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Temporal variation in trap net catch per effort of Black Crappie in seven Minnesota lakes

by

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Abstract — We estimated monthly and daily trap net catch per effort (CPUE) of Black Crappies 200 mm and longer in seven Minnesota lakes. We then determined if annual patterns in monthly CPUE were consistent among lakes and between years, determined the time of year when CPUE is highest and lowest, and determined the time of year when CPUE best reflects population density. The highest CPUE occurred during the spring and the lowest in June in most lakes, but temporal patterns differed among lakes and between years within lakes. Spawning probably contributed to low June CPUE in all lakes, and fall turnover probably contributed to decreased CPUE in October in the five dimictic lakes. Daily variation in air temperature did not affect daily variation in CPUE within sampling periods, and synchrony in daily fluctuations in CPUE did not occur between pairs of lakes sampled on the same days. Trap net CPUE in early spring and September best reflected density, and CPUE in late spring, August, and October also increased with increasing density. Conversely, CPUE in June and July did not. Inconsistencies in aquatic plant density, mortality, growth, and recruitment of Black Crappies probably contributed to inconsistent temporal variation in CPUE among lakes. These results suggest that trap net CPUE collected with Minnesota Department of Natural Resources standard surveys during June and July will not be very useful as an index of relative abundance of Black Crappies.

INTRODUCTION

Fisheries staff of the Minnesota Department of Natural Resources (MNDNR) frequently rely on trap net catch per effort (number per trap net lift; CPUE) obtained during standard surveys as an index of relative abundance of Black Crappie, even though trap net CPUE varies temporally during the summer. Sampling guidelines recommend that trap nets be set during the same time period between late May and early September in a given lake so that some factors causing temporal variation in CPUE are controlled (MNDNR 1993). However, MNDNR also calculates from all trap net CPUE data quartiles of CPUE of Black Crappie for each lake class. These quartiles are used as a basis to judge as average, low, or high, CPUE estimates for a given survey even though temporal variation in trap net CPUE is not factored in calculations of these quartiles (MNDNR unpublished data).

We know that trap net CPUE of Black Crappie varies temporally within lakes during a given year, but we did not know if these trends occurred consistently among years or if CPUE during standard surveys reflects population density. Trap net CPUE of Black Crappie $\geq$ 130 mm or $\geq$ age 1 in a South Dakota lake differed among months between March and October, and summer (June, July, or August) CPUE often differed from fall (September or October) CPUE in 40 Minnesota lakes (Guy and Willis 1991; McInerny et al. 1993). Trap net CPUE of Black Crappie 200 to 299 mm TL in April, May, September, and October increased with increasing population density among seven Minnesota lakes, but trap net CPUE of smaller Black Crappie did not (McInerny and Cross 2006). Trap net CPUE during summer months has not been compared with estimates of population density of Black Crappie; thus, we do not know if CPUE reflects density. Understanding these aspects of temporal variation in CPUE will enhance inference on Black Crappie population density in Minnesota lakes. Both predictable and unpredictable factors probably affect temporal variation in catchability *q*, one of the two components, along with population size (or density) that compose CPUE (Ricker 1975). For trap netting, *q* reflects the likelihood of Black Crappies moving into shallow (< 2 m deep) water within 12 to 15 m of the shoreline (where nets are usually set) and being captured by the net. Identifying and quantifying these factors will aid interpretation of CPUE.

Predictable seasonal changes in *q* should occur because responses of Black Crappies to warming water temperatures in spring, warm water temperatures in summer, and cooling temperatures in fall should be similar. Black Crappies prefer water temperatures between 20 and 30 ^{o}C (Neill and Magnuson 1974; Reynolds and Casterlin 1977), and they seek warmer water temperatures when inhabiting water below preferred temperatures (Knights et al. 1995). Thus, in dimictic lakes, we expect Black Crappies to be near the surface in spring and in deeper water during fall, but this species could occupy any depth in polymictic lakes. Additionally, we expect lower *q* during spawning, when water temperatures are between 14 and 25 ^{o}C, because nesting males remain on nests (Carlander 1977; Hanson and Qadri 1980; Pope et al. 1996a; Pope and Willis 1997). Thus, trap nets should capture few mature males during spawning. Capture of females could still occur because they deposit eggs on several nests and produce eggs several times during the spawning season (Schneberger 1972; Pope et al. 1996a).

Other less predictable factors likely increase the daily and seasonal variability in *q* by affecting Black Crappie behavior and movement patterns; these factors include varying thermal stratification patterns among lakes, weather, and prey availability. Minnesota lakes have different morphologies and different thermal stratification patterns conceivably leading to different seasonal movements for Black Crappies among lakes. Daily weather patterns potentially affect behavior of Black Crappies. For example, Guy et al. (1992) observed that Black Crappies 295 mm and longer in a natural South Dakota lake exhibited greater movement (m/h) during periods of high barometric pressures and low wind speeds. Black Crappies usually rest during the day at depths ranging from 1.5 to 5 m and move to either deeper or shallower habitats during the evening presumably to feed (Keast and Harker 1977; Helfman 1981; Guy et al. 1992). Prey availability varies spatially and seasonally within lakes (Keast and Fox 1992) and influences where Black Crappies will move to feed. These unpredictable movements can either increase or decrease *q* depending on whether or not trap nets are set in feeding areas.

Temporal variation in mortality, recruitment, and growth affects population density, which in turn affects CPUE, and these parameters can vary among lakes and over time. Although rarely estimated, annual mortality of Black Crappies ranges from 48 to 91% (Carlander 1977; Parsons and Reed 1998), but mortality is probably not constant throughout a given year. Recruitment patterns of Black Crappies range from relatively stable to sporadic (Isermann et al. 2002), and growth rates differ substantially among natural lakes, even those in close proximity to each other (Carlander 1977; McInerny and Cross 1999). Variable growth affects both the rate of recruitment (Ricker 1975) and *q* because trap nets select for larger Black Crappies (Laarman and Ryckman 1982; McInerny and Cross 2006).

This study addressed several objectives intended to improve the utility of trap net CPUE for management of Black Crappie in Minnesota lakes. Because it is widely used as an index of population density, we evaluated whether seasonal patterns in CPUE are similar within and among lakes and determined what time(s) of year CPUE reflects density. To further understand differences in CPUE between lakes, we characterized the relationship between temporal patterns in CPUE and growth, recruitment, and mortality rates. Lastly, to help separate the effect of variation in *q* from that of changes in density, we determined the effects of environmental factors such as water temperature and weather on CPUE.

STUDY AREA

We sampled Black Crappie populations from seven lakes located within McLeod, Meeker, and Wright counties. These lakes represent a set of lakes with relatively high angler harvests of Black Crappie (Minnesota Department of Natural Resources statewide (MNDNR) creel survey database). Lake surface areas ranged from 18 to 168 ha, and maximum depths ranged from 3.0 to 15.2 m (Table 1). Marion and Swan lakes do not thermally stratify during ice-free periods, but the other five lakes are dimictic. Thermal stratification in dimictic lakes begins in late April or early May and is strongest by July. The top 4 to 5 m in each dimictic lake compose the epilimnion, and the hypolimnion becomes anoxic by July (MNDNR, unpublished data). Fall turnover begins in late September, but is not complete until October. At the time of this study, Marion, Erie, Little Swan, and Dog lakes supported moderate to dense stands of submergent aquatic macrophytes from June through early October (Cross and McInerny 2001; MNDNR, unpublished data). Dense stands of *Potamogeton crispus* occurred in Ida Lake from early May through June, but these plants begin dying off in July. Conversely, Swan and French lakes lacked substantial stands of submergent macrophytes (Cross and McInerny 2001; MNDNR, unpublished data).

TABLE 1. Surface area, maximum depth, thermal stratification status, and sampling duration of Black Crappie at seven lakes in south central Minnesota.

Lake	Surface area (ha)	Maximum depth (m)	Stratification status	Sampling duration
Marion	168	3.7	Polymictic	1996-1998
Swan	139	3.0	Polymictic	1996-1998
Erie	74	10.4	Dimictic	1997-1999
French	134	15.2	Dimictic	1997-1999
Little Swan	18	9.4	Dimictic	1998-2000
Dog	38	7.6	Dimictic	1999-2001
Ida	32	7.9	Dimictic	1999-2001

METHODS

Monthly and daily variation in trap net CPUE was determined by sampling Black Crappie during the open water season beginning in June and ending in late spring during the following year. We sampled each lake for two consecutive years but not all seven were sampled during the same years (Table 1). We set standard trap nets at the same eight (Little Swan Lake only) or nine standard shoreline locations (MNDNR 1993). Leads were tied to shore, and nets were stretched perpendicular to shore. Codends of nets sat in depths of 2 m or shallower at all locations in each lake except for one location in Lake Erie. Numbers of net locations reflected procedures used during standard sampling by MNDNR fisheries staff (MNDNR 1993). Net locations within each lake were roughly equidistant from each other, and nets were set for two to four consecutive days within a week. Trap nets were set during a one week period within the middle of June, July, August, September, and October sampling periods, and one to two weeks in early (April to early May) and late spring (mid-May to early June) sampling periods. The additional samples in early and late spring were needed for estimating population size of Black Crappies. The early spring sampling period began one to two weeks after ice completely melted from lakes, and the late spring sampling period began two to three weeks after the last day of the early spring sampling period. Nets were lifted, emptied of all fish, and reset once per day. We measured total lengths (TL; in mm) of all Black Crappies captured in each net.

For each sampling period and lake, we calculated CPUE only for Black Crappies 200 mm and longer because trap nets do not effectively sample smaller Black Crappies (McInerny and Cross 2006); this length is also a standard for some size-structure indices (Neumann et al. 2012). We defined as our sample unit daily trap net CPUE (total catch per day in all nets combined/ total number of nets in the lake), and we excluded from analysis all sampling days when less than nine (eight for Little Swan Lake) nets fished.

Monthly variation in CPUE - We determined if trap net CPUE differed among monthly sampling periods and evaluated whether intra-annual patterns in CPUE were similar among lakes and years by using graphical analysis and mixed effects models (Searle et al. 1992). We first constructed line graphs to illustrate temporal trends in mean CPUE among monthly sampling periods (June through late spring) in each lake and year. Based on the monthly patterns observed in CPUE, we then fit a series of models with $\log_e$ (CPUE+1) as the response variable and a cubic polynomial of sample period as a fixed explanatory variable (June = 1, July = 2, August = 3, September = 4, October = 5, early spring = 6, and late spring = 7). The first model assumed a common cubic polynomial relationship between sample period p and $\log_e$ (CPUE+1):

$$\log_e(\text{CPUE}+1) = \mu + pb_1 + p^2b_2 + p^3b_3, \quad (1)$$

where μ is the intercept, b_1 is the linear parameter, b_2 is the quadratic parameter, and b_3 is the cubic parameter. The second model assumed the same common polynomial as in (1), but added a random lake effect that moves the polynomial curve upward or downward, accounting for different Black Crappie densities among lakes:

$$\log_e(\text{CPUE}+1) = \mu + c_i + pb_1 + p^2b_2 + p^3b_3, \quad (2)$$

where c_i is a random intercept deviation for lake i assumed to be distributed Normal $(0, \sigma_L^2)$. The third model contained lake-year (i.e., a single year in an individual lake) as a random effect, which accounted for different Black Crappie densities among lakes and years:

$$\log_e(\text{CPUE}+1) = \mu + c_{ij} + pb_1 + p^2b_2 + p^3b_3, \quad (3)$$

where c_{ij} is the random effect for the ith lake in year j assumed to be distributed Normal $(0, \sigma_{LY}^2)$. The fourth model included a random lake-year effect, but fit a unique polynomial for each lake. This allowed for a unique annual pattern in CPUE for each lake while adjusting for differences in Black Crappie densities between years within each lake:

$$\log_e(\text{CPUE}+1) = \mu + c_{ij} + pb_{1,i} + p^2b_{2,i} + p^3b_{3,i}, \quad (4)$$

where $b_{1,i}$ is the linear parameter for the ith lake, $b_{2,i}$ is the quadratic parameter for the ith lake, and $b_{3,i}$ is the cubic parameter for the ith lake.

The final model assumed a unique polynomial model for each lake-year (each lake had a unique annual pattern in CPUE each year):

$$\log_e(\text{CPUE}+1) = b_{0,ij} + pb_{1,ij} + p^2b_{2,ij} + p^3b_{3,ij}, \quad (5)$$

where all the b parameters are fixed effects and represent the ith lake in year j.

For these models, we assumed that our study lakes were random samples of lakes, and that lake-years were random samples of annual conditions for Black Crappie populations in Minnesota. We used the *lm* and *lme* procedures in the statistical software *R* (version 2.4.1) to fit models. We compared models using the Schwarz Information Criterion *SIC* (Schwarz 1978). This criterion, also known as Bayesian Information Criterion, is similar in form to the Akaike Information Criterion (Akaike 1973) but usually selects for more parsimonious models.

Relationship between CPUE and population density within monthly sampling periods - We examined the relationship between mean daily CPUE and population density within each monthly sampling period. We first tested if CPUE increases with increasing population density and then tested if catchability *q* is density dependent for each monthly sampling period. We estimated population size of Black Crappie 200 mm and longer during each fall (September and October) and early spring sampling period. Fall estimates were made with fall marking and spring recapture, and early spring estimates were made with early spring marking and late spring recapture (McInerny and Cross 2005). We used the Petersen method with the Chapman modification when four or more marked Black Crappies were captured in recapture samples (Ricker 1975). Population density was estimated by dividing population size by the surface area of each lake. We plotted $\log_e$ mean trap net (CPUE +1) in early spring, late spring, June, and July as a function of $\log_e$ spring population density among lakes, and plotted $\log_e$ mean trap net (CPUE+1) in July, August, September, and October as a function of $\log_e$ fall population density. We applied orthogonal regressions to quantify these relationships because both CPUE and population density were measured with error (SAS 2002). Orthogonal regressions require a ratio of the variance of the error in $\log_e$ (CPUE+1) to the error in $\log_e$ population density. Variance in density estimates was calculated with the following formula: $(\log_e \text{density})^2 * (C\text{-}R)/(C+1)*(R+2)$, where C is the size of the recapture sample and R is the number of marked fish recaptured (Ricker 1975). To approximate the measurement error ratio within each sampling period, we divided the estimated variance of the $\log_e$ population density estimate within each lake by the sampling variance of daily $\log_e$ (CPUE+1), and used the median variance ratio among all lakes sampled within a particular sampling period in the orthogonal regression. Increases in the measurement variance ratio, e.g. from high variance in density estimates, will increase the estimated slope of the regression. Lastly, we tested for density dependency in trap net *q* by examining slopes in orthogonal regressions. If 95% confidence intervals of slopes include 1 then *q* is likely density independent because the relationship between CPUE and density is linear (Peterman and Steer 1981). If slopes differed from 1 then we reported the most likely scenario of density dependency on *q* by visually examining the relationship between untransformed CPUE as a function of untransformed density (Richards and Schnute 1986). Catchability decreases with increasing density if the relationship between CPUE and density is nonlinear and the intercept is zero (Case 2 in Richards and Schnute 1986) or when no relationship is evident (Case 3). Catchability decreases or increases with density if the relationship is linear and the intercept differs from zero (Case 4), and *q* either decreases with increasing density or peaks with intermediate density if the relationship is nonlinear and the intercept is above or below zero (Case 5).

Water temperature and weather effects on CPUE - We gathered data on water temperature and local air temperatures to aid in interpretation of monthly trends in trap net CPUE or relationships between CPUE and population density. We measured with a hand held thermometer water temperature at the surface just offshore of the boat access once each day when we lifted trap nets. We plotted daily CPUE as a function of water temperature during spring and fall at each lake, and fitted to plots locally weighted scatterplot smoothing (LOWESS) lines (tension = 1) (SPSS 2000). We defined spring as early spring through June sampling periods within the same year, and fall as August through October sampling periods within the same year. Therefore, we evaluated relationships between water temperature and CPUE for one spring and two fall periods at each lake.

We used a two-fold approach to test the hypothesis that weather affected daily CPUE. First, we tested if stability in air temperatures (a surrogate for weather stability) was linked with daily variation of CPUE among lakes and sampling periods. We gathered from the National Weather Service monitoring station in Hutchinson, MN mean air temperatures (average of the high and low daily air temperature) for each day of trap netting (this station did not record daily barometric pressure or wind velocity). We then calculated coefficient of variation (CV) for $\log_e$ (CPUE +1) and for mean daily air temperatures within each monthly sampling period at each lake. We used a three-way ANOVA to test the effects of CV of mean air temperature, lake, and sampling period on CV of $\log_e$ (CPUE+1). Within this ANOVA, CV of air temperature was a continuous variable, and lake and sampling period were categorical variables. We used Tukey’s Honestly Significant Difference (HSD) tests to identify means that differed significantly ($P < 0.05$). We reported the ANOVA results only if the residual plot was uniform.

We then examined synchrony in daily CPUE within monthly sampling periods. If daily variation in CPUE is synchronous among lakes, then daily weather patterns probably affect CPUE similarly among lakes. If daily CPUE trends are not synchronous among lakes, then either weather does not affect CPUE or Black Crappies in different lakes do not behave similarly in response to weather. We sampled three pairs of lakes (Marion and Swan, Erie and French, and Dog and Ida) on the same days during all sampling periods. Sampling during the first year on Little Swan Lake occurred on the same days as sampling during the second year on French and Erie lakes. The second year of sampling at Little Swan Lake occurred on the same days as the first year of sampling at Dog and Ida lakes. Marion and Swan lakes are 18 km apart, Erie and French lakes are 30 km apart, and Dog and Ida lakes are about 0.2 km apart. Little Swan Lake is 17 km from Lake Erie, 13 km from French Lake, and 28 km from Dog and Ida lakes. We assumed that similar weather conditions occurred at lakes sampled on the same days. We counted the number of times when trap net CPUE in lake pairs simultaneously increased by any amount, decreased by any amount, or stayed the same between sampling days within sampling periods. We also counted the number of times when CPUE increased by any amount between days in one lake and decreased by any amount in the other.

Recruitment and mortality effects on CPUE - We estimated recruitment and mortality to help aid in interpretation of monthly variation in CPUE and density. To evaluate recruitment effects on CPUE, we estimated year-class strengths in each sampling period in each lake and monthly growth rates of Black Crappie 200 mm and longer. We collected scale samples from a minimum of five individuals per 10-mm length group during each sampling period except early and late spring. Collection of scale samples in early and late spring was not necessary because no growth occurs in these lakes between October and early June the following year (McInerny and Cross 2005). Scale samples from length groups not sampled in the previous fall were collected from individuals captured in early or late spring. We estimated age by counting annuli on scale impressions made on acetate strips, and we relied on age-length keys to assign ages to un-aged individuals (Quist et al. 2012). We used as an index of year-class strength the mean CPUE of each year-class 200 mm and longer. We estimated growth between sampling periods by calculating mean total lengths of a single year-class (usually the strongest) at the time of capture in all sampling periods, and plotted mean total length as a function of monthly sampling period.

We estimated total annual mortality A as 1 – survival rate S for the strongest year-class or groups of consecutive year-classes longer than or near 200 mm at each lake. We calculated S by dividing population size estimated during the second year N_{t+1} by the estimate during the first year N_t (Ricker 1975). Variance of S was calculated with the delta method (Rao 1965) and used to calculate 95% confidence intervals CI of S. The lower confidence limit of A equaled 1- the upper confidence limit of S, and the upper limit of A equaled 1 – the lower limit of S. We calculated mean A and 95% CI if two estimates of A were made at a lake.

RESULTS

Trap net CPUE of Black Crappie 200 mm and longer differed inconsistently among monthly sampling periods among all lakes and within all lakes except Lake Erie (Figure 1). The lowest CPUE in nearly all lakes and years occurred during June, and moderate to high CPUE occurred during the late spring sampling period in all lakes except Ida (Figure 1). Model 5, which assumed a unique cubic polynomial model for each lake and year, best explained $\log_e$ (CPUE+1) (*SIC* = 811), but model 4, which also assumed a unique cubic polynomial for each lake but with a random year effect, also fit these data relatively well (*SIC* = 821). Model 1, which assumed a common cubic polynomial (fixed sample period effect only), had the worst fit (*SIC* = 1,099), while models 2 (*SIC* = 892) and 3 (*SIC* = 860), which included random effects to the common polynomial model, were intermediate. These models suggest that lakes have unique monthly patterns in CPUE, and that the monthly pattern within an individual lake varies between years.

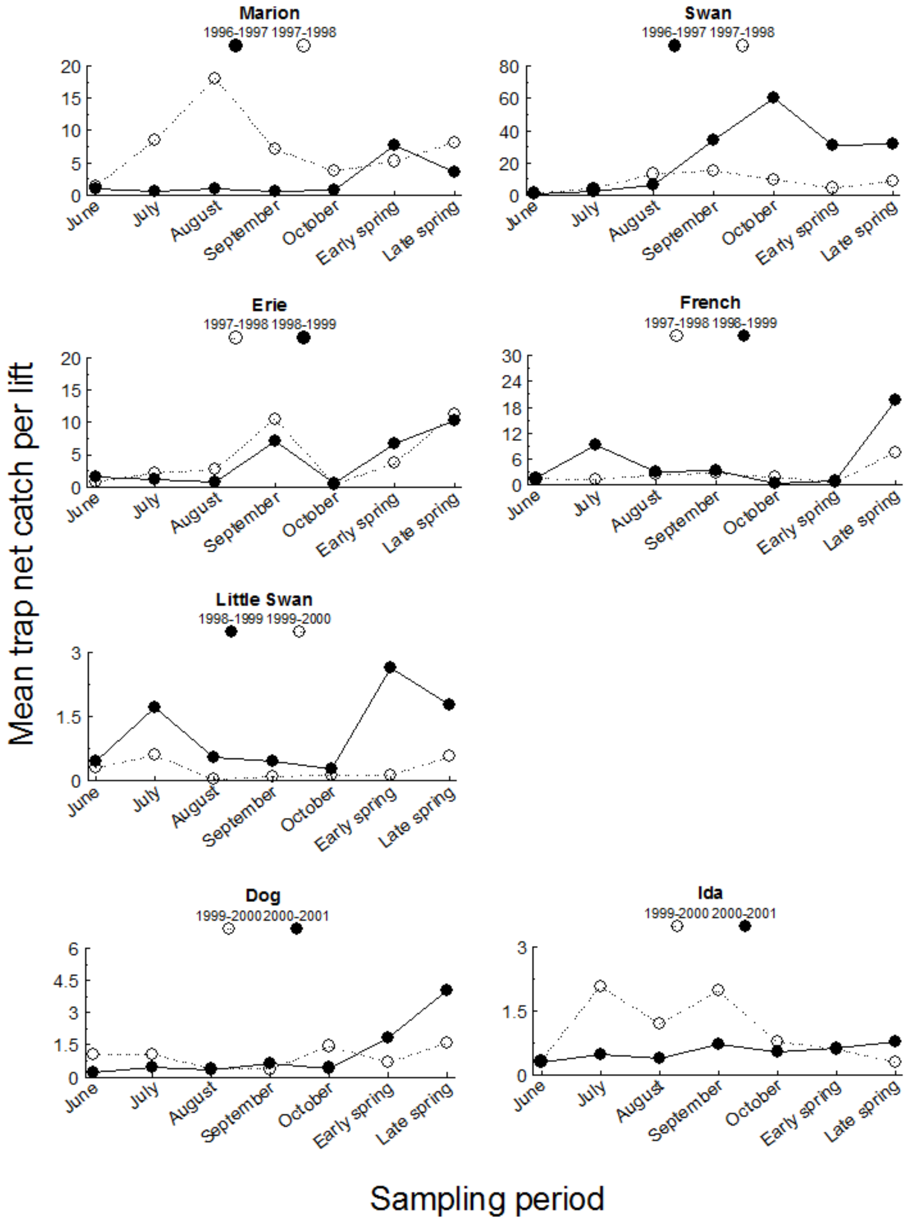


FIGURE 1. Mean trap net catch per effort (CPUE; number/lift) of Black Crappie 200 mm and longer during seven sampling periods across two years at seven Minnesota lakes.

Trap net CPUE in September and early spring reflected density among study lakes better than the other sampling periods. Log*e* (CPUE+1) increased linearly with log*e* population density during all sampling periods except June and July (Figure 2). Correlation coefficients between log*e* (CPUE + 1) and log*e* population density were higher in September and early spring than in late spring, August, or October (Table 2). We also found no evidence that *q* in early spring, late spring, August, September, and October is density dependent during any sampling period because slopes determined with orthogonal regressions of log*e* (CPUE+1) as a function of log*e* population density did not differ from 1 (Table 2). Catchability in June and July decreased with increasing density because CPUE did not change with increasing density (Richards and Schnute (1986) Case 3; Figure 2).

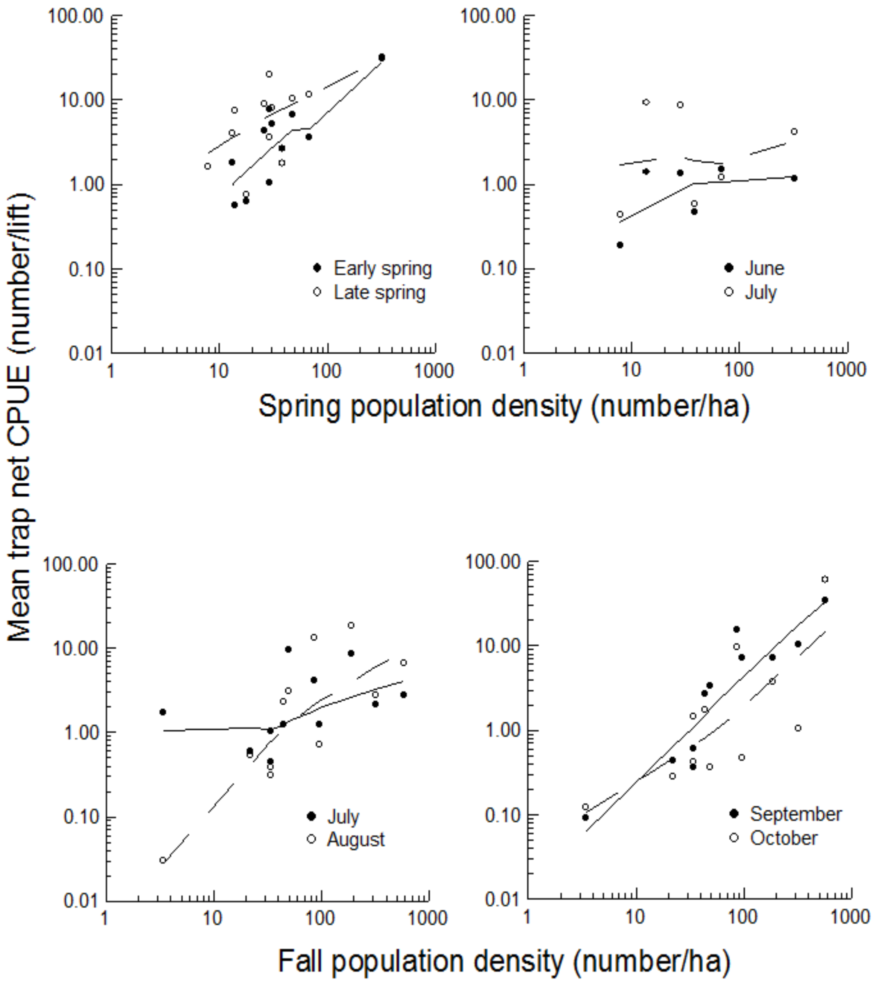


FIGURE 2. Mean trap net catch per effort (CPUE; number per lift) of Black Crappies 200 mm and longer among seven monthly sampling periods as a function of population density among seven Minnesota lakes (solid lines go with solid circles and dashed lines go with open circles; lines fitted with LOWESS smoothing; tension = 1).

TABLE 2. Slopes with 95% confidence intervals, intercepts, variance ratios, correlation coefficients *r*, sample size, and probabilities that slopes equaled zero for orthogonal regression models of $\log_e$ mean trap net catch per lift (CPUE + 1) as a function of $\log_e$ population density of Black Crappie 200 mm and longer during monthly sampling periods among seven Minnesota lakes.

Sampling period	Slope (95% confidence intervals)	Intercept	Variance ratio	*r*	*n*	*P*
Early spring	1.04 (0.72 – 1.81)	-2.23	0.067	0.85	12	0.0004
Late spring	1.29 (0.70 – 6.03)	-2.50	0.064	0.66	12	0.0183
June	0.58 (0.11 - ∞)	-1.47	0.006	0.40	6	0.4258
July (spring density)	5.19 (0.33 - ∞)	-17.46	0.033	0.12	6	0.8215
July (fall density)	1.01 (0.38 - ∞)	-3.06	0.018	0.43	11	0.1829
August	0.95 (0.51 – 4.91)	-2.70	0.024	0.68	11	0.0211
September	0.91 (0.65 – 1.53)	-2.28	0.028	0.88	11	0.0003
October	1.20 (0.65 – 7.12)	-3.93	0.022	0.67	11	0.0238

Some variation in trap net CPUE appears related to changes in water temperature. Trap net CPUE decreased with increasing spring water temperature at Marion and Swan lakes, the two polymictic lakes (Figure 3). Conversely, CPUE increased with increasing spring water temperature at Erie and French lakes (the two larger dimictic lakes); however, because of an atypical cold snap before June sampling, cooler surface water temperatures occurred in June (16 to 17 ^oC) than in late spring (19 to 20 ^oC). In the three small dimictic lakes, CPUE decreased with increasing spring water temperature at Little Swan Lakes, but CPUE at Dog and Ida lakes did not change (Figure 3). Catch per effort was low in all seven lakes when spring water temperatures exceeded 20 ^oC. In fall, CPUE in the two polymictic lakes varied inconsistently with decreasing water temperature (Figure 4). However, fall CPUE in all dimictic lakes except Dog declined with decreasing fall water temperatures. During the year when fall CPUE was very low, fall CPUE did not change with declining water temperatures at Ida and Little Swan lakes (Figure 4).

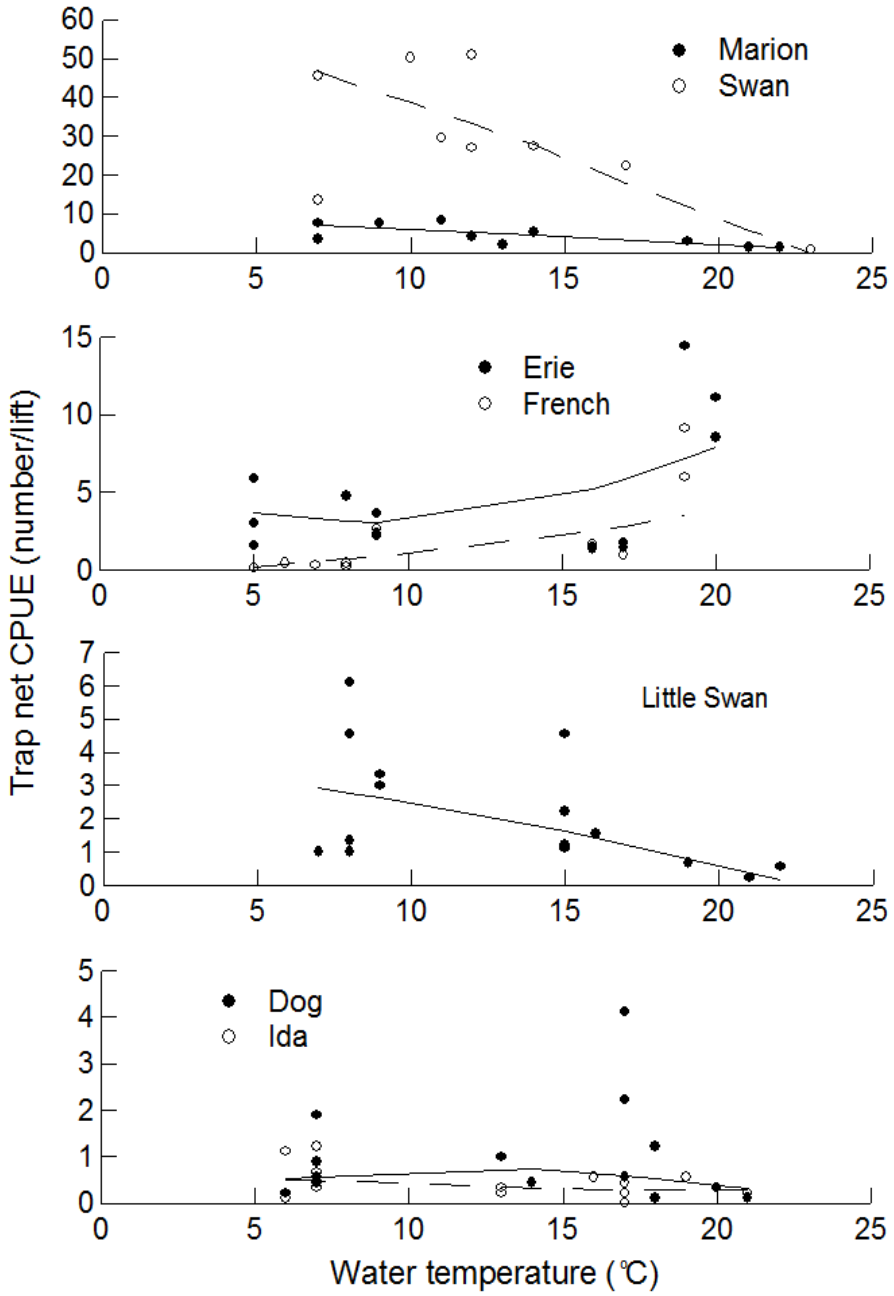


FIGURE 3. Daily trap net catch per effort (number per lift) of Black Crappie 200 mm and longer as a function of water temperature during spring (early spring to June sampling periods) in seven Minnesota lakes (solid LOWESS smoothing lines show relationships for solid circles, and dashed line shows relationships for open circles).

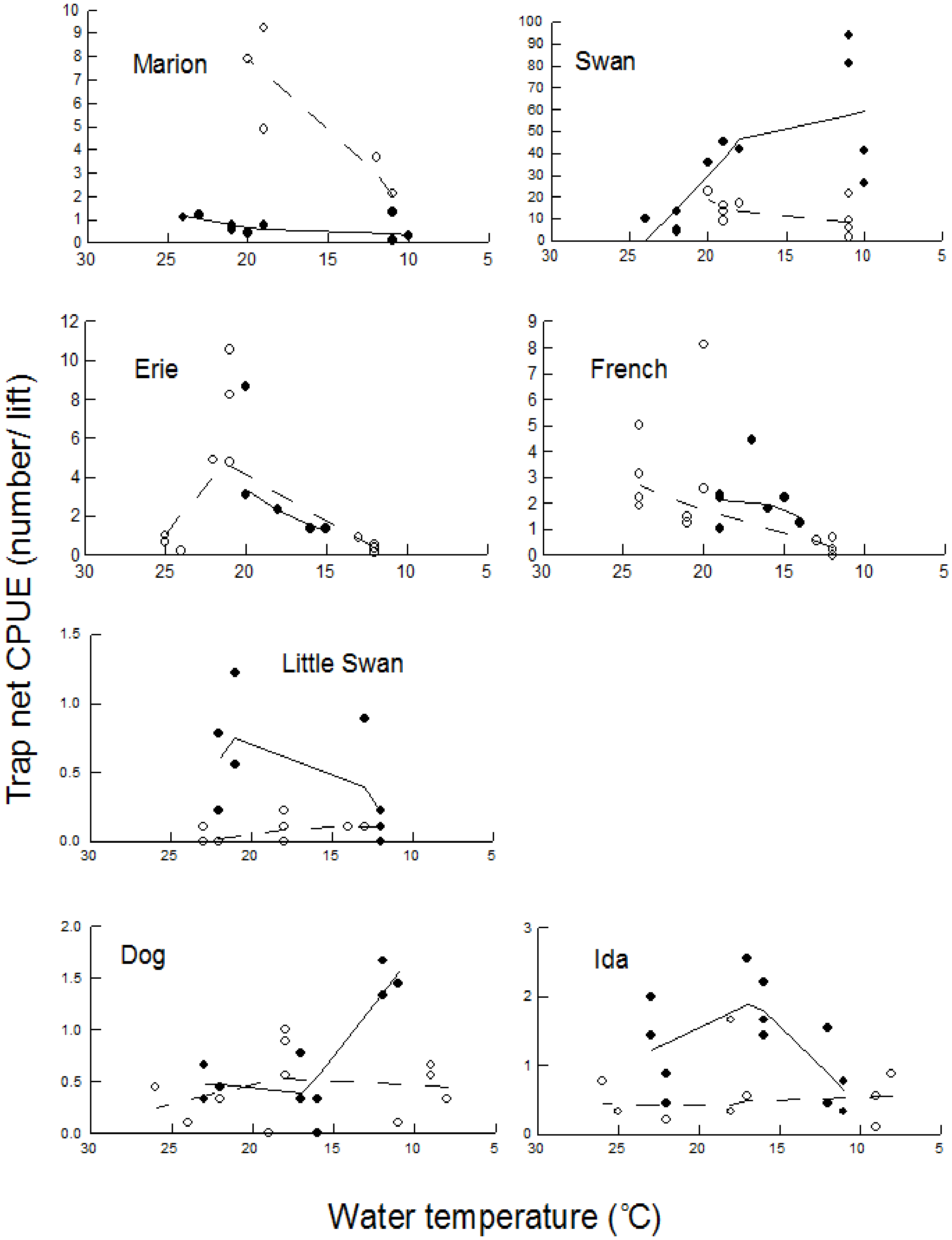


FIGURE 4. Daily trap net catch per effort (number per lift) of Black Crappie 200 mm and longer as a function of water temperature during fall (August through October sampling periods) in seven Minnesota lakes during two different years (solid circles and solid line denote first year; open circles and dashed lines denote second year).

We found no link between daily variation in trap net CPUE and daily variation in air temperature, and if weather did affect CPUE in lakes sampled at the same time, these effects appeared inconsistent between lakes. Coefficient of variation of $\log_e$ (CPUE+1) did not change with changing CV of mean air temperature (*F* = 0.07; df = 1, 36; *P* = 0.7980; Figure 5). Coefficient of variation of $\log_e$ (CPUE+1) differed among lakes (*F* = 2.71; df = 6, 36; *P* = 0.0286); CV in Little Swan exceeded CV in Swan and Marion lakes (Tukey's HSD test). However, CV of $\log_e$ (CPUE+1) did not strongly differ among sampling periods (*F* = 2.09; df = 6, 36; *P* = 0.0791). All two-way interactions appear weak (*F* = 2.03; df = 6, 36; *P* = 0.0874 for CV of mean air temperature*sampling period; *F* = 0.43; df = 6,36; *P* = 0.8566 for CV of mean air temperature*lake; and *F* = 1.28; df = 36, 36; *P* = 0.2344 for the lake*sampling period), and we lacked sufficient data to test for the three-way interaction. No obvious synchrony in daily fluctuations in CPUE occurred between lakes sampled on the same days (Figure 6).

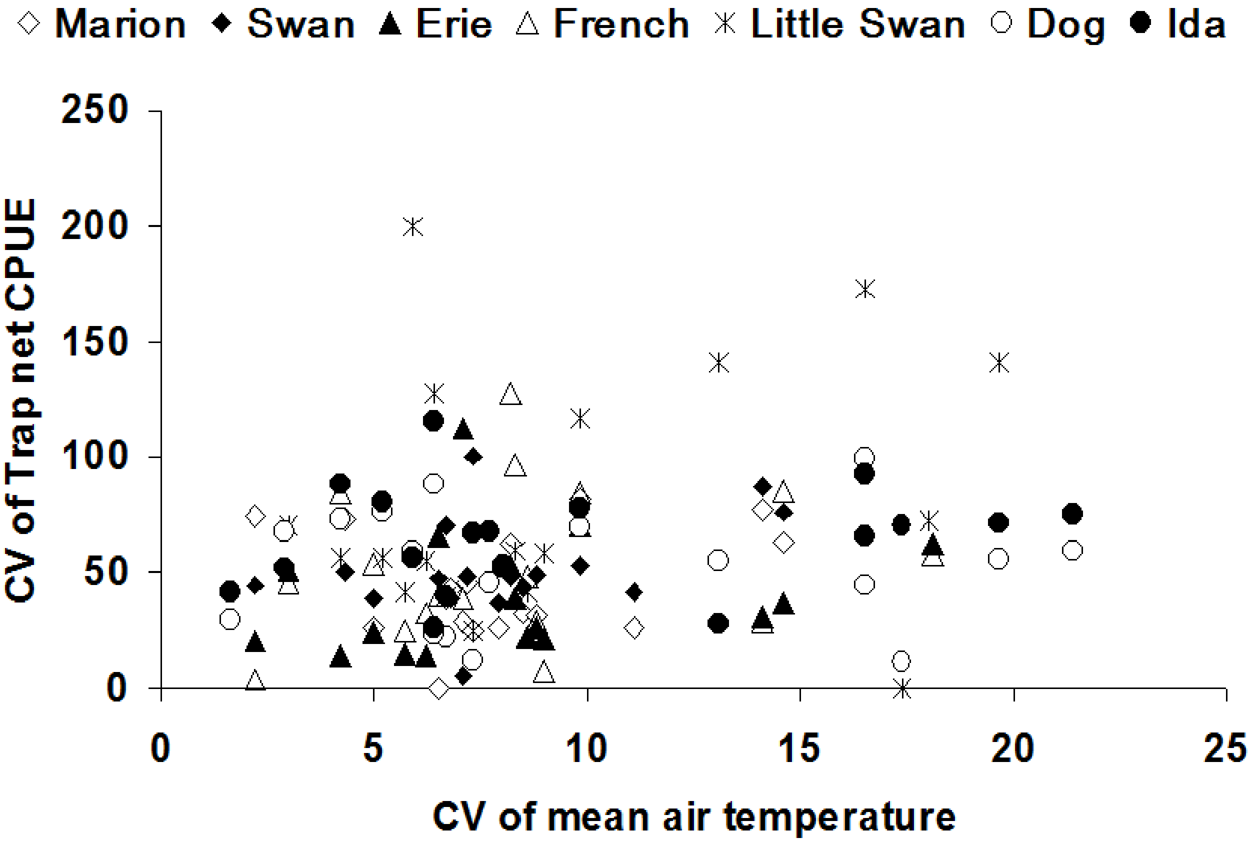


FIGURE 5. Mean coefficients of variation (CV) of trap net catch per effort (number/lift) of Black Crappie as a function of CV of air temperature within sampling periods among seven Minnesota lakes.

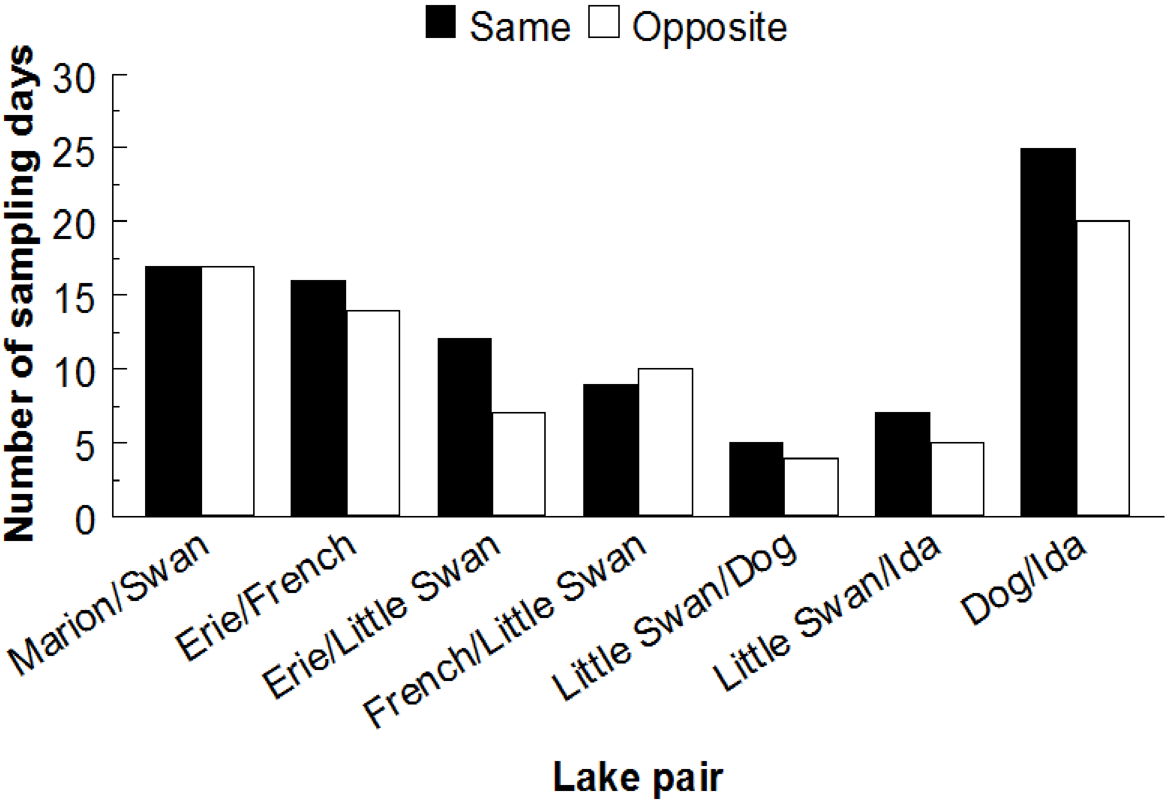


FIGURE 6. Number of sampling days when trap net catch per effort of Black Crappie 200 mm and longer simultaneously increased or decreased (same) in lakes sampled on the same days and the number of days when CPUE increased in one lake and decreased in the other (opposite).

Black Crappie populations in the seven study lakes exhibited variable recruitment, inconsistent growth, and high but variable annual mortality (*A*). Trap nets captured individuals 200 mm and longer from 5 to 11 year-classes in each lake during this study (Figure 7). Single year-classes composed nearly all of the trap net catch in Marion, Swan, French, and Little Swan lakes, two year-classes composed most of the catch at Lake Erie, and multiple year-classes composed the catch at Dog and Ida lakes (Figure 7). The greatest change in mean total length of individual year-classes occurred between June and August whereas essentially no change occurred between September and the following June (Figure 8A; we lacked sufficient catch data to show growth trends in Little Swan Lake). Black Crappies in Swan, Marion, and Erie lakes grew faster than in the other three lakes, and *A* ranged from 59 (French Lake) to 94% (Swan Lake) (Figure 8B). Annual mortality could not be estimated at Ida Lake because we were unable to estimate population size for two consecutive falls or springs.

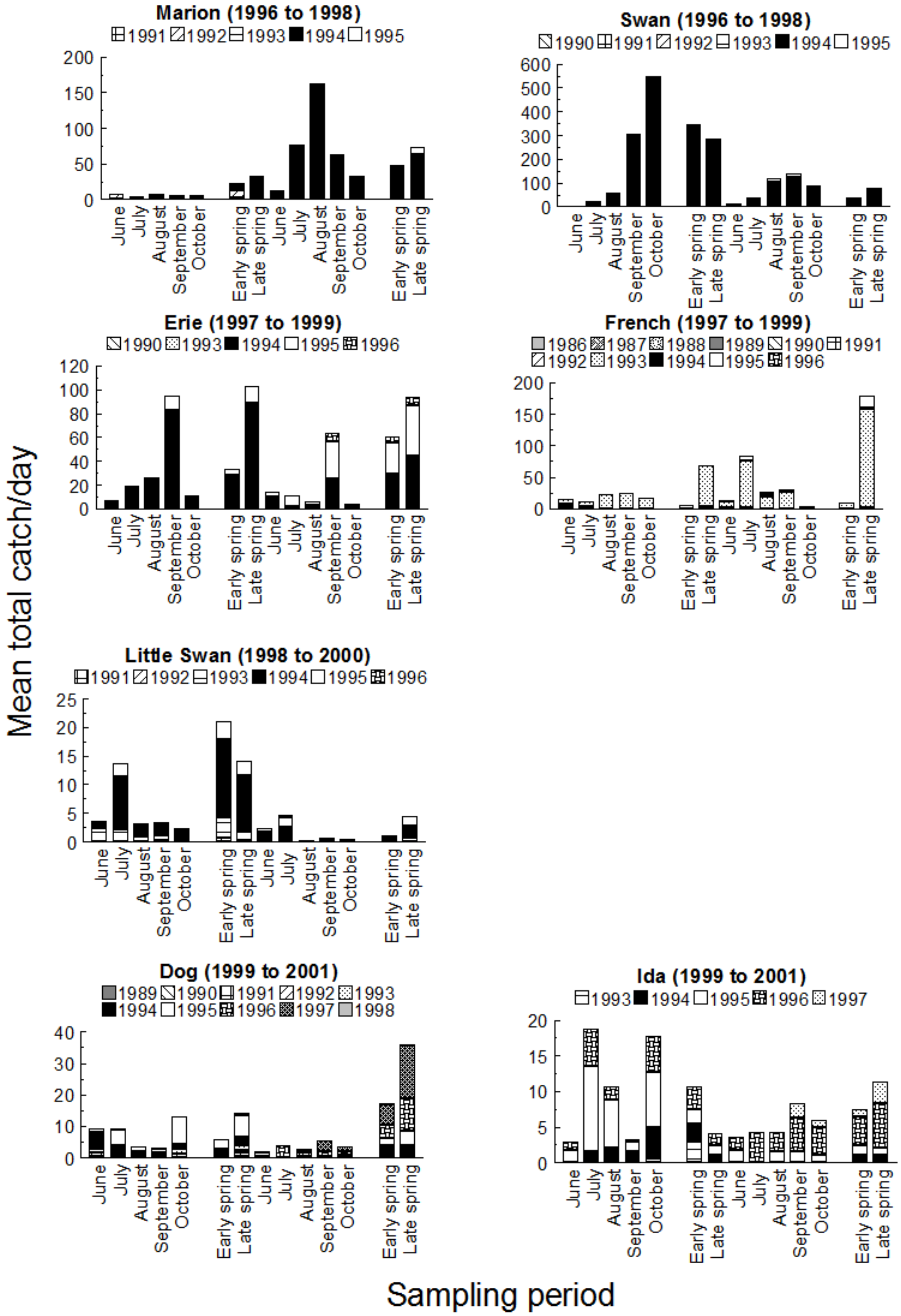
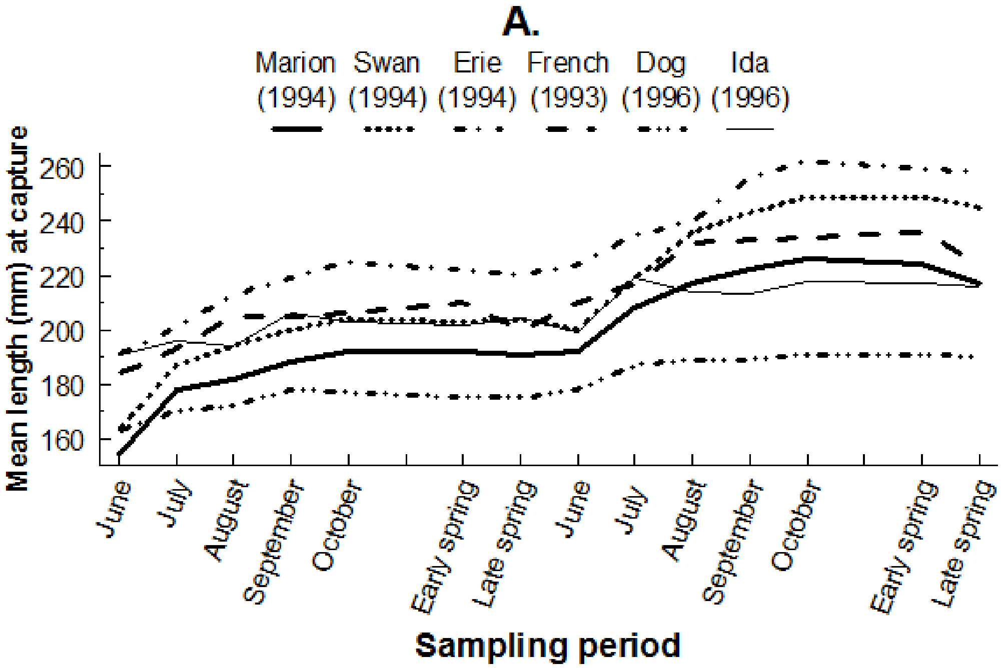


FIGURE 7. Mean trap net catch of each year-class of Black Crappie 200 mm and longer in seven Minnesota lakes for two consecutive years.



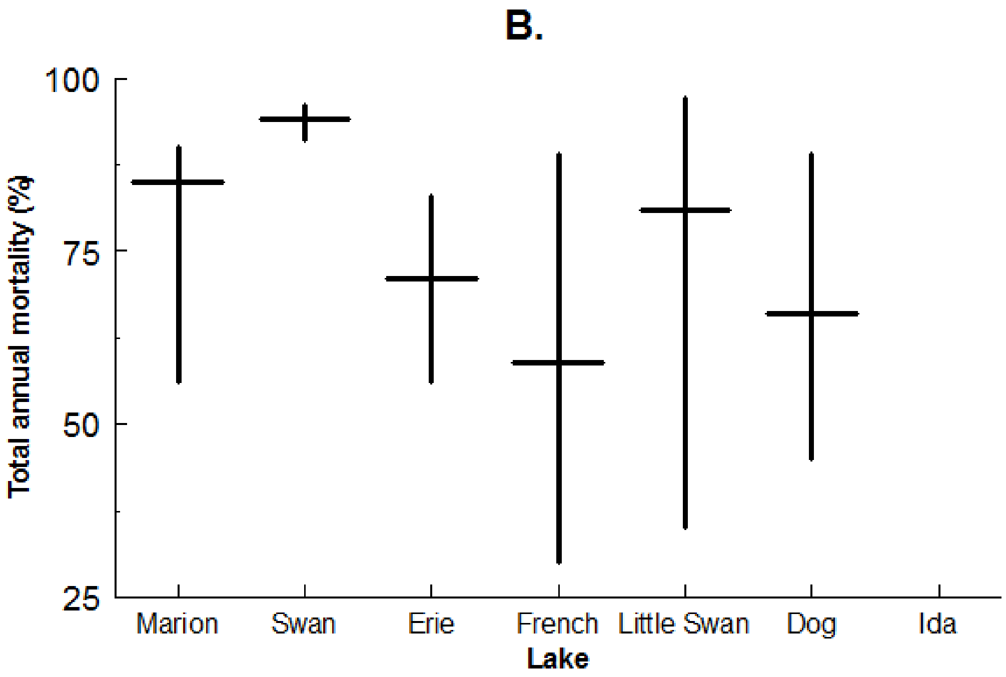


FIGURE 8. A. Mean length at capture of the strongest year-class (in parentheses) of Black Crappie closest to 200 mm captured in trap nets during seven monthly sampling periods for two consecutive years, and B. total annual mortality of either one strong year-class or two or more consecutive year-classes of Black Crappie closest to 200 mm in seven Minnesota lakes.

DISCUSSION

Numerous factors, such as behavior, habitat, forage, and population density, likely caused inconsistencies in monthly or daily CPUE of Black Crappies among study lakes and within years. In other north temperate lakes, this species usually inhabits deeper (1.5 to 5 m) water from April through August (Hall and Werner 1977; Keast and Harker 1977; Helfman 1981; Keast and Fox 1992; Guy et al. 1992). Capture of Black Crappies in trap nets depends on movement into water less than 2 m deep and within 12 m of shore; however, crepuscular, nocturnal, or diurnal movement patterns likely differed within lakes over time and among lakes. Unfortunately, we did not know the spatial, daily, or monthly distribution patterns of Black Crappies in these study lakes.

Prey availability varies spatially and seasonally within lakes, as a result, foraging areas used by Black Crappies probably differed among lakes and changed seasonally. Prey consumed by Black Crappie differed among Minnesota lakes and varied seasonally within these lakes (Scidmore and Woods 1959; Seaburg and Moyle 1964). Black Crappies in north temperate lakes will move from daytime rest areas to either near shore or offshore feeding areas depending on location of prey (Keast and Harker 1977; Keast and Fox 1992). Given these observations it is not surprising that CPUE differed between lakes and within sampling periods.

Although we did not find a direct link between weather and CPUE, local weather conditions most likely affect daily CPUE, but not in a predictable manner. This was reflected in the poor synchrony observed in daily catches between pairs of lakes sampled on the same days. Guy et al. (1992) observed increased movement of Black Crappie in Brandt Lake, South Dakota, associated with increasing barometric pressure. Increased movement, however, does not necessarily result in increased CPUE.

Spawning behavior almost certainly lowered vulnerability to trap netting in the study lakes resulting in lower trap net CPUE in June in all study lakes and perhaps even in July in some lakes. Essentially all Black Crappies 200 mm and longer in Minnesota and elsewhere at similar latitudes are sexually mature (Vesser and Eddy 1941; Nelson 1974; Hanson and Qadri 1980). At latitudes similar to Minnesota, Black Crappies spawn from May to July when water temperatures are between 14 and 25 ^{o}C (Carlander 1977; Hanson and Qadri 1980; Pope et al. 1996a; Pope and Willis 1997). This spawning period coincides with the lowest spring CPUE in most study lakes. Male Black Crappies nest at depths 0.2 to 6 m deep and essentially do not leave nests (Schneberger 1972; Hanson and Qadri 1980; Pope and Willis 1997; Phelps et al. 2009; Reed and Pereira 2009). Guy et al. (1992) observed that Black Crappie 295 mm (7 of the 8 were males) and longer tagged with ultrasonic transmitters in Brant Lake, South Dakota moved less in May and June (15 to 55 m/h), when most likely spawning, than they did in April, July (July water temperatures = 27 ^{o}C), or August (85 to 130 m/h).

Thermal preference of Black Crappie coupled with thermal stratification and destratification probably influenced monthly patterns in CPUE in the dimictic study lakes. Black Crappies prefer water temperatures between 20 and 30 ^{o}C (Neill and Magnuson 1974; Reynolds and Casterlin 1977); thus, surface water temperature in the study lakes was always at or below thermal preferences of this species. Black Crappies seek warmer water temperatures when they inhabit waters below preferred levels (Knights et al. 1995). The warmest spring water temperatures in the dimictic lakes are usually at the surface including those depths where trap nets are set, and likely contributed to higher CPUE in early and late spring sampling periods. Conversely, during fall lake turnover, the warmest water temperatures occur in deeper water offshore where trap nets are not set, which explains declines in CPUE between September and October observed in most of the dimictic lakes. Fall lake turnover could also have contributed to the poorer correlation between CPUE in October and density.

We hypothesized that high plant densities either impede movement of Black Crappies to nets or compete as cover with nets, either of which could cause decreased *q* and CPUE. Submergent aquatic plant densities in Lake Marion exceeded that in Swan Lake, and plant densities in Lake Erie exceeded densities in French Lake; both pairs of lakes sampled on the same days but with differing temporal patterns in CPUE. The high density of *Potamogeton crispus* in Ida Lake probably contributed to lower late spring CPUE compared to nearby Dog Lake, which had sparser stands of *P. crispus*. Furthermore, aquatic plant densities within lakes frequently differ among years (MNDNR, statewide lake survey database).

Variable mortality, growth, and recruitment also affected monthly variation in CPUE and inconsistent trends in CPUE among lakes. Mortality in the study lakes was not only high but also erratic over time because of periodic summer kills and unequal angler harvests. Summer kills linked with *Columnaris* spp. periodically occur in all of the study lakes (MNDNR, unpublished data), and we observed summer kills (unknown magnitude) in both Dog and Ida lakes during this study. These kills usually occur soon after spawning, especially during warm days with little wind. Anglers also harvested Black Crappies in all study lakes. Most angling harvest of crappies in Minnesota lakes occurs during winter and early spring, but peak harvests in some lakes also occurs in late summer (MNDNR statewide creel database). Recruitment in Ida and Dog lakes probably offset losses in density from mortality, but not in the other five study lakes. Lastly, the trap nets we used select for larger Black Crappies (McInerny and Cross 2006); thus variable length structures (linked with inconsistent growth) also contributed to inconsistent temporal trends in CPUE among lakes.

Trap net CPUE in August and late spring could reflect density as well as September and early spring CPUE; however, trap net CPUE in June and July have little value in monitoring density in the study lakes. Poorer correlations between CPUE and density in late spring and August could have been caused by the time lag between trap netting and when population density was estimated. September and early spring CPUE were estimated at the same time as density estimates, but a month separated the time between CPUE in late spring and spring estimates and August CPUE and fall estimates. Because of variable recruitment and high mortality, actual population densities in early and late spring and in August and September probably differed in each lake. Conversely, trap net CPUE in June and July could not detect the 40-fold difference between the highest and lowest spring estimates or the 193-fold difference in fall estimates of density among lakes, differences greater than intra-annual variation in density in the study lakes.

MANAGEMENT IMPLICATIONS

Although inconsistencies in temporal variation were observed, trap net CPUE provides a meaningful estimate of relative abundance during much of the time when lakes are ice-free. Although early spring and September CPUE were more strongly correlated with population density, the weaker relationships between CPUE and density in late spring and August could simply be caused by changes in density between trap netting and the time when density was estimated. Thus, managers using trap net CPUE to monitor Black Crappie abundance will likely not gain any advantage by changing sampling times from late spring to early spring or from August to September. Managers interested in determining if Black Crappies exist in a given lake should consider sampling in spring when water temperatures are 9 to 19 ^{o}C because CPUE was relatively high in most lakes. Managers should avoid trap netting when Black Crappies are spawning or when water temperatures in dimictic lakes drop below 15 ^{o}C in fall because the risk is greater for low catches or CPUE will likely not reflect density. Lastly, findings in this study and in McInerny and Cross (2006) suggest that the value of the quartile system used by MNDNR fisheries staff for evaluating CPUE from standard trap netting could be improved by excluding catches of Black Crappies < 200 mm TL and excluding samples collected in June and July.

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