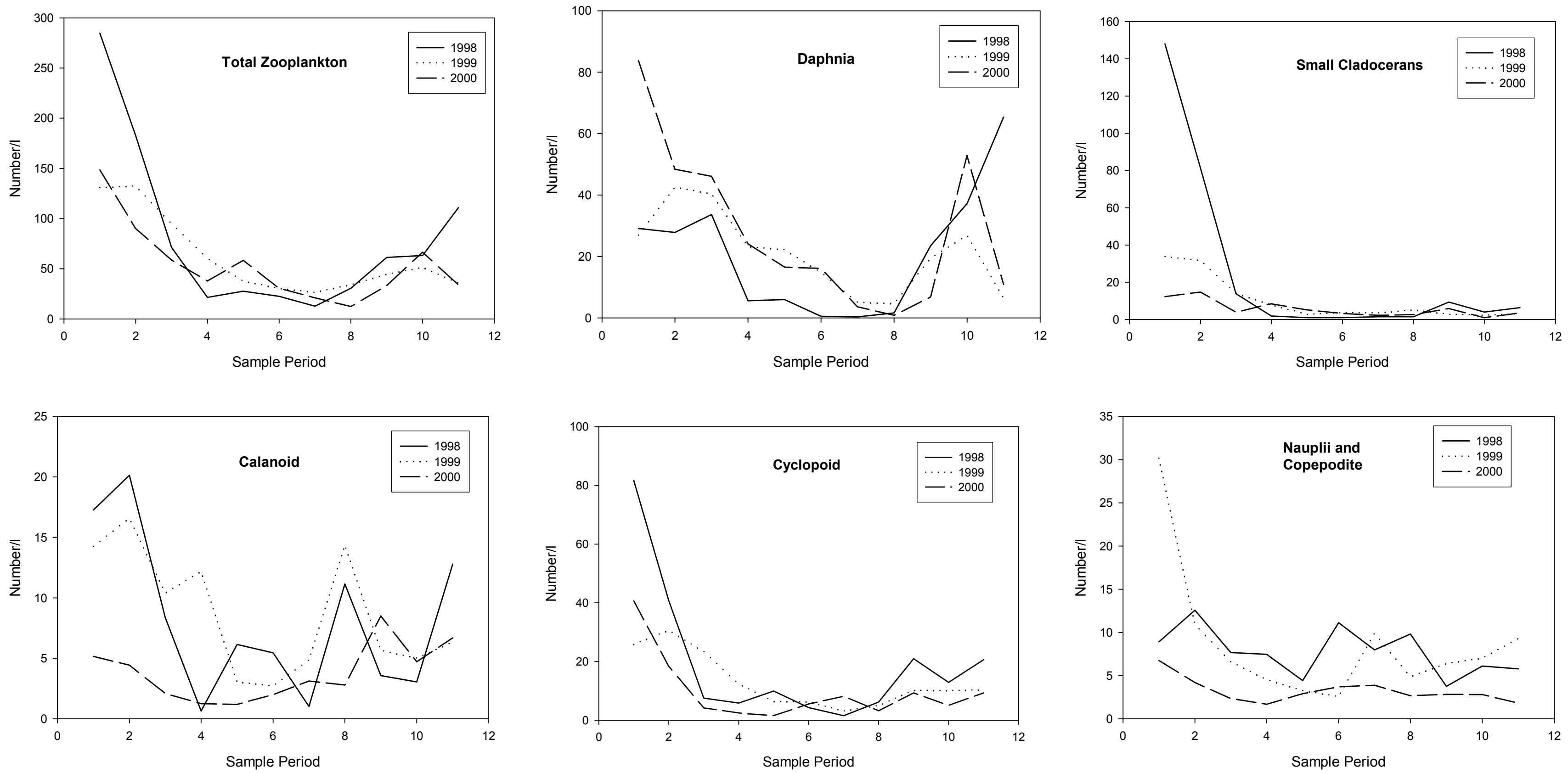

Figure 18. Densities (number/l) of all zooplankton and zooplankton groups by sample period for Louise Lake, 1998-2000. Sample periods correspond to larval and purse seine sample dates. Samples 1-4 are May, 5-8 are June, 9 is early August, 10 is late August, and 11 is mid-September.

Table 14. Total number of diet items, and number in each taxonomic group, by length group (mm) of fish examined for larval black crappie (BLC), yellow perch (YEP) and logperch (LOG) from Blackwell, Brophy, and Louise lakes, 1998, and Freeborn Lake 1998-2000. Number of fish stomachs examined and number empty are also reported.

Species	Length	Stomachs	Empty	Total	Cyclopoid	Calanoid	Nauplii	D galeata	D pulex	Bosmina	Diphanasoma	Chydorus	Leptodora	Other
Blackwell														
BLC	5.4-9.5	23	14	22		4	18							
BLC	10.1-14.1	30	4	163	5	83	17	3		18	36	1		
BLC	15.3-18.4	14		144		108				4	32			
YEP	8.9-11.6	10		51		12	38				1			
YEP	12.1-14.8	11	1	46		21	2	3		14	5		1	
YEP	15.0-22.5	5		73		14		28		24	6	1		
LOG	10.2-14.1	18	1	104		21		5		59	11	7		1 chiro
Brophy														
BLC	5.7-9.0	9	4	16			13							3 rotifer
BLC	11.3-13.8	2		8				5		1				2 rotifer
YEP	17.6-22.6	4		100		26		70		4				
YEP	27.1-30.1	3		295		105		178				4	8	
LOG	10.6-13.5	4	2	16		6		2		2		6		
Freeborn														
BLC	5.8-7.6	4		18			18							
BLC	15.7-25.9	6		140		48			92					
YEP	14.5-17.1	15		118		36		47	12	13	3	7		
LOG	7.8-17.3	12		61		16	2	1	29	5		6		2 chiro
Louise														
BLC	5.6-7.5	7		16			7			3				6 rotifer
BLC	10.8-14.6	5		50		14		22		3		11		
YEP	15.5-24.0	6		22		24	5	44		3		4	1	
LOG	9.8-17.9	15	1	288		15		72		170		31		

perch larvae were available on Blackwell Lake, we computed Shoener's diet overlap index. There was a moderate diet overlap between large larval black crappie, and both logperch (0.38) and yellow perch (0.47). Primary differences were that black crappie consumed a higher proportion of calanoid copepods and *Diphanasoma birgei* than the other two species, while logperch consumed a higher proportion of *Bosmina longirostrus* and yellow perch consumed a higher proportion of *Daphnia galeata* and *Bosmina longirostrus*. Somewhat higher overlap was found between logperch and large larval yellow perch (0.68).

Discussion

Weather has been shown to affect crappie year class strength (McDonough and Buchanan 1991; McInerny and Degan 1991; Mitzner 1991). In our study, the 1992 year class was consistently absent in all four lakes, and 1993 was very weak except in Louise Lake. Both years had a very cold, wet June; July was also extremely cold in 1992, nearly 4° F colder than the second coldest July, which was 1993. Apparently, very adverse weather conditions in early summer can suppress black crappie recruitment. This phenomenon has also been noted for walleye (Schupp 2002) and bluegill (Reed and Parsons 1996) in Minnesota. However, the fact that Louise Lake produced a moderate year class in 1993, and that strong year classes occurred in Brophy and Louise lakes in 1998 and in Freeborn Lake in 2000, demonstrates that a cold, wet June can apparently be overcome by an average to warm July.

The mechanism by which the adverse weather conditions in 1992 affected black crappie recruitment from these lakes is unknown. Possible reasons include poor spawning success and thus low larval densities, or poor growth and survival of larvae. We have no early life history data from 1992, but our early life history data from 1998-2000 and literature reports suggest poor survival is more likely. May air temperatures were warmer in 1998 than in 1999 and 2000 (Table 3), and peak larval density occurred earlier (late May) in 1998. Pope and Willis (1998) found similar results in two eastern South Dakota lakes in other years. They found date of first black crappie hatch and peak larval density to be 10-15 days earlier in 1994 than in 1995-1996. May air temperatures were much warmer in 1994 than in 1995 or 1996 (Table 3), and May air temperatures in eastern South Dakota and west-central Minnesota were highly correlated (r = 0.94). Thus, May weather in 1992 gives us no reason to suspect that black crappie failed to successfully spawn that year, and suggests that poor survival due to adverse June weather was more likely.

Crappie populations have been characterized as cyclic (Swingle and Swingle 1967), but Allen and Miranda (2001) suggested that a better description would be "quasi-cycles" forced by interactions among population characteristics and the environment. It appears that year class strength from our four lakes in 1998 reflects these interactions. Black crappies initiate nesting in May, so intuitively, a warm May should set the stage for good recruitment. However, there was no correlation between May temperatures and year class strength in any of the lakes. In 1998, May air temperatures were warm, and our larval data showed an early hatch and good growth of black crappie on each lake except Freeborn Lake. Subsequently, Brophy and Louise lakes produced strong year classes, but Blackwell and Freeborn lakes did not. However, Blackwell and Freeborn lakes both had a strong 1997 year class, and suppression by a prior year class is common for crappie (Allen and Miranda 2001). Warm May temperatures may indeed set the stage for good black crappie reproduction, but no weather conditions assure a strong year class. Strong year classes were clearly lake-specific, perhaps due to intraspecific processes.

Guy and Willis (1995) reported that black crappie populations in natural lakes in South Dakota had inconsistent recruitment that resulted in low density populations with high growth rates and favorable size structures. Of our four study lakes, only Freeborn Lake met all of these criteria. Conversely, Blackwell Lake did have inconsistent recruitment, but also had a very high population density and slow growth due to two extremely strong year classes. Our study indicates that missing or extremely poor year classes are rare in small natural lakes in west-central Minnesota. Therefore, prior techniques to describe year class fluctuations, such as the recruitment variability index (RVI, Guy and Willis 1995) or the recruitment coefficient of determination (RCD, Isermann et al. 2002a), are of limited value for black crappie management in Minnesota.

Recruitment in interconnected lakes, such as Brophy and Louise lakes, could also be affected by immigration from nearby lakes. Year class strength was relatively consistent in Brophy and Louise lakes, but in both lakes recruitment was likely due more to migration of adult fish (Parsons and Reed, in press) or dispersal of young fish than to stable recruitment within the lakes. In 1998, estimated minimum larval density of black crappie in Louise Lake was only 15,000, yet a strong year class resulted. It is highly unlikely that larval survival was high enough to cause the strong year class, so supplemental recruitment from other connected water bodies was the likely factor. Therefore, it would appear that similar management of connected waters rather than as separate entities is necessary.

We felt our sampling adequately characterized the larval black crappie dynamics in our study lakes. Our peak CPUE of 2.61/m^3 in Blackwell Lake in 2000 exceeded the highest values we found in the literature. Dubac and DeVries (2002) found peak CPUE ranging from 0.3-1.5/m^3 in three Alabama Reservoirs. Additionally, low CPUE, such as we found in all three years in Brophy and Louise lakes, have also been commonly reported for black crappie. Pope and Willis (1998) sampled two South Dakota waters for three years, and peak catch in Brant Lake never exceeded 0.03/m^3, while peak catch in Richmond Lake ranged from 0.04-0.16/m^3 over the three-year period. In Normandy Reservoir, Tennessee, Sammons and Bettoli (1998) found peak catch over a three-year period ranged from 0.001-0.24/m^3.

We found no evidence to suggest that yellow perch suppressed black crappie populations in these lakes. This is in contrast to Pope et al. (1996), who found that a strong year class of black crappie measured as fall age-0 fish occurred only when the yellow perch year class was weak in the same year in Brant Lake, South Dakota. In Freeborn Lake, the highest catch of larval black crappie coincided with good catches of yellow perch in 2000. A subsequent strong year class of both species was observed in the 2003 trap netting. Furthermore, Blackwell Lake had abundant black crappie year classes in 1996 and 1997, and length frequencies of adult yellow perch suggest that those same years were the last viable yellow perch year classes. Only the very high larval black crappie catch in 2000 in Blackwell Lake corresponded with a significantly lower catch of larval yellow perch.

Furthermore, we found no evidence that diet interactions between larval black crappie and yellow perch affected recruitment. When larval black crappie appeared, they were generally eating copepod nauplii, while yellow perch ate *Daphnia* spp. and small cladocerans at that time. Both species appeared to be opportunistic and variable in their feeding. Furthermore, we found no evidence that larval yellow perch preyed on larval black crappie, despite a size advantage (15-20 mm vs. < 7 mm) that would have enabled them to do so.

The diets of age-0 black crappie and yellow perch in our study lakes were generally in agreement with the prior literature. As we found, black crappie < 10 mm have been reported to primarily eat nauplii, calanoid copepods, rotifers, and *Bosmina* spp. (Bulkley et al. 1976; Pope and Willis 1998; Bunnell et al. 2003). Diets of our larger (10-26 mm) larval black crappie were primarily calanoid copepods and *Daphnia* spp., with *Diphanasoma birgei* and *Bosmina longirostrus* in Blackwell Lake and *Chydorus sphaericus* in Louise Lake contributing as well. Black crappie larvae 10-29 mm in two South Dakota lakes also ate primarily *Daphnia* spp. and calanoid copepods (Pope and Willis 1998) over a 3-year period. Pope and Willis (1998) also found positive selection for *Diphanasoma* spp. in one lake in one year, but negative selection for *Chydorus* spp. and *Bosmina* spp. in both lakes. Larval yellow perch diets have been extensively reported in the literature (Wong and Ward 1972; Bulkley et al. 1976; Hansen and Wahl 1981; Fisher et al 1998). Our general results of calanoid copepods and nauplii for small larvae and calanoid copepods, *Daphnia* spp., and *Bosmina* spp. for larger larvae are consistent with previous reports.

The diets of age-0 black crappie and yellow perch in late summer were generally similar to previous reports (Fisher and Willis 1997; Pope and Willis 1998; Pelham et al. 2001). One notable exception was the consumption of age-0 *Lepomis*, probably bluegill, by black crappie in Brophy and especially Freeborn lakes. Piscivory was not reported in either South Dakota (Pope and Willis 1998) or Iowa (Pelham et al. 2001). Although age-0 black crappie were unusually large in 1998 in Freeborn Lake (89 mm), the fish lengths in Brophy Lake (57 mm) and other years in Freeborn Lake (52 and 63 mm) are within the ranges examined in the South Dakota and Iowa studies. Crappie have generally been considered to feed strictly on zooplankton and insects until at least 130 mm in length (O'Brien et al. 1984; Gablehouse 1991; Pine and Allen 2001).

The peak larval yellow perch catch rates we found in this study were relatively high, consistent, and occurred roughly the same time each year. These results are in contrast to those reported by Ward et al. (2003), who compiled data from several lakes in eastern South Dakota. With the exception of a low catch in Freeborn Lake in 1998, peak catch in every year and lake in our study was higher, and usually substantially so, than five of the seven lakes they studied. Only Sinai Lake in 2001 ($31/m^3$) had a catch higher than any year from Brophy or Louise lakes. Furthermore, Brant, East 81, Madison, and Sinai (except 2001) lakes did not have a catch $>1/m^3$, whereas in our study, only Freeborn Lake in 1998 failed to reach that level. It is unlikely that gear differences were responsible. The South Dakota larval sampling gear was similar in mouth size (0.75 m diameter), but mesh size was 500 or 1,000 µm, compared to 800 µm in our nets. However, Isermann et al. (2002b) reported that peak larval yellow perch densities did not differ between 500 or 1,000 µm mesh sizes. In South Dakota, the net was towed behind a boat at 1-2 m/s rather than pushed in front at 0.75 m/s as we did. However, the high catch in Sinai Lake in 2001 (Ward et al. 2003) suggests the ability of their gear to sample large numbers of larvae. It appears that yellow perch spawning is more successful in Minnesota, likely due to differences in habitat.

We found no similarity among lakes for which year had a high or low catch of yellow perch larvae. Thus, it is clear that no single weather factor can be isolated as affecting yellow perch reproduction in these lakes. Ward et al. (2003) did find significant correlations between larval yellow perch abundance and weather variables in 7 South Dakota lakes, but the particular variable that was correlated with abundance varied among lakes. They included March or May wind speed, April precipitation, and May temperature. Ward et al. (2003) suggest that effects of weather on yellow perch reproduction should be studied on a lake-specific basis. However, the apparent lack of a single influential weather factor, the fact that no active management for yellow perch occurs in Minnesota, and no apparent relationship between yellow perch and black crappie recruitment leads us to recommend that significant effort or resources should not be expended to answer this question.

The failure of the high numbers of yellow perch larvae in Blackwell Lake in 1998 and 1999 to yield any numbers of fish > 120 mm suggests extremely high mortality rates. The cause and timing of this mortality, however, is unknown. Fisher et al. (1998) found larval yellow perch < 14 mm strongly selected for calanoid copepods, then added cladocerans to the diet at lengths > 14 mm in South Dakota lakes (Fisher and Willis 1997). In Blackwell Lake, yellow perch reached 14 mm at about the fourth larval sampling period. Calanoid copepod densities in 1998 and 1999 were generally 20-40/l during this period. This corresponds well with calanoid densities reported by Fisher et al. (1998). Also, calanoid densities in Brophy, Freeborn, and Louise lakes were lower than that found in Blackwell Lake, and they all produced at least moderately strong year classes. Thus, starvation at the early larval stage seems unlikely. Furthermore, June densities of small cladocerans and *Daphnia* spp. were similar in all our study lakes. This suggests that starvation during the late larval to early juvenile stage was also unlikely. Additionally, gill net CPUE of northern pike and walleye were lower in Blackwell Lake than the other study lakes.

The primary difference in the Blackwell Lake fish community was the very high abundance of black crappie. While we have no diet data for black crappie older than age-1, they can be highly piscivorous (Seaburg and Moyle 1963; Reed and Parsons 1996; Liao et al. 2004). Liao et al. (2004) reported that yellow perch comprised 12% of black crappie diets in one of three years studied on Spirit Lake, Iowa. Purse seine CPUE never exceeded 2.0 age-0 yellow perch. Thus, we suggest that predation by black crappie, probably on age-0 fish, may have caused the failure of yellow perch in Blackwell Lake to recruit to 120 mm.

Reduction of yellow perch numbers by northern pike is a common phenomenon in Minnesota lakes (Anderson and Schupp 1986; Goeman and Spencer 1992). It is very likely that this has occurred in Brophy and Louise lakes. Northern pike numbers were high in Louise Lake in the 1996 gill net survey (16.2/net) and then rose to 25.2/net in the 2002 survey (Table 12), well above the third quartile for Lake Class 31 lakes (10.5/net). Concurrently, yellow perch numbers went from a total catch of 52 in the 2000 spring trap netting and 5.2/ net in the 1996 gill netting to 14 in the 2003 spring trap netting and non-existent in the 2002 summer gill netting. Northern pike gill net CPUE in Brophy Lake was 14.2/net in 1996 and 11.2/net in 2002 (Table 10), also above the third quartile. Concurrently, yellow perch gill net CPUE was 0.7 in 1996 but none were caught in 2002. Total spring trap net catch in Brophy Lake was about 40 in 1999-2002 and only 17 in 2003.

Yellow perch were more abundant in Freeborn Lake, and northern pike CPUE was consistently lower. Spring trap netting yielded over 100 yellow perch in each year except 2001 (77), and gill net CPUE was 4.8/net in 1999 and 12.0 in 2004 (Table 11), within the interquartile range for Lake Class 34 (3.7-28.4). Meanwhile, northern pike CPUE was 8.2/net in 1999 and 6.3/net in 2004, below the third quartile for lake class 34 (9.2/net). However, walleye were more abundant in Freeborn Lake (13.8/net in 1999, 4.2/net in 2004). Walleye have also been shown to control yellow perch numbers (Pierce and Tomcko 2003; Forney 1974), but that did not appear to be the case in Freeborn Lake.

The extremely high number of juvenile black crappie produced in 2001 in Freeborn Lake suggests that low population size and thus low population fecundity are not limiting factors to black crappie recruitment. The adult population estimate was only 1,216 (12.4/ha) that spring, and assuming a 1:1 sex ratio yields only 608 females. Applying the length-fecundity relationship from Baker and Heidinger (1994) to the length distribution in spring 2004, we can estimate that potentially over 83 million ova were in the lake. While not all ova will develop into viable eggs, and not all females will successfully spawn, clearly few females are necessary for sufficient reproductive potential. Peak estimated larval density was 356,000 in Freeborn Lake in 2000. This result is consistent with results from Alabama reservoirs, where Dubac and DeVries (2002) suggested minimal influence of adult fecundity on larval production and recruitment.

Our study indicates that black crappie recruitment is generally less variable than previously thought for small Minnesota lakes. While unusually cold early summer temperatures may restrict black crappie year class formation, no weather conditions guarantee strong year class formation. As suggested by Allen and Miranda (2001), year class formation was lake specific, apparently due to complex interactions between various biotic and abiotic factors. Among the biotic factors, we found no evidence that yellow perch or zooplankton dynamics were influential, but intraspecific influences, either competition or cannibalism, from previous year classes were a likely factor.

Management Implications

Weather effects during trap netting may override any relationship between CPUE and population density of black crappie. In all four study lakes, spring trap net CPUE dropped considerably between 1999 and 2000, despite stable or increasing population density. In lakes where black crappie management is a high priority, at least two consecutive years of sampling with marking are necessary to define population dynamics.

The results from Blackwell and Freeborn lakes show that density-dependent growth effects may be substantial for black crappie. Therefore, we urge caution with restrictive angling regulations on lakes such as these with high variability in recruitment. For example, a 230 mm minimum size limit was rescinded on Lake Alvin, South Dakota, because black and white crappie numbers increased and growth decreased after the regulation was implemented (Bister et al. 2002). If deemed necessary, restrictive regulations in these situations should be based on bag limits rather than minimum size limits. Furthermore, the production of a strong year class in 2000 in Freeborn Lake by a very low density adult population suggests that increasing adult biomass to improve spawning success may be an inappropriate justification for a restrictive black crappie regulation. Given the clear potential to produce very large (> 325 mm) fish, we recommend consideration of a five fish daily bag limit for black crappie in Freeborn Lake. High population density, along with slow growth rates, indicates no additional restrictions should be placed on black crappie in Blackwell Lake.

Larval black crappie sampling appeared to have some utility in isolated lakes such as Blackwell and Freeborn lakes, but is likely of limited management value. Fall trap netting in Blackwell and Freeborn lakes provided a good indication as to year class strength at age 1+ with much reduced labor costs. However, fall trap netting was ineffective in Brophy and Louise lakes, and has proved unreliable for black crappie < 200 mm in southern Minnesota lakes (MN DNR unpublished data). If, for some reason, black crappie spawning success needed to be identified at a very early stage, our data suggests that targeting larger larvae in early to mid-June might confirm their presence with considerably less effort. While Sammons and Bettoli (1998) suggested that crappie switch from pelagic to littoral habitats after 9 mm, our data did not support this conclusion. Black crappie > 10 mm were not uncommon in our pelagic larval samples. Also, there was some evidence that catch of larger larval black crappie may be a better indicator of eventual year class strength than CPUE. Both Brophy and Louise lakes had strong year classes in 1998. Although consisting of only two individuals (11.3 mm and 13.8 mm), the only large larval black crappie caught in three years on Brophy Lake were in 1998. Furthermore, the only indication from the larval sampling of success in the 1998 year class in Louise Lake was the catch of 10 black crappie on 3 June 1998 which averaged 11.2 mm. In both Blackwell and Freeborn lakes, large catches of large individuals were common in 2000 when moderate to strong year classes developed. This indication was not entirely consistent, since catches of larger individuals were common in Blackwell Lake in 1998.

The results from Brophy and Louise lakes clearly demonstrate the need to manage interconnected lakes in a similar fashion. Since it appeared that Brophy and Louise lakes were dependent on other lakes in the chain for supplemental black crappie recruitment, the need to assure adequate fish passage among lakes is clear. Furthermore, these two lakes had relatively consistent recruitment and growth rates, the documented presence of fish > 300 mm, moderate natural mortality rates, and exploitation rates over 25%. This suggests restrictive black crappie angling regulations could be considered to improve the quality of black crappie angling in these two lakes, provided such a regulation applied to at least the entire southwestern portion of the chain (Parsons and Reed, in press.).

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Appendix 1A. Mean number of diet items of age-0 black crappie and yellow perch caught by purse seine by date 1998-2000 in Blackwell Lake.

Date	Mean length (mm)	Sample size	Mean total diet items	*Daphnia retro/galeata*	*Daphnia pulex*	*Ceriodaphnia* sp.	*Bosmina* sp.	Chydorid	*Leptodora kindti*	*Diaphanosoma* sp.	Calanoid	Cyclopoid	Ostracod	Diptera larva/pupa	*Chaoborus* sp.	Trichoptera	Ephemeroptera	Odonata	Amphipod	Other
Black Crappie																				
8/5/98	40	11	141.82	2.18	0	0	67.91	0	0	11.55	3.18	56.09	0.09	0.73	0	0	0	0	0	0.09
8/26/98	NA	0																		
9/17/98	46	3	198.67	3.33	0	3.33	3.33	1.00	0	15.67	141.67	29.00	0	1.00	0.33	0	0	0	0	0
8/2/99	38	2	3.50	0	0	0	2.00	0	0	0	0	0	0	1.50	0	0	0	0	0	0
8/19/99	42	1	110.00	1.00	0	0	14.00	0	0	4.00	83.00	7.00	0	0	0	0	0	0	0	0
9/16/99	52	10	237.60	5.80	1.80	0.40	0.40	0.10	0	7.00	210.10	12.00	0	0	0	0	0	0	0	0
8/2/00	NA	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/31/00	46	30	246.37	27.20	0	0.27	0.47	0.03	0	63.10	149.87	5.10	0	0.03	0.30	0	0	0	0	0
9/26/00	47	40	146.53	41.45	0.25	0	4.98	0.13	0.03	1.43	58.93	39.00	0	0	0.10	0	0	0	0	0.23
Yellow Perch																				
8/5/98	56	10	50.90	0.50	0	2.70	13.40	0	0	4.20	27.80	1.70	0	0.20	0	0	0.30	0	0.10	0
8/26/98	NA	0																		
9/17/98	64	5	50.00	1.20	0	12.80	0.40	1.40	0	0	20.20	13.80	0	0	0	0	0.20	0	0	0
8/2/99	48	1	6.00	0	0	0	0	0	0	0	0	0	0	1.00	0	0	0	0	5.00	0
8/19/99	NA	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9/16/99	58	10	137.20	5.10	0	0	0	0	0.10	2.00	129.20	0.30	0	0	0	0	0	0	0.20	0
8/2/00	50	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/31/00	58	2	69.50	0	0	0	0	0	0	1.50	67.00	0	0	0.50	0	0	0	0.50	0	0
9/26/00	60	10	217.90	121.30	0	2.50	0.20	0	0.20	10.20	0	83.20	0	0	0	0.10	0	0	0	0.20

Appendix 1B. Mean number of diet items of age-0 black crappie and yellow perch caught by purse seine by date 1998-2000 in Brophy Lake.

Date	Mean length (mm)	Sample size	Mean Total diet items	*Daph. ret-roc/galeata*	*Daphnia pulex*	*Ceriodaphnia* sp.	*Bosmina* sp.	Chydorid	*Leptodora kindti*	*Diaphanosoma* sp.	Calanoid	Cyclopoid	Ostracod	*Chaoborus* sp.	Diptera pupa/larva	Ephemeroptera	Odonata	Amphipod	*Latonopsis* sp.	Fish	Other
Black Crappie																					
8/5/98	45	18	136.56	4.61	0	0.11	0.17	0.17	0	41.67	30.67	57.56	0.11	0.22	1.17	0	0	0	0	0.06	0
8/25/98	56	14	92.86	81.43	0	0	0.07	0.21	0	0.14	4.14	3.36	0	0.50	2.57	0	0	0	0	0.07	0.07
9/16/98	60	18	43.94	13.72	0	0	0	0.06	0	1.89	10.00	4.56	0.11	12.00	1.44	0	0	0.11	0	0	0
9/15/99	59	8	101.13	21.38	0	0	0	0.25	0	0	73.25	0.88	0	3.75	1.00	0	0.02	0	0	0	0
8/3/00	39	57	120.60	0.09	0	4.46	7.89	8.49	0	13.35	22.19	59.18	0.04	1.60	2.28	0.02	0	0	0	0.04	0.67
8/29/00	52	3	30.67	0	0	0	0.33	4.33	0	0	0	2.00	0	3.33	20.00	0	0	0	0	0	0
9/29/00	48	4	80.50	6.25	0	0.25	0	1.00	0	4.50	53.00	13.50	0.25	0	0.75	0	0	1.00	0	0	0
Yellow Perch																					
8/5/98	46	23	61.87	12.35	0	1.83	0.22	0.26	0.04	13.09	32.43	1.48	0	0	0.13	0	0	0	0	0	0.04
8/25/98	50	13	94.54	80.77	0	0	0.08	1.69	0	1.69	8.77	0.54	0	0	0.38	0	0	0	0.54	0	0.08
9/16/98	57	8	32.63	9.75	0	9.63	0	0.50	0	0.38	8.75	0.38	0	0	0.00	1.38	0	0.25	1.63	0	0
8/3/99	40	20	19.85	0	0	9.15	0.30	2.15	0	0.50	0	0.65	0	0	0.80	0	0	0	6.30	0	0
8/20/99	44	10	43.70	0	0	20.70	8.60	2.30	0	2.50	0	1.00	0	0	3.00	0	0	0	5.60	0	0
9/15/99	49	10	100.60	70.30	1.90	1.70	0.30	0.80	0	0.40	23.80	0.40	0	0	0.70	0	0	0.30	0	0	0
8/3/00	47	32	20.69	0	0	13.94	0.31	1.84	0	0.13	0.03	2.56	0.06	0.03	0.41	0	0	0.06	1.19	0	0.13
8/29/00	51	2	45.00	0	0	38.50	0	1.50	0	0.50	0	2.00	0	0	1.00	0	0	0	1.50	0	0
9/29/00	57	1	39.00	0	0	32.00	0	7.00	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1C. Mean number of diet items of age-0 black crappie and yellow perch caught by purse seine by date 1998-2000 in Freeborn Lake.

Date	Mean length (mm)	Sample size	Mean total diet items	*Daphnia retro/galeata*	*Daphnia pulex*	*Ceriodaphnia* sp.	*Bosmina* sp.	Chydorid	*Leptodora kindti*	*Diaphanosoma* sp.	Calanoid	Cyclopoid	Copepod nauplii	Ostracod	Diptera larva/pupa	*Chaoborus* sp.	Ephemeroptera	Odonata	Trichoptera	Amphipod	Fish eggs	Fish	Other
												Black Crappie											
8/5/98	62	3	77.67	0.67	0	0	71.0	0	0	0	0	4.33	0	0	1.00	0	0	0	0	0	0	0.67	0
8/26/98	78	10	12.10	0	0	0	0	8.50	0	0	0	0	0	0.50	0	0	0	0.10	1.20	0	0.70	1.10	0
9/18/98	89	5	53.00	10.40	0	0	0	0	1.40	2.40	4.60	30.60	0	0	1.40	0	1.00	0	0	1.00	0	0.20	0
8/2/99	42	29	69.88	0.38	0.14	0.03	0.07	0.03	0.31	2.31	51.31	5.90	0	0.17	0.47	8.76	0	0	0	0	0	0	0
8/19/99	53	40	58.93	0	0.40	0.03	0.25	0.03	0.18	14.65	23.78	13.35	0	2.25	0.51	2.35	0.05	0	0.03	0.30	0.08	0.50	0.19
9/16/99	52	20	55.95	1.65	0.45	0.05	1.50	3.10	1.05	2.75	32.00	10.70	0	0.30	0.50	1.75	0	0	0	0.15	0	0	0
8/2/00	48	40	326.23	38.78	141.23	0	0.93	0.05	0	0.80	64.65	71.23	0	6.80	0.68	0.58	0.05	0.05	0	0.25	0	0	0.15
8/31/00	64	39	77.26	0	0.13	0.28	0.38	0.08	21.10	1.95	21.21	28.44	0	0.90	0.52	0.28	0.05	0.11	0	1.77	0	0.03	0.03
9/26/00	63	11	60.82	2.55	1.09	0	0.09	0.36	6.73	0.27	20.45	17.82	0	0.55	0.18	1.91	0	0.09	0	3.64	5.09	0	0
												Yellow Perch											
8/5/98	NA	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/26/98	74	3	8.00	1.67	0	0	0	0.33	5.33	0	0	0	0	0	0	0	0	0.67	0	0	0	0	0
9/18/98	78	4	62.00	34.25	0	0	2.25	1.00	23.50	0	0	1.00	0	0	0	0	0	0	0	0	0	0	0
8/2/99	43	12	8.25	0	1.67	0.08	0.17	0.17	0.17	0.83	0.25	0.17	0	2.50	0.49	0	0	0	0.75	0.17	0	0	0.83
8/19/99	47	14	38.93	0	33.29	0.07	0.29	0.07	0	1.36	0	0.64	2.29	0.07	0.28	0	0.07	0	0.43	0.07	0	0	0
9/16/99	NA	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/2/00	64	7	206.15	39.86	149.86	0	0	0	0	0	8.57	7.00	0	0.86	0	0	0	0	0	0	0	0	0
8/31/00	65	13	37.00	0	1.00	0	0	0	35.08	0	0	0.15	0	0.08	0.23	0	0	0	0.31	0.15	0	0	0
9/26/00	62	1	95.00	4.00	0	0	0	0	59.00	0	14.00	0	0	0	0	0	0	0	0	0	18.00	0	0

Appendix 1D. Mean number of diet items of age-0 black crappie and yellow perch caught by purse seine by date 1998-2000 in Louise Lake.

Date	Mean length (mm)	Sample size	Mean total diet items	*Daph. retro/galeata*	*Daphnia pulex*	*Ceriodaphnia* sp.	*Bosmina* sp.	Chydorid	*Leptodora kindti*	*Diaphanosoma* sp.	*Latonopsis* sp.	Calanoid	Cyclopoid	Ostracod	Diptera larva/pupa	*Chaoborus* sp.	Ephemeroptera	Odonata	Amphipod	Other
Black Crappie																				
8/4/98	39	5	137.20	27.60	8.60	2.60	5.20	6.00	0.00	57.20	0.00	5.00	19.20	0.00	5.00	0.60	0.00	0.00	0.00	0.00
8/25/98	48	45	85.44	13.58	0.00	0.22	1.80	3.27	0.00	7.31	0.00	43.38	12.62	0.13	1.09	1.62	0.00	0.00	0.07	0.11
9/16/98	56	3	45.00	11.33	0.00	0.00	0.33	1.00	0.00	0.67	0.00	8.33	19.33	0.00	2.33	1.67	0.00	0.00	0.00	0.00
8/3/99	40	16	178.75	9.75	0.00	0.00	0.06	0.56	0.00	0.25	0.00	134.50	31.19	0.00	0.81	1.13	0.00	0.00	0.00	0.00
8/20/99	49	26	101.15	73.06	0.00	0.13	0.50	3.44	0.13	2.13	0.00	21.19	42.75	1.88	4.31	14.06	0.00	0.00	0.19	0.13
9/15/99	NA	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/3/00	40	31	69.29	0.13	0.00	0.03	18.16	7.29	0.00	11.68	0.00	17.65	13.45	0.00	0.42	0.00	0.00	0.00	0.00	0.16
8/29/00	49	29	101.00	26.24	0.00	0.07	0.24	4.93	0.41	9.90	0.00	35.69	19.86	1.10	0.41	0.83	0.00	0.00	0.00	0.44
9/27/00	54	8	77.13	43.13	0.00	0.25	0.38	0.38	0.00	0.50	0.13	28.63	2.88	0.00	0.25	0.13	0.00	0.00	0.13	0.13
Yellow Perch																				
8/4/98	43	30	82.47	12.93	1.83	3.43	2.77	6.57	0.00	23.27	0.07	20.60	10.83	0.00	0.10	0.00	0.00	0.00	0.00	0.00
8/25/98	48	37	120.41	53.59	0.00	2.41	38.14	10.08	0.00	3.68	1.54	8.24	2.22	0.00	0.37	0.00	0.00	0.03	0.00	0.00
9/16/98	55	29	50.72	37.45	0.00	0.83	0.07	1.24	0.00	2.10	0.24	7.45	0.69	0.10	0.38	0.00	0.03	0.00	0.10	0.03
8/3/99	46	33	199.76	175.06	0.00	0.33	0.03	0.18	0.18	0.30	0.00	23.61	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00
8/20/99	47	9	93.00	52.67	0.00	5.11	0.33	2.00	0.11	4.22	1.89	26.22	0.22	0.00	0.22	0.00	0.00	0.00	0.00	0.00
9/15/99	59	15	19.93	11.67	0.00	1.00	0.07	1.20	0.00	0.53	0.47	4.60	0.27	0.00	0.14	0.00	0.00	0.00	0.00	0.00
8/3/00	46	6	15.00	0.00	0.00	2.33	0.00	4.33	0.00	0.00	6.00	0.00	0.67	0.00	0.67	0.00	0.00	0.00	0.17	0.83
8/29/00	47	17	44.29	26.06	0.00	5.82	0.00	3.24	0.00	2.88	0.00	3.29	2.29	0.00	0.24	0.00	0.29	0.18	0.00	0.00
9/27/00	56	18	65.33	35.94	0.00	0.78	0.61	0.44	0.06	0.06	0.00	26.61	0.78	0.00	0.06	0.00	0.00	0.00	0.00	0.00

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