

# Early life history and recruitment of black crappie (*Pomoxis nigromaculatus*) in two South Dakota waters

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**Abstract** – We compared the early life history of black crappie (*Pomoxis nigromaculatus*) in Richmond (an impoundment) and Brant (a natural lake) lakes during 1994–1996. We expected variable recruitment (i.e., missing year classes) in the natural lake and more consistent recruitment in the impoundment. Larval black crappie abundance was always higher in Richmond Lake than Brant Lake. Peak abundance of larval black crappie was highest during 1994 in both waters. However, peak larval abundance did not correspond with fall trap-net catch per unit effort (CPUE) of age-0 black crappie, which was highest during 1995. Thus, recruitment of black crappie was not simply a function of the number of larvae hatched. Similar trends in catches of age-0 black crappie with the ichthyoplankton trawl and trap nets for both water bodies during 1994–1996 suggest that broad environmental factors similarly affected reproduction and recruitment in Richmond and Brant lakes.

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Un resumen en español se incluye detrás del texto principal de este artículo.

## Introduction

Understanding recruitment processes is a prerequisite for effective fisheries management. Crappie (*Pomoxis* spp.; Centrarchidae) recruitment is usually erratic (Hooe 1991). However, variation in crappie year-class strength was reduced when predators reduced age-0 crappie density (Powell 1973; Gabelhouse 1984b). Climatic conditions can also affect crappie year-class strength. For example, Siefert (1968) reported that low water temperature before and during spawning was detrimental to white crappie (*P. annularis*) year-class strength. In addition to predators and climate, habitat conditions can also affect year-class strength. Ming (1971) concluded that in small impoundments, the likelihood of overpopulation by crappies was directly related to the amount of aquatic vegetation present. The more aquatic vegetation, the greater likelihood that consistently strong year classes of crappies would be produced. In reservoirs, larger year classes of crappies are associated with increased water levels (Mitzner 1981; Beam 1983).

Much of the past work on crappie recruitment has focused on white crappie or white and black crappie (*P. nigromaculatus*) combined, with little work published on recruitment of black crappie alone. Although white and black crappies are similar in a number of characteristics, several important differences exist. For example, Chatry & Conner (1980) consistently collected larval black crappie earlier than larval white crappie in southeastern Louisiana waters, suggesting that black crappie spawned before white crappie.

Food and feeding strategies of the two crappies also differ. Overmann et al. (1980) found that juvenile white crappie primarily fed near the bottom, whereas juvenile black crappie fed near the surface in Rough River Lake, Kentucky. The food of adult black crappie is primarily composed of zooplankton and insects, whereas white crappie are more likely to be piscivorous (Unkenholz 1971; Ball & Kilambi 1972; Li et al. 1976; Ellison 1984). However, black crappie were piscivorous in other studies (Seaburg & Moyle 1964; Busiahn 1977).

When sympatric, one species of crappie is

usually dominant; white crappie typically outnumber black crappie in turbid waters, while black crappie are usually dominant in clear waters (Goodson 1966). Barefield (1984) speculated that this difference was not due to differential feeding ability of the two species, as their feeding rates were similar in turbid waters. However, Pope (1996) found that physical turbidity reduced growth and survival of juvenile black crappie.

Differences in population dynamics between water types also exist within a species. For example, recruitment of black crappie in South Dakota natural lakes was more variable than recruitment of black crappie in South Dakota impoundments. Missing year classes of black crappie were more common in natural lakes (Guy & Willis 1995b).

To better understand recruitment processes of black crappie, we compared the early life history of black crappie in Richmond (an impoundment) and Brant (a natural lake) lakes over a three-year period. Pope & Willis (1997) evaluated nest site selection by black crappie in these two water bodies. Our objectives were 1) to document early life history of black crappie in systems without white crappie, and 2) to further investigate the finding by Guy & Willis (1995b) that missing year

classes were less common in impoundments than in natural lakes (i.e., contrasting the early life history of black crappie in these two water bodies may help explain differences in recruitment patterns). Because the study duration was three years, we hoped to obtain information during years with year classes both present and absent (or nearly so) in Brant Lake. We also hoped to identify any critical period when recruitment failure (or at least catastrophic mortality) might occur so that management strategies could be developed to address the problem.

**Study sites**

Richmond Lake is a 336-ha impoundment in northeastern South Dakota (Brown County). Brant Lake is a 405-ha natural lake of glacial origin in eastern South Dakota (Lake County). Physicochemical variables and black crappie population characteristics differ between these two water bodies (Table 1).

**Materials and methods**

**Sampling adult fish**

Adult black crappie populations were sampled using trap (modified fyke) nets (1.3-m × 1.5-m frame, 13-mm bar mesh, 1.2-m × 23-m lead) during late spring and fall. Ten trap-net nights were used during spring on each water body, while 20 trap-net nights were used on each water body during the fall. All black crappie ≥ 130 mm total length (TL) [i.e., stock-length crappie (Gabelhouse 1984a)] were measured (nearest mm TL) and tallied to the nearest cm length group. Ten black crappie per cm length group were weighed (nearest gram) and scales were removed from the side of the fish below the lateral line at the tip of the pectoral fin (DeVries & Frie 1996) for age determination. All adult fish were released after data were collected.

**Age-0 fish and zooplankton collection**

Larval black crappie were sampled weekly from late spring through summer using a 0.76-m diameter ichthyoplankton net (bar mesh size = 500 μm) towed [mean tow speed ± 1 standard error (SE) of all trawls made during 1994-1996 was 1.0 ± 0.001 m/s] just under the surface during daylight. Two consecutive tows were collected from four standardized sites in each water body on each sampling date (a total of eight trawls per sampling date). A flow meter mounted in the mouth of the net allowed estimation of the volume of water filtered and, hence, larval abundance (number/m<sup>3</sup>).

During late summer when age-0 black crappie

Table 1. Physicochemical variables (Stueven & Stewart 1996) and black crappie population characteristics (Guy & Willis 1993, 1995a, 1995b) for Richmond and Brant lakes, South Dakota.

Parameter	Richmond	Brant
<b>Physicochemical</b>		
Shoreline development index	5.8	1.2
Mean depth (m)	4.6	3.4
Maximum depth (m)	8.8	4.3
Morphoedaphic index	71	191
Watershed: lake area ratio	124	8
<b>Black crappie populations</b>		
Density	High	Low
Growth	Slow	Fast
Recruitment	Relatively consistent	Inconsistent

Table 2. Calculation of  $S_N$  variable in the recruitment variability index (RVI; Guy & Willis 1995b) using a hypothetical example of age structure for a black crappie population sample ( $N$ =number) collected in 1997.

Year class	Age group	$N$	Relative frequency	Cumulative relative frequency
1995	2	80	0.55	0.55
1994	3	40	0.28	0.83
1993	4	20	0.14	0.97
1992	5	0	0.00	0.97
1991	6	5	0.03	1.00
		145	1.00	$S_N=4.32$

## Pope & Willis

Table 3. Mean ( $\pm 1$  SE) catch per unit effort (CPUE; number of fish per trap net night) and effort (number of trap net nights) for age-0 (CPUE-0) and stock-length (CPUE-S; black crappie  $\geq 130$  mm total length (TL)) black crappie, and stock density indices with 95% confidence intervals in parentheses for crappie collected in two South Dakota water bodies during 1993–1996. Note: these data are not normally distributed – mean and SE are for descriptive purposes only and are not meant to be statistically tested. PSD=proportional stock density (i.e., the proportion of black crappie  $\geq 130$  mm TL that are also  $\geq 200$  mm TL); RSD-P=relative stock density (RSD) of preferred-length fish (i.e., the proportion of black crappie  $\geq 130$  mm TL that are also  $\geq 250$  mm TL); RSD-M=RSD of memorable-length fish (i.e., the proportion of black crappie  $\geq 130$  mm TL that are also  $\geq 300$  mm TL); A=inappropriate to calculate confidence intervals for stock density values of 0 and 100; B=sample size insufficient to reliably calculate confidence interval.

Lake	Season	Year	Effort	CPUE-0	CPUE-S	N	PSD	RSD-P	RSD-M
Richmond	Fall	93	10	3.9 $\pm$ 3.7	18.8 $\pm$ 8.2	188	20 (6)	0 A	0 A
	Spring	94	10		118.4 $\pm$ 19.6	1,205	42 (3)	0 A	0 A
	Fall	94	20	5.0 $\pm$ 4.0	31.1 $\pm$ 5.2	265	82 (5)	1 B	0 A
	Spring	95	10		19.8 $\pm$ 4.3	198	96 (3)	4 (3)	0 A
	Fall	95	19	8.6 $\pm$ 3.8	41.3 $\pm$ 7.4	779	38 (4)	1 (1)	0 A
	Spring	96	10		47.0 $\pm$ 12.2	469	32 (4)	2 (1)	0 A
	Fall	96	18	2.0 $\pm$ 0.8	51.6 $\pm$ 8.0	929	31 (3)	1 (1)	0 A
Brant	Fall	93	6	5.5 $\pm$ 1.0	4.2 $\pm$ 1.9	25	20 (21)	0 A	0 A
	Spring	94	10		2.6 $\pm$ 1.0	28	79 (20)	36 (23)	0 A
	Fall	94	20	2.6 $\pm$ 0.7	2.8 $\pm$ 0.8	56	95 B	18 (12)	0 A
	Spring	95	10		0.8 $\pm$ 0.4	35	100 A	54 (20)	0 A
	Fall	95	17	34.4 $\pm$ 10.9	3.1 $\pm$ 1.3	52	69 (15)	33 (15)	0 A
	Spring	96	10		3.1 $\pm$ 1.8	31	97 B	26 (20)	3 B
	Fall	96	17	0.4 $\pm$ 0.2	2.2 $\pm$ 0.6	38	66 (18)	34 (18)	3 B

were able to avoid the 500- $\mu$ m mesh trawl, a 0.91-m diameter surface trawl with 1.6-mm mesh (bar measure) was used to capture juvenile fish, which were used only for diet assessments. Trawl sites for juvenile black crappie were the same used to collect larval crappie. All collected fishes were preserved in ethanol and returned to the laboratory where they were identified and enumerated. All age-0 black crappie captured during the fall trap netting were placed on ice and returned to the laboratory for further analysis.

At the end of each surface trawl, zooplankton samples were collected using a 2-m tube sampler (75-mm diameter; DeVries & Stein 1991). Samples were filtered through a 80- $\mu$ m mesh net and preserved in 4% sucrose-formalin (Haney & Hall 1973). Water temperature ( $\approx 20$  cm below surface) was also measured once on each sampling trip.

### Laboratory analysis

*Adult fish.* The CPUE of adult black crappie was defined as the number of crappie  $\geq 130$  mm TL

caught per trap-net night. The CPUE was used as an index to adult black crappie density (Hubert 1996). Fish population size structure was quantified using proportional stock density (PSD) and relative stock density (RSD) (Anderson & Neumann 1996). The formulae for these indices are:

$$\text{PSD} = \frac{\text{Number of fish} \geq \text{quality length}}{\text{Number of fish} \geq \text{stock length}} \times 100;$$

$$\text{RSD} = \frac{\text{Number of fish} \geq \text{specified length}}{\text{Number of fish} \geq \text{stock length}} \times 100$$

For black crappie, minimum stock, quality, preferred, and memorable lengths are 130, 200, 250, and 300 mm, respectively (Gabelhouse 1984a).

Scales from adult black crappie were pressed into cellulose acetate using a non-heat scale press (Smith 1954). Scale impressions were projected with a microfiche reader, annuli (Kruse et al. 1993) were recorded on strips of paper, and mean back-calculated length at age was determined using a

digitizing pad and DISBCAL software (Frie 1982). Back-calculated length at age was determined using the Fraser-Lee modification of the direct proportion method (Busacker et al. 1990). The formula for the Fraser-Lee modification is:

$$L_i = a + (L_c - a) (S_i / S_c)$$

where  $L_i$  is the calculated TL of fish at age  $i$ ,  $L_c$  is the TL of fish at capture,  $S_c$  is the radius of scale at capture, and  $S_i$  is the measurement at annulus  $i$ . The "a" value (i.e., intercept for the body length-scale radius relation) used for black crappie was 35 mm (Carlander 1982).

Recruitment patterns for adult black crappie populations were quantified using the recruitment variability index (RVI; Guy & Willis 1995b). The formula for this index is:

$$RVI = \frac{S_N}{N_M + N_P} - \frac{N_M}{N_P}$$

where  $S_N$  is the summation of the cumulative relative frequency distribution based on the number of fish in each year class (see example in Table 2),  $N_M$  is the number of year classes missing from the sample that should be present (not including ages

past last age captured) and  $N_P$  is the number of year classes present in the sample. The RVI was calculated only for fish fully recruited to the sampling gear (i.e., age 2 and older black crappie). Theoretically, RVI ranges from -1 to 1; as RVI increases, recruitment is more consistent.

*Zooplankton.* Zooplankton samples were adjusted to a known volume, and measured subsamples were counted until at least 200 individuals from the most abundant taxon were counted. Organisms were identified (to genus for cladocerans, and as nauplii, calanoid, or cyclopoid for copepods) and counted under a dissecting microscope. The first 10 individuals encountered from each taxon were measured (nearest 0.01 mm) using an ocular micrometer.

*Age-0 fish.* Stomachs from up to 20 age-0 black crappie collected in each sample (i.e., ichthyoplankton trawl, 1.6-mm mesh trawl, or trap net) were removed to quantify diets after TL was recorded for each fish. Prey items were removed under a dissecting microscope, identified, and enumerated. Prey selection by age-0 black crappie in both water bodies was quantified using Chesson's

Table 4. Age structure (number of fish per age group), recruitment variability index (RVI; Guy and Willis 1995b), and mean back-calculated length-at-age estimates with SE in parentheses and sample size ( $N$ ) for black crappie collected using trap nets in two South Dakota water bodies during 1993-1996. A=insufficient year classes present to calculate RVI; B=unable to calculate SE for one fish.

Lake	Season	Year	RVI	Age								$N$	Length at age (mm)							
				2	3	4	5	6	7	8	1		2	3	4	5	6	7	8	
Richmond	Fall	93	0.764	25	118	37	8	1			72	86	153	188	208	216	214			
	Spring	94	0.360	0	453	410	281	62			42	(2)	(1)	(1)	(2)	(4)	B			
	Fall	94	0.649	11	16	186	46	5	1		80	88	155	190	211	231	242	243		
	Spring	95	0.411	3	0	61	97	24	7	4	92	(2)	(1)	(2)	(1)	(2)	(3)	B		
	Fall	95	0.796	422	62	37	210	46	3		132	(2)	(2)	(2)	(2)	(4)	(3)	(4)	(6)	
	Spring	96	0.849	316	10	7	98	27	10	1	107	86	156	188	213	228	238	255		
Brant	Fall	93	A	20	5						26	(2)	(2)	(2)	(2)	(5)	(5)			
	Spring	94	0.887	20	8	1					44	87	161	192	213	228	241	250	280	
	Fall	94	0.845	40	16	7	4				53	(2)	(2)	(2)	(2)	(2)	(3)	(6)	B	
	Spring	95	0.615	2	15	18	2				28	88	176	231						
	Fall	95	0.835	40	3	14	3				53	(4)	(2)	(3)						
	Spring	96	0.872	23	3	5	2	1			36	94	178	227	251					

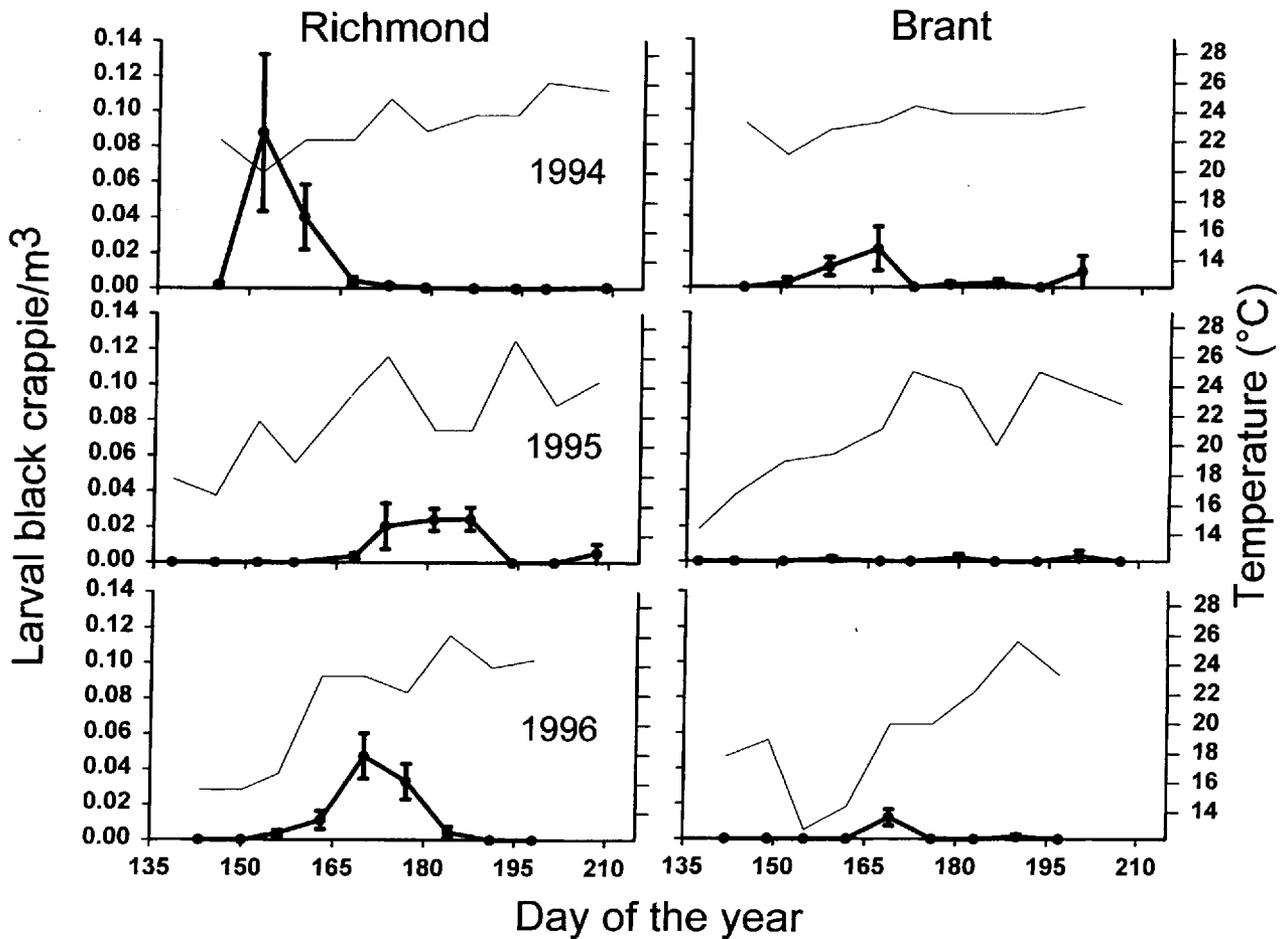


Fig. 1. Larval black crappie abundance (mean ± 1 SE) and surface water temperature in Richmond and Brant lakes, South Dakota, during 1994–1996

alpha (Chesson 1978, 1983). The formula for this index is:

$$\alpha = \frac{r_i/p_i}{\sum(r_i/p_i)}, i = 1, 2, 3, \dots, m,$$

where alpha is the prey selection index for prey taxon,  $r_i$  is the proportion of prey type  $i$  in the fish diet,  $p_i$  is the proportion of prey type  $i$  in the water body, and  $m$  is the total number of prey types available. With this index, a value of  $1/m$  indicates neutral selection, where consumption of a prey type is in proportion to its abundance in the environment; values greater than this indicate positive selection, and values less than this indicate negative selection.

To assess daily growth, sagittal otoliths from a subsample ( $n = \text{up to } 20$  fish per trap net) of age-0 black crappie collected during fall trap netting were removed after recording TL for each fish. Accuracy of daily growth ring counts has not been validated for black crappie; however, this aging

technique has been validated for white crappie (Sweatman & Kohler 1991), a closely related species. This technique has also been used by other researchers (Muoneke 1982; Travnichek et al. 1996). Otoliths were air dried and mounted (convex side up) on glass slides using thermoplastic cement, ground with wet 600-grit sandpaper, and polished on a polishing cloth with alumina powder until center rings were visible. A droplet of low-viscosity (type A) immersion oil was placed on the otolith to improve the optical quality of the rings (Sweatman & Kohler 1991). Daily ring counts by two independent readers were compared for precision; counts that differed by  $\geq 10\%$  were re-examined by both readers until agreement within 10% was reached. The counts of the two readers were then averaged to obtain an age estimate for each fish. Using daily ring counts, we estimated hatch dates (capture date - fish age) and average daily growth rates (mm/day) for age-0 black crappie collected during fall.

Statistics

Differences in larval black crappie abundance, zooplankton abundance, and mean zooplankton size between the two water bodies were analyzed using a split-plot repeated-measures analysis of variance (Maceina et al. 1994). Each sample collected was used as a replicate observation for analyses. Differences in fall age-0 catches from trap nets were assessed by ranking the catch data because data were not normally distributed (Conover & Iman 1981). A general linear model (GLM; SAS 1992) was then used to test for differences in ranked catches. A GLM was also used to test for differences in growth rates determined from otoliths of fall age-0 black crappie between water bodies and among years. Statistical significance was set at 95% ( $\alpha=0.05$ ). When the GLM assessment indicated significant differences among treatments, Tukey's multiple range test was used to determine which means were different at  $\alpha=0.05$ .

Results

Adult fish

The CPUE for black crappie  $\geq 130$  mm TL varied from year to year and between seasons (Table 3). However, CPUE of adult black crappie in Richmond Lake was always at least an order of magni-

tude higher than CPUE in Brant Lake. The size structure of adult black crappie in both waters also varied among years and between seasons (Table 3). However, the black crappie population in Brant Lake always had higher stock density index values than the population in Richmond Lake. For example, few fish exceeded minimum preferred length (25 cm) in Richmond Lake, while substantial proportions exceeded this length in Brant. In fact, memorable-length (i.e.,  $\geq 30$  cm) black crappie were collected in Brant Lake during the final year of this study. The age structures for both black crappie populations shifted toward older fish from 1993 to 1996; the Richmond Lake black crappie population always had older individuals than the Brant Lake population (Table 4). Growth rates of black crappie were faster in Brant Lake than in Richmond Lake (Table 4). During spring 1996, a 5-year-old black crappie in Brant Lake was the same length as an 8-year-old crappie in Richmond Lake.

Larval fish abundance

During 1994–1996, larval black crappie abundances in Richmond Lake peaked on 1–8 June 1994 (day of the year 152–159), 22 June–6 July 1995 (173–187), and 18–25 June 1996 (170–177; Fig. 1). In Brant Lake, larval black crappie abundances peaked on 7–15 June (day of the year 158–

Table 5. Statistical comparisons (split-plot repeated-measures analysis of variance; Maceina et al. 1994) of larval black crappie abundance (number/m<sup>3</sup>) estimated from collection with a 500- $\mu$ m mesh ichthyoplankton net, and of crustacean zooplankton abundance (number/L) and mean size (mm) estimated from collection with a tube sampler and filtered through a 80- $\mu$ m mesh net in Richmond (R) and Brant (B) lakes, South Dakota. Statistical tests were made among years within each water body, and between each water body within each year (labeled R and B). The F-value (F), degrees of freedom (df), and the probability (P) of observing a larger test statistic are provided for treatment (year or water body) and treatment  $\times$  date interaction. P-values  $\leq 0.05$  are in bold.

Test	Year	Treatment			Treatment $\times$ date		
		F	df	P	F	df	P
Larval black crappie abundance							
Richmond		1.73	2, 14	0.214	5.82	17, 186	<b>0.0001</b>
Brant		16.21	2, 14	<b>0.0002</b>	2.60	16, 181	<b>0.001</b>
R and B	94	5.37	1, 14	<b>0.036</b>	4.42	8, 115	<b>0.0001</b>
	95	16.00	1, 14	<b>0.001</b>	4.20	10, 140	<b>0.0001</b>
	96	25.58	1, 14	<b>0.0002</b>	5.69	8, 112	<b>0.0001</b>
Zooplankton abundance							
Richmond		58.66	2, 14	<b>0.0001</b>	5.08	17, 189	<b>0.0001</b>
Brant		56.56	2, 14	<b>0.0001</b>	2.13	17, 188	<b>0.007</b>
R and B	94	37.29	1, 14	<b>0.0001</b>	9.52	9, 126	<b>0.0001</b>
	95	17.39	1, 14	<b>0.001</b>	15.81	10, 140	<b>0.0001</b>
	96	14.45	1, 14	<b>0.002</b>	1.46	8, 111	0.178
Zooplankton size							
Richmond		20.84	2, 14	<b>0.0001</b>	8.36	17, 189	<b>0.0001</b>
Brant		8.81	2, 14	<b>0.003</b>	4.65	17, 188	<b>0.0001</b>
R and B	94	0.29	1, 14	0.600	9.93	9, 126	<b>0.0001</b>
	95	17.40	1, 14	<b>0.001</b>	8.71	10, 140	<b>0.0001</b>
	96	0.48	1, 14	0.501	6.23	8, 111	<b>0.0001</b>

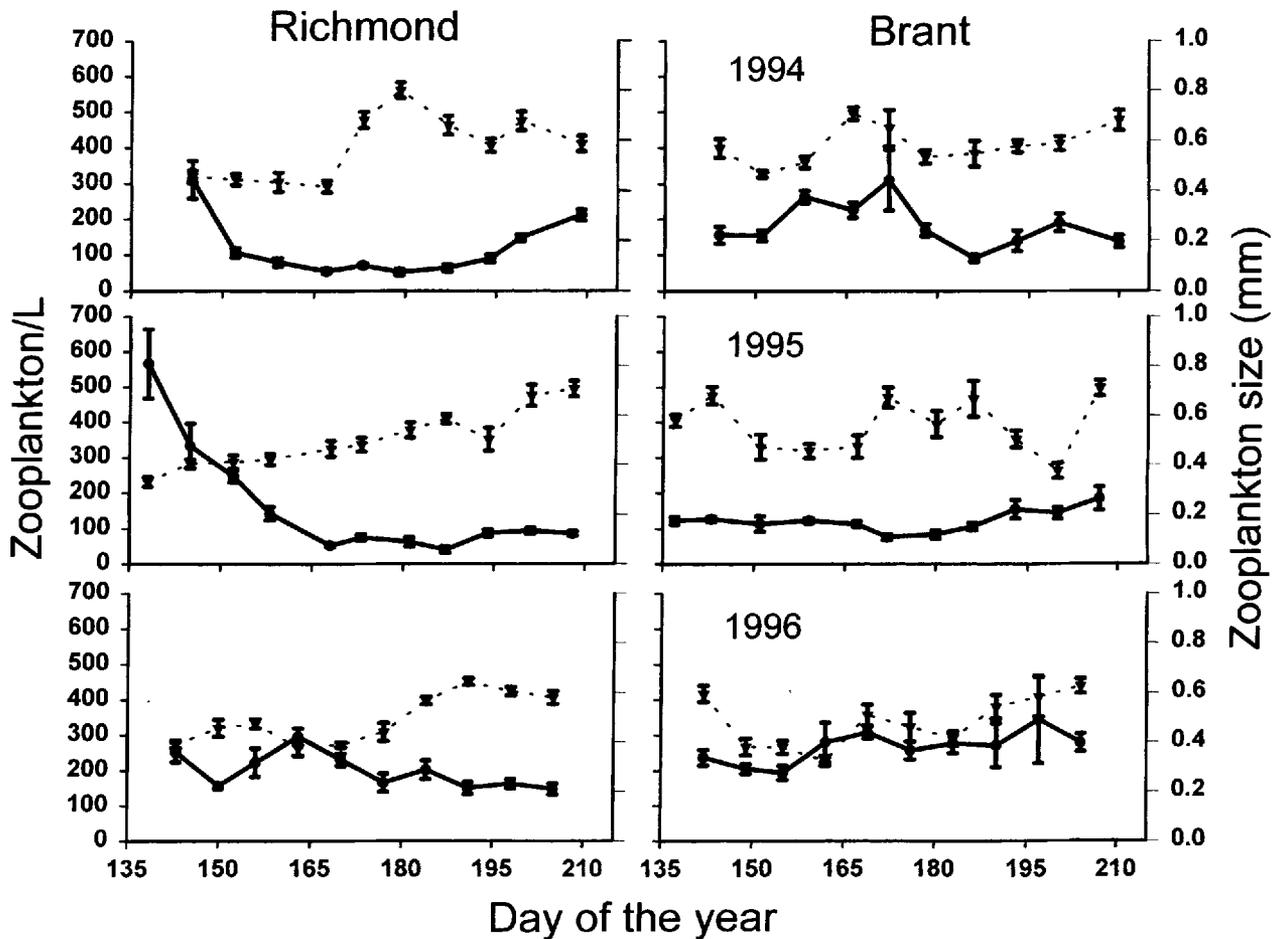


Fig. 2. Crustacean zooplankton abundance (mean±1 SE; circles) and size (mean±1 SE; triangles) in Richmond and Brant lakes, South Dakota, during 1994–1996

166) and again on 19 July 1994 (200); 8 June (159), 29 June (180), and 19 July 1995 (200); and 17 June 1996 (169; Fig. 1). Within each year, larval black crappie abundances differed between water bodies ( $P < 0.04$ ; Table 5). The water body  $\times$  date interactions were also significant all three years ( $P = 0.0001$ ). Larval black crappie abundances were always higher in Richmond Lake than in Brant Lake, and larval black crappie abundances in Brant Lake peaked several times during 1994 and 1995. When comparing among years within each water body, no significant difference in larval abundance was found in Richmond Lake ( $P = 0.214$ ), whereas a significant difference was observed in Brant Lake ( $P = 0.0002$ ). However, the year  $\times$  date interactions for both waters were significant ( $P \leq 0.001$ ). Larval black crappie were collected earlier in 1994 than in 1995 or 1996 in both waters. This likely was a result of water temperatures warming earlier in 1994 (Fig. 1).

#### Zooplankton

During 1994 and 1995, zooplankton abundance in Richmond Lake was highest at the time of first sampling and then declined (Fig. 2). Zooplankton abundance began to increase toward the end of the sampling period during 1994, while little increase in zooplankton abundance occurred during 1995. During 1996, the zooplankton abundance in Richmond Lake was more consistent throughout the sampling period. In Brant Lake, the zooplankton abundances for 1994–1996 (Fig. 2) resembled abundances found in Richmond Lake during 1996. Within each year, zooplankton abundances differed between water bodies ( $P \leq 0.002$ ; Table 5). The water body  $\times$  date interactions were also significant for 1994 and 1995 ( $P = 0.0001$ ), but not for 1996 ( $P = 0.178$ ). Not only did zooplankton abundances differ between water bodies each year, they also differed across years within each water body

( $P=0.0001$ ); the year  $\times$  date interactions were also significant ( $P\leq 0.007$ ).

In Richmond Lake, the zooplankton community was dominated by *Daphnia*, calanoid copepods, cyclopoid copepods, and copepod nauplii (Fig. 3). The Brant Lake zooplankton community contained the same four groups plus *Bosmina* during 1994 and 1995 and *Chydorus* during 1994 and 1996 (Fig. 3). Qualitatively, differences in zooplankton composition occurred between waters within each year. Brant Lake always contained one more common (i.e., composed more than 2% of zooplankton community composition) zooplankton taxon than Richmond Lake. Also qualitatively, differences in zooplankton composition occurred between years within each water body. In Richmond Lake, *Daphnia* constituted a larger percentage of zooplankton

composition during 1994 than in 1995 or 1996, while calanoid copepods had a larger percentage during 1996 than in 1994 or 1995. In addition, cyclopoid copepods were present only for a short time during 1996 in Richmond Lake. In Brant Lake, *Bosmina* was not a common zooplankton taxon during 1996, while *Bosmina* occurred in late June-early July 1994 and in late July 1995.

Mean zooplankton size in Richmond Lake tended to increase through the sampling seasons, while no pattern was evident during the sampling seasons at Brant Lake (Fig. 2). Mean zooplankton size was similar in both water bodies during 1994 and 1996 ( $P>0.5$ ; Table 5), but different during 1995 ( $P=0.001$ ). The water body  $\times$  date interactions were significant all three years ( $P=0.0001$ ). Differences in zooplankton sizes between waters were likely a function of differences in zooplank-

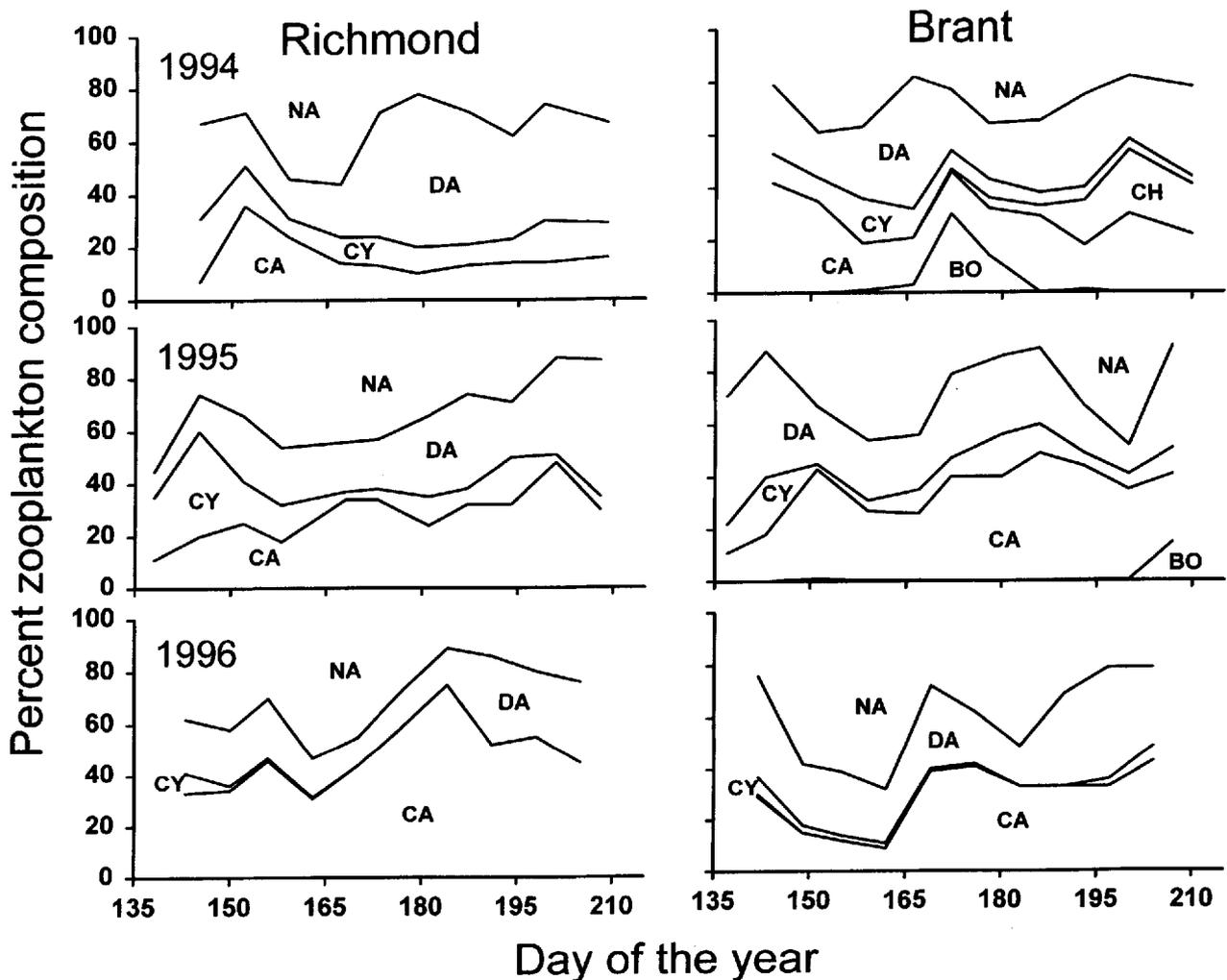


Fig. 3. Crustacean zooplankton percent composition by number in Richmond and Brant lakes, South Dakota, during 1994-1996. BO=*Bosmina* sp.; CA=calanoid copepod; CH=*Chydorus* spp.; CY=cyclopoid copepod; DA=*Daphnia* spp.; and NA=copepod nauplii. *Bosmina* sp. and *Chydorus* spp. in Richmond Lake, and *Ceriodaphnia* spp. and *Diaphanosoma* sp. in Brant Lake composed <2% of zooplankton composition and are not depicted.

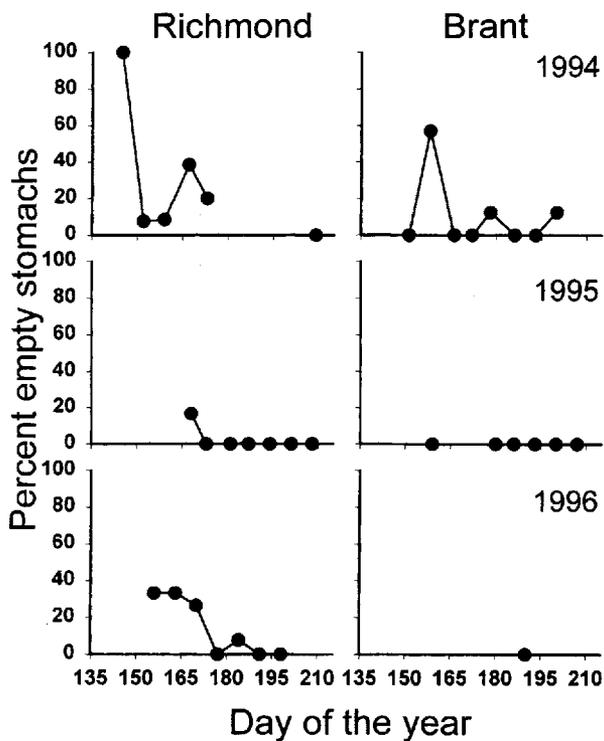


Fig. 4. Percentages of larval black crappie with empty stomachs collected using a 500- $\mu$ m mesh ichthyoplankton net in Richmond and Brant lakes, South Dakota, during 1994–1996.

ton composition. Zooplankton size differed across years within each water body ( $P \leq 0.003$ ); the year  $\times$  date interactions were also significant ( $P = 0.0001$ ). Similarly, differences in zooplankton sizes between years were likely a function of differences in zooplankton compositions.

Age-0 black crappie diets

In general, the percent of larval black crappie with empty stomachs declined as the summer progressed in both water bodies during all 3 years (Fig. 4). Qualitatively, it appeared that the percentage of empty larval stomachs was less during 1995 than during either 1994 or 1996 for both waters.

Calanoid copepods were positively selected for by small (<10 mm TL) larval black crappie during 1994 and 1996 in Richmond Lake, and during 1994 in Brant Lake (Fig. 5). Medium-sized (10–29 mm TL) age-0 black crappie also positively selected for calanoid copepods in Richmond Lake during all three years. Medium and large sized (10–59 mm TL) age-0 black crappie in Brant Lake positively selected *Daphnia* during 1994 and 1995. The medium and large sized (10–59 mm TL) age-0 black crappie also exhibited negative selection for smaller sized zooplankton (i.e., copepod nauplii,

*Bosmina* and *Chydorus*) in both water bodies during all three years.

Fall age-0 abundance

The CPUE for age-0 black crappie in fall trap nets were <10 fish/net night, except in Brant Lake during 1995 (Table 3). The GLM analysis on ranked data for 1994–1996 revealed a significant water body  $\times$  year interaction ( $F = 6.48$ ,  $df = 2, 106$ ,  $P = 0.002$ ); multiple range tests on water body and

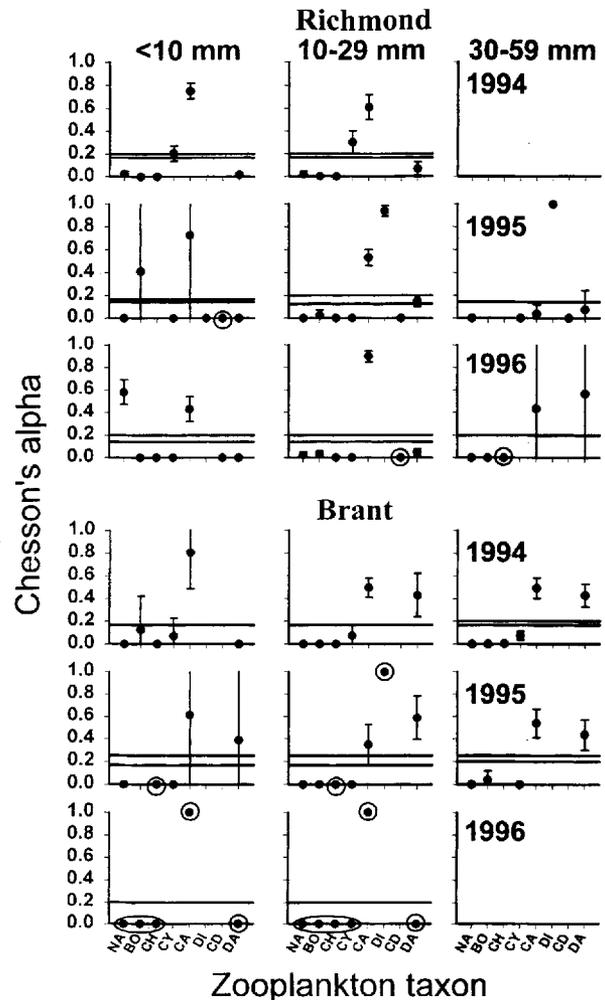


Fig. 5. Prey selection (Chesson's alpha; mean  $\pm$  95% confidence intervals) by age-0 black crappie collected in Richmond and Brant lakes, South Dakota, during 1994–1996. Fish were grouped by total length and prey taxa were ordered by increasing size from left to right. BO=*Bosmina* sp.; CA=calanoid copepod; CD=*Ceriodaphnia* spp.; CH=*Chydorus* spp.; CY=cyclopoid copepod; DA=*Daphnia* spp.; DI=*Diaphanosoma* sp.; and NA=copepod nauplii. Horizontal lines represent the range of neutral selection, determined as the reciprocal of the number of available prey groups; values above this range indicate positive selection and values below this range indicate negative selection. Circled data points represent one fish and thus no 95% confidence interval could be calculated.

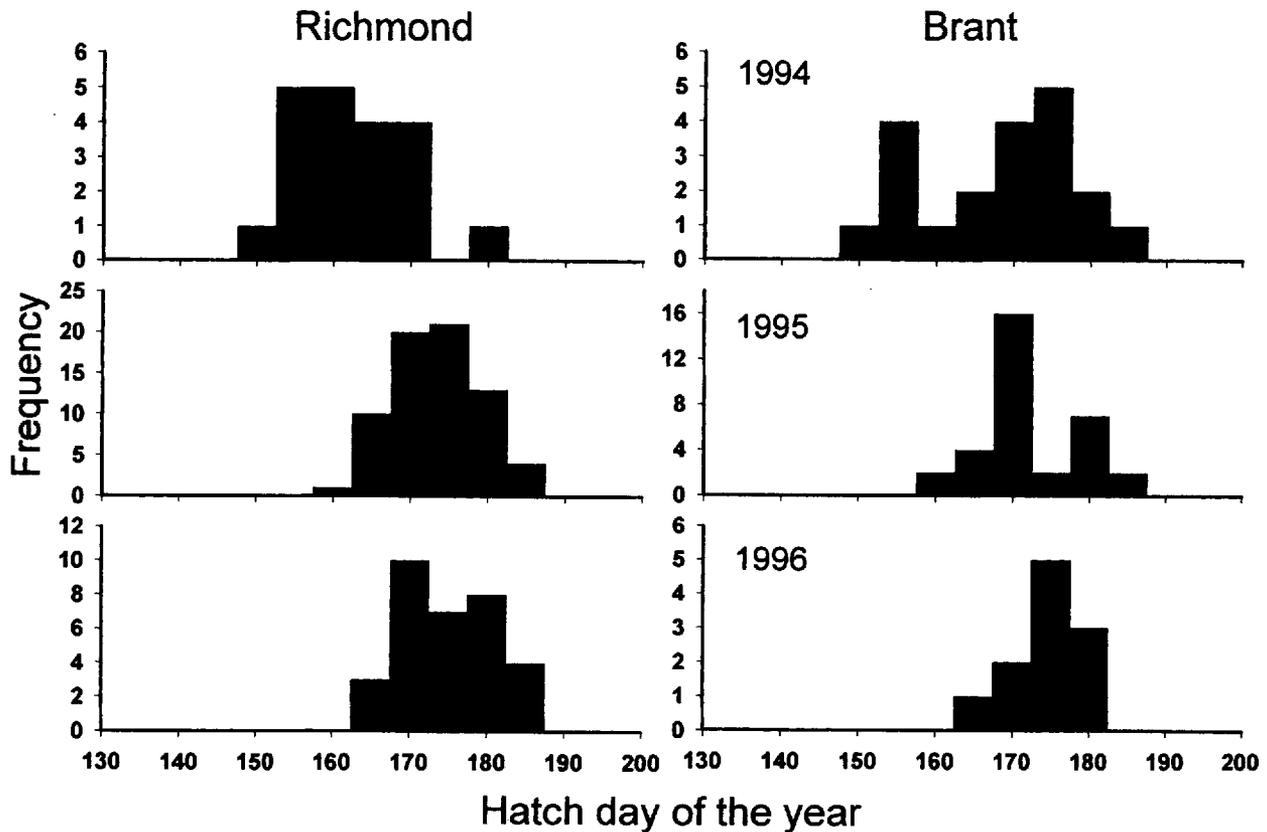


Fig. 6. Hatch date-frequency histograms for age-0 black crappie collected during fall 1994-1996 using trap nets in Richmond and Brant lakes, South Dakota. Hatch dates were based on daily ring counts from otoliths.

year were therefore inappropriate. Although larval black crappie abundances in Richmond Lake were always greater than in Brant Lake, fall trap-net CPUE of age-0 black crappie in Brant Lake was greater than or equal to that in Richmond Lake. Thus, we speculate that age-0 black crappie were much more susceptible to capture with trap nets in the shallow, bowl-shaped natural lake because overall crappie abundance was substantially higher in Richmond Lake than in Brant Lake.

#### Hatch date and growth of age-0 fish

Based on otolith assessments, age-0 black crappie that were collected in fall trap nets hatched on 29 May–28 June 1994 (day of the year 149–179), 10 June–6 July 1995 (161–187), and 14 June–4 July 1996 (166–186) in Richmond Lake (Fig. 6). In Brant Lake, age-0 black crappie hatched on 28 May–4 July 1994 (day of the year 148–185), 11 June–3 July 1995 (162–184), and 16–30 June 1996 (168–182; Fig. 6). Mean growth rates  $\pm 1$  SE for age-0 black crappie in Richmond Lake were  $0.95 \pm 0.02$ ,  $1.08 \pm 0.01$ , and  $0.96 \pm 0.01$  mm/day during 1994, 1995, and 1996, respectively. In Brant Lake, mean growth rates were  $1.03 \pm 0.02$ ,  $1.18 \pm 0.02$ , and  $1.06 \pm 0.02$  mm/day dur-

ing 1994, 1995, and 1996, respectively. The GLM analysis revealed significant differences between water bodies ( $F=28.9$ ,  $df=1,179$ ,  $P=0.0001$ ) and years ( $F=34.97$ ,  $df=2,179$ ,  $P=0.0001$ ) with no water body  $\times$  year interaction ( $F=0.19$ ,  $df=2,179$ ,  $P=0.83$ ). Based on Tukey's multiple range test ( $\alpha=0.05$ ), growth rates were faster in Brant Lake (mean = 1.11 mm/day) than in Richmond Lake (1.03 mm/day). Growth rates in both waters combined were faster during 1995 (1.11 mm/day) than in 1994 (0.99 mm/day) or 1996 (0.99 mm/day), with no difference in growth rates between 1994 and 1996.

#### Discussion

The adult black crappie population in Richmond Lake was characterized by higher catches of slower growing fish, while the Brant Lake population was characterized by lower catches of faster growing individuals. We expected consistent recruitment of black crappie in Richmond Lake and inconsistent recruitment (i.e., one or more years with little or no recruitment) in Brant Lake, based on previous work by Guy & Willis (1995b). However, no complete recruitment failure occurred in Brant Lake

during 1994–1996, although larval abundance was extremely low in two of the three years.

The ichthyoplankton trawl and trap nets had similar trends in age-0 black crappie CPUE for both water bodies (i.e., ranked peak larval abundance in ichthyoplankton trawl and ranked mean catches in trap nets were the same for both waters) during 1994–1996; peak larval abundance was highest in 1994 in both waters, and fall age-0 CPUE was highest in 1995 in both waters. We speculate that broad environmental factors may have similarly affected black crappie reproduction and recruitment in the natural lake and impoundment. Climatological conditions varied across the three years of this study (Pope 1996). We found evidence that the rate of spring water warming influences larval black crappie abundance, with abundance being greater in years where waters warm earlier (such as occurred during 1994). However, nesting success and resulting larval abundance apparently was not related to black crappie recruitment in our study waters. Instead, the year with the highest fall age-0 catches in both waters (i.e., 1995) was characterized by delayed black crappie spawning and low larval catches. The presence of age-0 black crappie during fall does not necessarily indicate recruitment to the adult population; however, these fish are closer to being recruited than are the larvae. We found the lowest percentage of empty larval stomachs and the fastest growth rates of age-0 black crappie during 1995, suggesting that decreased intraspecific competition may have resulted in faster growth and a stronger year class. In addition, precipitation was highest during 1995 (Pope 1996), and larger year classes of crappies have been associated with increased water levels (Mitzner 1981; Beam 1983).

In Richmond Lake during 1994 and 1995, larval black crappie abundance peaked after overall zooplankton abundance had already declined. During 1996, overall zooplankton abundance did not decline as in the two previous years in Richmond Lake and provided the highest numbers of total zooplankton per liter when larval black crappie abundance peaked. In Brant Lake, larval black crappie abundance peaked when overall zooplankton abundance was high during 1994 and 1996. During 1995, overall zooplankton abundance remained low in Brant Lake. However, 1995 was the year that produced highest catches of age-0 black crappie in the fall trap netting. Thus, timing of larval black crappie abundance and overall zooplankton abundance did not appear important for recruitment of black crappie in these two South Dakota waters. These results are in contrast to the match/mismatch hypothesis proposed by Cushing (1975; i.e., synchrony between hatching and first

feeding of larval fish and the occurrence of favorable foraging conditions is an important regulating mechanism of larval survival and year-class strength). Furthermore, to our surprise, nothing was unique about the cladoceran, calanoid copepod, cyclopoid copepod, or copepod nauplii abundance or mean size during 1994 or 1995 that could be related to either the high larval black crappie abundance during 1994 or the high fall age-0 crappie abundance during 1995 (Pope 1996).

The food habits of age-0 black crappie in combination with zooplankton availability and vulnerability may partially determine year-class strength in South Dakota waters. The highest CPUE of age-0 black crappie in fall trap nets occurred during 1995 in both study waters. During 1995, small (<10 mm TL) age-0 black crappie consumed *Bosmina* in equal proportion to their occurrence in Richmond Lake but negatively selected them during 1994 and 1996. Similarly, small black crappie consumed *Daphnia* in equal proportion to their occurrence in Brant Lake during 1995 but negatively selected them during 1994 and 1996.

This study occurred during three relatively wet years with temporal differences in precipitation among years. Pope et al. (1996b) found that fall age-0 black crappie CPUE in a bottom trawl was negatively correlated with precipitation in Brant Lake over an 8-year period (1988–1995). However, Pope (1996) speculated that this relationship might be caused by a biological interaction between age-0 yellow perch *Perca flavescens* and black crappie, as Pope et al. (1996b) documented an inverse relation between CPUE of age-0 yellow perch and black crappie. Thus, fall age-0 trap net CPUE would likely be higher during drier years than occurred during our study, at least in Brant Lake. Unfortunately, we were unable to determine the cause of black crappie year-class failure (or near-failure) in Brant Lake. A combination of harsh climatic conditions during spawning (Pope & Willis, 1997) and again during a time period when juvenile black crappie are especially vulnerable (some time between when larvae were collected and fall trap netting) may be the cause, although larval yellow perch abundance could also be a contributing factor.

Spawning date is important because successful nesting is a prerequisite to black crappie recruitment. Siefert (1968) suggested that low water temperatures before and during white crappie spawning could reduce year-class strength. Our study, however, suggests that low water temperature during spring is not detrimental to black crappie year-class strength. The year with the highest CPUE of age-0 black crappie during fall trap netting (1995) was characterized by low spring water

temperatures and delayed black crappie spawning. Black crappie may be able to adjust to unfavorable spawning conditions. For example, some adult female black crappie in Richmond Lake demonstrated the potential to spawn more than once during a single spawning season (Pope et al. 1996a). Based on our otolith age assessment of age-0 black crappie, the population in Brant Lake had two distinct spawning times during 1994 and 1995 and there is a hint of a similar occurrence in Richmond Lake. This is not evidence that individuals spawned more than once in either of these waters; however, the otoliths provide evidence that the population as a whole did not invest all of its spawning potential at one time.

There may be a critical period for black crappie recruitment between the larval stage in early summer and the fall when trap netting was conducted. Large numbers of larvae were collected in 1994, but few age-0 fish were captured in the trap nets. Future research should concentrate on this mid- to late-summer period; we had difficulty collecting age-0 black crappie during this time. We believe that the bottom trawl discussed by Pope et al. (1996b) would effectively sample age-0 black crappie in most eastern South Dakota natural lakes; however, we are unsure of its utility in steep-sided impoundments such as Richmond Lake.

The results of this study initially appear contrary to the findings of Guy & Willis (1995b) that impoundments had more consistent black crappie recruitment (i.e., missing year classes were not common), while natural lakes had more inconsistent recruitment. However, we suspect that so-called missing year classes in eastern South Dakota natural lakes reflect very low abundance, simply correspond with weak but apparent year classes in South Dakota impoundments, and are largely a result of environmental factors. Thus, one possible difference in black crappie recruitment processes between these two water bodies is the degree to which environmental factors influence black crappie year-class strength. Recruitment of black crappie in Brant Lake is more variable than in Richmond Lake likely because climatological influences on Brant Lake are more extreme due to its shallow nature and bowl-shaped basin. In addition, yellow perch (which are well established in South Dakota natural lakes but sparse in South Dakota impoundments) could also increase variability of black crappie year-class strength in natural lakes [see Pope (1996) for a discussion of this possible phenomenon].

## Resumen

1. En dos lagos de Dakota del Sur (USA), el Lago Richmond (lago de inundación), y el Lago Brant (lago natural), compara-

mos, durante el período 1994–1996, la biología de los primeros estadios de *Pomoxis nigromaculatus*. En principio, esperamos un reclutamiento variable en el algo natural y más consistente en el de inundación.

2. Los juveniles de edad 0 fueron colectados con tres tipos distintos de redes: redes de arrastre de ictioplancton de 500 µm; redes de arrastre de 1.6 mm de luz, y trampas de 13 mm de luz. El zooplancton fué colectado con un muestreador de tubo de 2 m de longitud y, posteriormente filtrado en zedazo de 80 µm de luz de malla. La dieta de los juveniles fué también analizada y, además, utilizamos otolitos de juveniles capturados en las trampas para determinar la fecha de eclosión.

3. La abundancia de larvas fué siempre mayor en el lago Richmond. En ambos lagos, el pico de abundancia se produjo en 1994. Sin embargo, este pico no se correspondió con las CPUE de los individuos de edad 0, que, por el contrario, alcanzó un máximo en 1995. Esto indica que el reclutamiento en *P. nigromaculatus* no se debió sólo al número de larvas eclosionadas. Los estudios sobre el zooplancton y la dieta no pusieron de manifiesto ningún hecho que explicase la máxima abundancia de 1995.

4. Tendencias similares observadas en las capturas realizadas con redes de ictioplancton y con trampas, indicaron que amplios factores ambientales actuaron de forma similar sobre la reproducción y el reclutamiento de la especie en ambos lagos.

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