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Comparisons between mark-recapture population estimates of Largemouth Bass and Black Crappie made with the same and different capture gears in Minnesota lakes

Michael C. McInerny
Minnesota Department of Natural Resources
Division of Fish and Wildlife
Section of Fisheries
23070 North Lakeshore Drive
Glenwood, Minnesota, 56334, USA

Timothy K. Cross
Minnesota Department of Natural Resources
Division of Fish and Wildlife
Section of Fisheries
20596 Highway 7
Hutchinson, Minnesota 55350 USA

Abstract - We compared population estimates of Largemouth Bass *Micropterus salmoides* and Black Crappie *Pomoxis nigromaculatus* made by using either the same or different gears for marking and recapture in several Minnesota lakes. In three lakes, fall Chapman-Petersen and spring modified Schnabel estimates of Largemouth Bass ≥ 200 and ≥ 300 mm TL made by using electrofishing for marking and recapture did not differ significantly from Chapman-Petersen estimates made with marking by electrofishing and recapture with angling. However, excluding the rather wide 95% confidence limits, estimates made with electrofishing only either equaled or exceeded estimates made with the combination of electrofishing and angling. These findings were similar to that found in the literature. In one of the study lakes, angling was ineffective for capturing Largemouth Bass. Lastly, a modified Schnabel estimate of Largemouth Bass ≥ 300 mm from a combination of ice-out trap netting and electrofishing catches equaled a Chapman-Petersen estimate made by using ice-out trap nets and electrofishing for marking and a fishing tournament for recapture. Fall Chapman-Petersen population estimates of Black Crappie ≥ 200 mm made with fall marking and spring recapture with only trap net catches did not differ from fall Chapman-Petersen estimates made with marking via fall trap netting and recapture via winter ice-angling. Ice angling provided sufficient sample sizes for estimating population size in four of six lakes. One of two spring Chapman-Petersen estimates of Black Crappie ≥ 200 mm made with marking and recapture from only trap net catches equaled the spring Chapman-Petersen estimate from marking via trap netting and recapture via open-water angling, but the other attempt failed because of insufficient sample sizes in both trap nets and angling. Because batch-marking was used for all estimates in this study, we could not determine if capture probabilities of marked and unmarked Largemouth Bass were equal in modified Schnabel estimates or if marked and unmarked bass and crappies were examined more than once in some Chapman-Petersen estimates. We recommend that for future population estimates that all Largemouth Bass and Black Crappie be uniquely marked so that capture probabilities can be estimated and biases better defined, and fish in recapture samples are not examined for marks more than once.

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INTRODUCTION

Petersen and Schnabel estimates of population size of Largemouth Bass *Micropterus salmoides* and Black Crappie *Pomoxis nigromaculatus* can be biased when samples for marking and recapture are collected with the same capture gears. Both Petersen and Schnabel estimates assume equal capture probabilities of all individuals in a fish population on each sampling occasion (Ricker 1975; Otis et al 1978). Negative bias in population estimates occurs if capture probabilities of marked fish are higher than unmarked fish, and positive bias occurs when marked fish become less vulnerable to capture than unmarked fish (Otis et al 1978; Bohlin and Sundström 1977). Additionally, estimates only apply to the portion of the population vulnerable to capture. For example, Pierce (1997) found negative-biased population estimates of Northern Pike *Esox lucius* made with marking and recapture via trap netting immediately after lake ice melted (ice-out trap netting) because only a nearshore segment of the population was captured. Many published estimates of population size of Largemouth Bass have been made by marking and recapture with boom electrofishing (electrofishing) only (Woodrum 1980; Hall 1986; Coble 1992; McInerny and Degan 1993; McInerny and Cross 1999; Shroyer et al. 2003; Schoenebeck and Hansen 2005; Schoenebeck et al. 2015). Most of the known population size estimates of Black Crappie were made with marking and recapture with trap nets only (Cooper 1952; McInerny and Cross 2005). Thus, these estimates of Largemouth Bass and Black Crappie could be biased.

Using combinations of angling and electrofishing or ice-out trap netting and electrofishing could offset potential heterogeneity of capture probabilities of Largemouth Bass captured with electrofishing only if capture with electrofishing affects subsequent catchability of bass or if some bass are located in too deep of water for capture with electrofishing. Thus marking and recapture with these different gear combinations could provide less biased Petersen or Schnabel estimates. Electrofishing effectively captures Largemouth Bass near shore at depths up to two meters but becomes less effective in deeper water (Reynolds and Kolz 2012). Conversely, various lures can be fished at any depth near shore or offshore. In Lake Minnetonka, Minnesota, electrofishing captured wider length ranges than angling; however, length distributions of Largemouth Bass ≥ 305 mm TL caught by non-tournament anglers, tournament anglers, and electrofishing did not differ (Ebbers 1987). Ice-out trap netting is another shallow-water gear that captures similar length ranges of Largemouth Bass as electrofishing (Minnesota Department of Natural Resources (MNDNR) statewide database). However, capture in trap nets requires some active movement of Largemouth Bass; thus, offshore and inshore bass could be vulnerable to capture.

Outside of Minnesota, estimates of population size of Largemouth Bass during spring have been made with the combination of angling and electrofishing (e.g., Isaak et al. 1992; Hill and Willis 1994), and estimates either equaled or tended to be lower than known population size or estimates made with electrofishing only. Edwards et al. (1997) reported that two of three Petersen estimates of Largemouth Bass ≥ 200 mm TL in Texas ponds equaled the total number of bass counted after draining these ponds, but the third estimate was 38% lower. Aggus and Rainwater (1977) found that a population estimate of Largemouth Bass ≥ 305 mm in an Arkansas reservoir made with marking by electrofishing and recapture via a fishing tournament was nine percent lower than the estimate made with marking and recapture via electrofishing only. However, they reported another estimate in another Arkansas reservoir made with marking with electrofishing, recapture from angler catches in a fishing tournament, and additional recapture via examination of harvested bass at boat accesses was similar (4.4% difference) to the estimate made with marking and recapture via electrofishing only. In all cases, 95% confidence intervals of compared estimates overlapped.

The combination of trap netting and angling could also offset potential heterogeneity of capture probabilities of Black Crappie caused by using trap nets only because natural and artificial baits can be fished deeper and farther offshore than where trap nets are set. For example, winter angling for Black Crappie in Minnesota almost always occurs offshore in deeper or the deepest parts of lakes; thus, for fall estimates of population size, potential offshore portions of Black Crappie populations not vulnerable to fall trap netting could be sampled with angling during winter. Cooper (1952) found that population size of panfishes (several species combined including Black Crappie) in a Michigan Lake estimated via marking with trap nets and recapture via angler catches were about twice as high as estimates made with spring trap netting only (confidence limits not reported). This is the only known study involving Black Crappie where estimates made with trap netting only was compared to estimates made with trap netting and angling.

Staff of the MNDNR in recent years have either used or proposed using angling as part of the recapture sample in addition to electrofishing when estimating population size of Largemouth Bass. However, it is unknown how angling samples affected or will affect population estimates of this species. To our knowledge, population estimates of Largemouth Bass made with the combination of ice-out trap netting and electrofishing have not been made. Crappies (Black Crappie and White Crappie *P. annularis*) currently rank second in popularity among anglers in Minnesota (Schroeder 2012), and population estimates may be needed in waters where more intensive management occurs. Objectives of this study were to determine if population estimates of Largemouth Bass and Black Crappie determined with marking and recapture with the same gears differ from estimates made with marking with one gear and recapture with one or two other gears. Specifically, we analyzed direct comparisons of population estimates, comparisons of length distributions of marked and recapture samples among gears, and capture efficiencies among gears.

METHODS

Largemouth Bass sampling

Electrofishing along shore was the primary sampling gear used to capture Largemouth Bass for marking and recapture in eight Minnesota lakes in fall (September and October) and the following spring (May to early June; Table 1). The hull of the electrofishing boat served as the cathode, a single sphere served as the anode, a 3.5 KW generator supplied electric power, and stunned bass were captured by a single netter. A minimum of four electrofishing shoreline circuits were done on each lake in fall and spring including two sets of day and night electrofishing (McInerny and Cross 1996). Additional electrofishing circuits were usually done until a total of at least four marked bass were recaptured, the minimum number of recaptures needed for unbiased Petersen or Schnabel estimates (Ricker 1975). During each circuit, electrofishing was periodically stopped so that captured Largemouth Bass could be measured (total length (TL) in mm), given a fin-clip (anal in fall; upper caudal in spring) if ≥ 120 mm TL, and released near the stopping point.

Besides electrofishing, angling and ice-out trap netting were used to capture marked and unmarked Largemouth Bass. One or two anglers per boat fished for Largemouth Bass in June at Elkhorn, Ida, Pleasant, and St. Anna lakes following the last spring electrofishing circuit when bass were still given a spring fin-clip. The entire shoreline of each lake was fished at least once. Because lure size affects size of capture of Largemouth Bass (Wilde et al. 2003), we casted a variety of lures of different sizes including crank baits, jigs, plastic worms, spinner baits, or a plain hook baited with a night-crawler. All angled bass were measured (TL in mm), examined for fall and spring fin-clips, and released (we did not keep track of which lures caught specific fish).

At Lake Marion, the combination of ice-out trap netting, a fishing tournament, and shoreline electrofishing were used to capture Largemouth Bass for estimating population size. Twenty to 25 standard lake survey trap nets (modified fyke nets consisting of two 0.9 x 1.8m frames, a single 12.2 m lead, a codend with five 0.8 m diameter hoops and two throats, and 1.9-cm bar-mesh webbing; MNDNR 2017) were set and lifted daily during a six-day period just after the ice melted in April. All trap netted Largemouth Bass were measured (TL in mm), examined for fall and spring fin-clips, given a spring fin-clip if ≥ 120 mm TL, and released. A one-day multispecies fishing tournament occurred in June after all marking sampling concluded. However, only Largemouth Bass ≥ 300 mm TL could be entered at the weigh-in. At the weigh-in site, all Largemouth Bass were measured (TL in mm), examined for both fall and spring fin-clips and then released.

TABLE 1. Lake, county, surface area (hectares), percent littoral area (surface area of lakes < 4.6 m), and maximum depth (m) of study lakes, and species sampled (LMB = Largemouth Bass, BLC = Black Crappie) for estimating population size with different capture gears.

Lake	County	Surface area (ha)	% Littoral area	Maximum depth (m)	Species sampled
Dog	Wright	38	78	7.6	BLC
Elkhorn	Kandiyohi	35	35	12.5	LMB
Erie	Meeker	74	45	10.4	BLC
French	Wright	134	47	15.2	BLC
Ida	Wright	32	76	7.9	LMB, BLC
Little Swan	Meeker	18	45	9.4	BLC
Marion	McLeod	168	100	3.7	LMB, BLC
Pleasant	Stearns	90	51	10.1	LMB
Richardson	Meeker	45	40	14.3	BLC
St. Anna	Stearns	48	26	32.6	LMB
Swan	McLeod	139	100	3.0	BLC

Black Crappie sampling

Standard lake survey trap nets were the primary gear used for marking and recapture of Black Crappies for estimating population size in fall (September and October) and in spring (early April to early May) in eight Minnesota lakes (MNDNR 2017; Table 1). Fall sampling consisted of setting nine trap nets at standard locations for four consecutive days in September and for four consecutive days in October (McInerny and Cross 2005). Spring trap netting consisted of setting nine trap nets at the same standard locations for a total of eight days, two sets of four consecutive days in April or early May (early spring trap netting). Trap netting also occurred at the same locations for six to seven days in late May or early June (late spring trap netting), but no more than four days were consecutive (McInerny and Cross 2005). Nets were set and lifted once per day. In fall and early spring trap netting, all Black Crappies were measured (TL in mm), examined for fin-clips, given a season-specific fin-clip (either anal or soft dorsal) if older than age 0 in fall and age 1 in spring. During late spring trap netting, all captured Black Crappie were examined for fall and spring fin-clips, but unmarked crappies were not fin-clipped before being released.

We used ice angling and open-water angling as alternate gear for recapturing Black Crappies. We visited each of the eight lakes during at least one winter following fall trap netting. If we observed angling activity, usually at dusk, we then asked ice anglers if they had harvested any Black Crappies and asked if we could examine their catch. During this examination, all Black Crappies were measured (TL in mm) and examined for fall fin-clips. Staff at the MNDNR Area office in Hutchinson provided additional ice angling data from Marion, Swan, Erie, and Dog lakes. Open-water angling was done at Lake Richardson during fall after the last trap-netting event in October because prior winter icehouse counts and local observations suggested that ice angling seldom occurred on this lake. Open-water angling was also done during spring at Dog and Richardson lakes after the last marking event in spring. Open-water angling started in mid-May and ended in early July. Baits used in fall and spring open-water angling were either small Fathead Minnows *Pimephales promelas* (i.e., 'crappie minnows') or 0.9-1.8-g jigs. All Black Crappies caught with spring open-water angling were measured (TL in mm) and examined for fall and spring fin-clips. Unlike ice-angling, some Black Crappies caught with open-water angling were released.

Data analysis

Attempts to estimate population size of Largemouth Bass and Black Crappie were made in both fall and the following spring. With one exception, a fall mark/spring recapture design coupled with the Chapman modification of the Petersen method (Chapman-Petersen) was used to estimate population size of fish in fall (Ricker 1975; McInerny and Cross 1999; 2005). The marked sample *M* consisted of all fish fin-clipped in fall, the sample for examining fish for fin-clips (*C-electrofishing* for Largemouth Bass; *C-trap net* for Black Crappie) consisted of all fish examined in spring minus the number of recaptured spring-marked fish, and the recapture sample *R* consisted of all fall-marked fish. Excluding spring-marked fish ensured that some individual fish in *C-electrofishing* or *C-trap net* were not examined for marks more than once Including fish examined more than once can change the estimate itself and confidence intervals of Chapman-Petersen estimates (Williams et al. 2002). A single fall-mark/fall recapture design was used to estimate fall population size of Black Crappie at Richardson Lake. All fall-marked crappies composed *M*, and *C-open water angling* was composed of all angler catches following the last marking period, and *R* consisted of all fall-marked crappies.

The spring mark/spring recapture design coupled with the modified Schnabel method was used to estimate population size of Largemouth Bass marked and recaptured with electrofishing in spring (Ricker 1975; McInerny and Cross 1999). Each electrofishing circuit served as a separate capture period, and all fin-clipped Largemouth Bass caught with ice-out trap netting at Lake Marion served as the first capture period. The early spring mark/late spring recapture design coupled with the Chapman-Petersen method was used to estimate population size of Black Crappie marked and recaptured with trap nets in Dog and Richardson lakes (Ricker 1975; McInerny and Cross 2005). For these estimates, *M-early spring trap net* equaled the total number of individual crappies fin-clipped during the early spring trap netting, *C-late spring trap net* was composed of all Black Crappies examined for fin-clips caught with late spring trap netting, and *R* was all spring-marked crappies in *C-late spring trap net*.

The Chapman-Petersen estimator was used to estimate population size of Largemouth Bass marked with electrofishing and recaptured with open water angling, the fishing tournament, or ice out trap netting, and population size of Black Crappie marked with trap netting and recaptured with ice angling or open-water angling. We chose to separate the tournament catch from open water angling because tournament anglers often use lures selecting for larger Largemouth Bass (Gabelhouse and Willis 1986). Additionally, population estimates of Largemouth Bass ≥ 305 mm TL at Lake Minnetonka estimated via bass caught by avid anglers were consistently lower than estimates made by examining bass entered in fishing tournaments (Ebbers 1987). For fall estimates of population size, *M* equaled the total number of fish fin-clipped in fall, *C-open water angling*, *C-tournament*, *C-ice out trap net*, and *C-ice angling* equaled to the total number of fish captured with the appropriate alternate gears and examined for fin-clips, and *R* equaled the number of fall-marked fish found in each of the appropriate *C*. For spring estimates, *M* equaled the total number of fish fin-clipped in spring, *C-open water angling* and *C-tournament* equaled the total number of fish captured with these two alternate gears and examined for fin clips, and *R* equaled the number of spring-marked fish found in *C-open water angling* and *C-tournament*.

Population estimates were calculated when $R \geq 4$, the minimum number of recaptures needed for unbiased estimates, and 95% confidence intervals were calculated by using *R* as a Poisson variable (Ricker 1975). Population size was estimated for lengths of fish captured with all capture gears, and preliminary analysis of catches in each gear suggested that population estimates could be made for Largemouth Bass ≥ 200 mm and ≥ 300 mm and for Black Crappie ≥ 200 mm. Fall Chapman-Petersen estimates and spring modified Schnabel estimates of Largemouth Bass ≥ 200 mm in lakes Elkhorn, Ida, Pleasant, and St. Anna and the fall Chapman-Petersen estimate of Largemouth Bass ≥ 200 mm in Lake Marion reported in McInerny and Cross (1999) are used in this report.

We compared length distributions or mean lengths of fish captured with each alternate gear in order to identify potential biases between capture gears. We used two proportional size distributions to describe length distributions of *M* and *C-electrofishing*, *C-open water angling*, and *C-ice out trap net* for each population estimate of Largemouth Bass. The basic proportional size distribution (PSD) equals the number of quality-sized fish divided by the total number of stock-sized fish (x 100), and proportional size distributions of preferred-size (PSD-P) equals the number of preferred-sized fish divided by the total number of stocked-size fish (x 100) (Neumann et al. 2012). For Largemouth Bass, stock length equaled 200 mm TL, quality length equaled 300 mm, and preferred length equaled 380 mm (Neumann et al. 2012). Because the fishing tournament excluded Largemouth Bass < 300 mm, we calculated mean total lengths (with 95% confidence limits) of bass ≥ 300 mm for *M*- fall electrofishing, *M* of spring electrofishing plus ice-out trap netting, *C-spring electrofishing*, *C-ice out trap net*, and *C-tournament*. Preliminary analysis clearly showed that anglers caught relatively few crappies < 200 mm TL; thus, mean total lengths with 95% confidence limits of Black Crappies ≥ 200 mm TL were calculated instead of PSD and PSD-P.

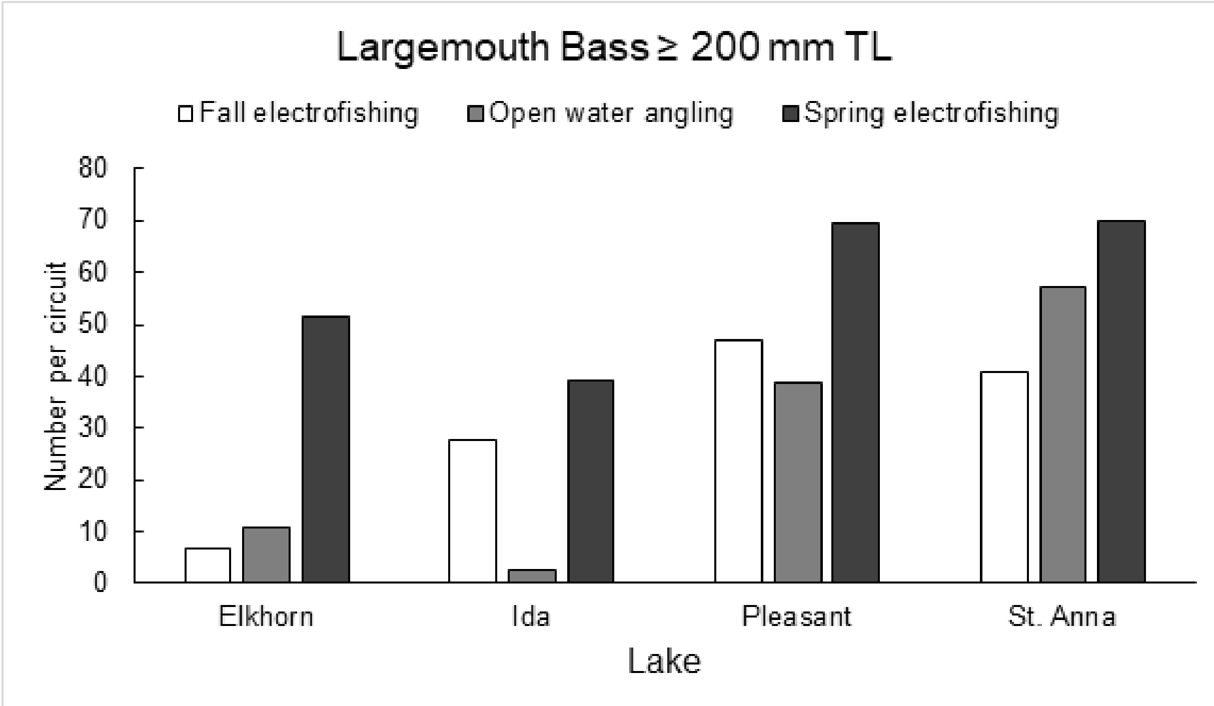
We estimated capture efficiencies of each gear used for estimating population size in order to determine relative effort needed to obtain population estimates. For Largemouth Bass, we compared the average number of bass caught per day of electrofishing, the average number of bass caught per shoreline circuit of open water angling, the average number of bass caught per day of ice out trap netting, and the total number of bass caught during the fishing tournament. For Black Crappie, we compared the average number of crappies caught per day of trap netting with the average number of crappies harvested by ice anglers per visit and the number of crappies caught per outing of open-water angling.

Lastly, we calculated the density of marked Largemouth Bass and Black Crappie at the time of marking to help determine the likelihood of a successful population estimate made with each combination of capture gears. These densities were calculated based on where the species was most likely to be when recapture sampling occurred. All winter angling for Black Crappie occurred farther offshore than fall trap nets were set, thus, density of fall-marked Black Crappie was estimated as the number/ha of the entire surface area of the lake. However, Largemouth Bass appeared strongly associated with aquatic macrophytes and many were probably spawning in spring when electrofishing occurred (Annett et al. 1996; MNDNR 2017), and Black Crappie in spring generally inhabited shallower water because they were attracted to warmer water temperatures or were spawning (Reynolds and Casterlin 1977; Pope and Willis 1997; Reed and Pereira 2009). Therefore, we estimated density of fall- and spring-marked bass and spring-marked crappies as numbers/ha of littoral area (area of lake where depths < 4.6 m).

RESULTS AND DISCUSSION

Largemouth Bass: C-open water angling vs. C-electrofishing

Angling was as effective as fall electrofishing for capturing Largemouth Bass ≥ 200 and ≥ 300 mm for estimating population size in three of four lakes, but angling was not as effective as spring electrofishing (Figure 1). Sample sizes of *C-open water angling* were sufficient for estimating population size of Largemouth Bass ≥ 200 mm in these three lakes and for estimating population size of Largemouth bass ≥ 300 mm in two lakes in fall and spring (Table 2). Conversely, angling at Lake Ida was ineffective because only five Largemouth Bass ≥ 200 mm were caught during two circuits around the lake despite using the same tactics as done in the other three lakes (Figure 1). Although sample sizes per shoreline circuit in *C-open water angling* were similar to sample sizes of fall electrofishing, angling should be viewed as less effective than double-boom electrofishing in fall. Fall catchability of Largemouth Bass with single-boom electrofishers like the one used in this study was about half of that of more commonly used double-boom electrofishers (Miranda and Kratochvíl 2008).



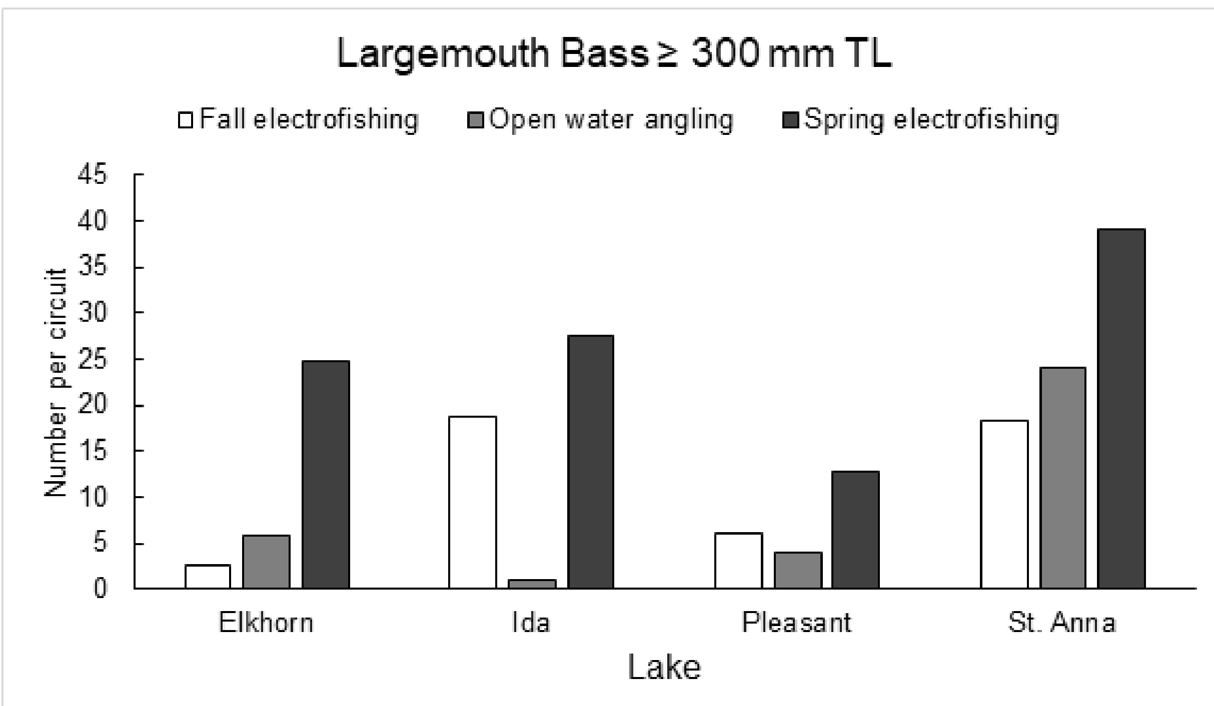


FIGURE 1. Mean number per shoreline circuit of Largemouth Bass ≥ 200 mm and ≥ 300 mm TL captured with fall electrofishing, open water angling, and spring electrofishing in four Minnesota lakes.

TABLE 2. Chapman-Petersen (CP) or modified Schnabel (S) estimates of population size (95% confidence limits) of Largemouth Bass ≥ 200 mm TL and ≥ 300 mm TL in fall and the following spring made with marking and recapture with electrofishing only (*C-electrofishing*), and marking with electrofishing and recapture with angling (*C-open water angling*) in four Minnesota lakes.

	Fall estimates		Spring estimates	
Lake	*C-electrofishing* (CP)	*C-open water angling* (CP)	*C-electrofishing* (S)	*C-open water angling* (CP)
		≥ 200 mm TL		
Elkhorn	869 (470-1,701)	526 (235-1,316)	793 (512-1,288)	530 (334-884)
Ida	1,440 (865-2,552)		760 (478-1,266)	
Pleasant	4,094 (2,646-6,648)	3,437 (1,785-7,236)	2,209 (1,427-3,587)	2,152 (1,373-3,553)
St. Anna	1,244 (929-1,705)	1,321 (708-2,702)	1,863 (1,120-3,302)	1,549 (856-3,097)
		≥ 300 mm TL		
Elkhorn	300 (142-692)	120 (54-300)	319 (181-616)	188 (109-352)
Ida	1,379 (685-3,016)		496 (293-895)	
Pleasant				
St. Anna	521 (315-683)	339 (168-742)	779 (430-1,557)	616 (291-1,423)

Although 95% confidence limits always overlapped between comparisons, estimates excluding confidence limits made with *C-electrofishing* usually exceeded estimates made with *C-open water angling*. Both the *C-electrofishing* and *C-open water angling* estimates of Largemouth Bass ≥ 200 mm at St. Anna Lake in fall and of Largemouth Bass ≥ 200 mm at Pleasant Lake in spring were within 10% of each other (Table 2). However, the other *C-open water angling* estimates of Largemouth Bass ≥ 200 and ≥ 300 mm at Elkhorn, Pleasant, and St. Anna lakes in fall and spring were 16 to 60% lower than *C-electrofishing* estimates (Table 2). The population at Pleasant Lake consisted of few bass ≥ 300 mm (Table 3); thus, estimates of population size of this length group could not be made with either capture gear. Our results were similar to that found outside of Minnesota where *C-electrofishing* estimates (excluding 95% confidence limits) or total counts either equaled or exceeded *C-open water angling* estimates (Aggus and Rainwater 1977; Edwards et al. 1997), but we did not find any study reporting *C-open water angling* estimates being higher than *C-electrofishing* estimates.

Estimates made with either *C-electrofishing* or *C-open water angling* could be biased because capture probabilities of marked Largemouth Bass could have differed from capture probabilities of unmarked Largemouth Bass. Positive bias in *C-electrofishing* estimates in spring would occur if marked Largemouth Bass were less susceptible to capture than unmarked Largemouth Bass in later electrofishing circuits, which was observed for *C-electrofishing* (all daytime electrofishing) estimates of Largemouth Bass ≥ 200 in four Carver County lakes (S. M. Shroyer, MNDNR, personal communication). However, night electrofishing in this study could have offset some capture bias of marked bass associated with day electrofishing. On the other hand, *C-open water angling* estimates in fall and spring could be negatively biased because capture probabilities of some marked Largemouth Bass could have been higher than capture probabilities of other individuals in the population. For example, Burkett et al. (1986) found that some individual Largemouth Bass in a 6-ha Illinois impoundment were caught up to 16 times per fishing season (spring to fall), whereas others were not caught at all. Angling catchability of about 15% of Largemouth Bass, nearly all were 201 to 254 mm TL, was zero. Conversely, all bass > 357 mm were caught at least once during a four-year period (Burkett et al. 1986). Multiple captures of the same individuals were possible at Elkhorn and Pleasant lakes where two or more angling events occurred, but less so at St. Anna Lake where only one circuit was completed.

Comparisons of size structure indices suggested that angling and electrofishing captured similar lengths of Largemouth Bass; thus, we could not directly conclude that different portions of the Largemouth Bass populations were sampled with different gears (although behaviors toward each capture gear could differ). At Elkhorn and Ida lakes, PSD and PSD-P in *C-open water angling* appeared slightly higher than PSD and PSD-P in *C-electrofishing*, but PSD and PSD-P of *C-open water angling* in Pleasant and St. Anna were lower than PSD and PSD-P in *C-electrofishing* (Table 3). At Lake Minnetonka, mean total lengths and PSD of Largemouth Bass caught by non-tournament anglers exceeded mean lengths and PSD caught with electrofishing in two of three springs, but mean lengths did not differ between gears during the other spring (Ebbers 1987).

TABLE 3. Proportional stock distributions of quality- (300 mm TL; PSD; sample size (n)), and preferred-sized (380 mm TL; PSD-P) Largemouth Bass fin-clipped after capture with electrofishing (*M-electrofishing*), examined for fin-clips after capture with electrofishing (*C-electrofishing*) and open water angling (*C-open water angling*) for Chapman-Petersen estimates, and PSD and PSD-P of Largemouth Bass fin-clipped and examined for fin-clips in modified Schnabel estimates of population size in fall and spring in four Minnesota lakes.

	Fall						Spring			
	M-electrofishing		*C-electrofishing*		*C-open water angling*		*M-electrofishing*		Schnabel	
Lake	PSD (n)	PSD-P	PSD (n)	PSD-P	PSD (n)	PSD-P	PSD (n)	PSD-P	PSD (n)	PSD-P
Elkhorn	41.3 (46)	15.2	47.3 (188)	19.1	52.7 (55)	21.8	46.2 (160)	16.9	48.0 (26)	18.4
Ida	67.6 (111)	31.5	70.4 (179)	36.3	80.0 (5)	40.0	74.3 (148)	38.5	70.8 (195)	35.9
Pleasant	13.2 (234)	3.4	18.5 (330)	5.4	10.3 (116)	0	18.5 (330)	5.4	18.4 (348)	5.4
St. Anna	45.1 (204)	4.9	55.3 (266)	4.5	42.1 (57)	7.0	55.3 (266)	4.5	55.9 (279)	4.7

The proportion of fall-marked to unmarked Largemouth Bass in each population should have been the same in spring regardless of recapture gear; thus, potential differences in estimates was caused by different gear-specific capture biases. Positive bias in *C-electrofishing* and *C-open water angling* estimates in fall would have occurred if over-winter mortality of marked bass exceeded mortality of unmarked bass. Although dead Largemouth Bass were never observed during sampling, we could not rule out this possibility. Fin-clips did not regenerate during the span of this study; thus, assumptions of no loss of marks and all marks being recognizable, required for unbiased Chapman-Petersen or modified Schnabel estimates (Ricker 1975), were met. All lakes lacked inlets or outlets suitable for fish migration; thus, no emigration of marked bass and no immigration of unmarked bass occurred, and the negligible growth of bass between fall and spring ensured that no recruitment occurred.

Largemouth Bass: C-ice out trap netting, C-tournament, and C-electrofishing

Chapman-Petersen estimates of population size of Largemouth Bass ≥ 200 mm at Lake Marion differed between *C-ice out trap net* and *C-electrofishing* probably because the two recapture gears captured different segments of the bass population. The *C-ice out trap net* estimate was 7,900 (95% CL = 3,527-19,749), over three times higher than the *C-electrofishing* estimate of 2,214 (95% CL = 1,256-4,274). *C-ice out trap net* was composed of longer Largemouth Bass (PSD = 84.5; PSD-P = 42.0; n = 226) than *C-electrofishing* (PSD = 75.5; PSD-P = 15.1; n = 139). However, proportional size distributions of fall-marked Largemouth Bass (PSD = 43.9; PSD-P = 7.5; n = 173) differed considerably from PSD and PSD-P in both *C-electrofishing* and *C-ice out trap net*.

No fall estimates of Largemouth Bass ≥ 300 mm could be made with *C-ice out trap net* or *C-tournament* because only one fall-marked bass was observed in each gear, but the *C-electrofishing* estimate equaled 1,632 (95% CL = 800-4,081). Density of fall-marked Largemouth Bass ≥ 300 mm was probably too low (0.45 bass/ha at the time of marking; Figure 2) because fall electrofishing was probably ineffective for capturing bass in this 100% littoral lake (Table 1). Mean total lengths of bass ≥ 300 mm differed little between *M-electrofishing* (359 ± 10 mm; n =76), *C-electrofishing* (358 ± 7 mm; n = 105), and *C-tournament* (362 ± 5 mm; n = 112), but *C-ice out trap net* was composed of longer bass (383 ± 5 mm; n = 191).

The use of multiple gears to capture Largemouth Bass could have ensured homogenous capture probabilities for the spring estimate of population size at Lake Marion. The spring Chapman-Petersen estimate of Largemouth Bass ≥ 300 mm made with *C-tournament* (4,326; 95% CL = 2,148 to 9,464) essentially equaled the modified Schnabel estimate of bass ≥ 300 mm made with the combination of catches with ice-out trap netting and spring electrofishing (4,281; 95% CL = 2,224-9,012). Even though tournament anglers try to catch the longest bass possible (Gabelhouse and Willis 1986), lengths of spring-marked Largemouth Bass ≥ 300 mm were longer (374 ± 4 mm; n = 296) than lengths in *C-tournament* (362 ± 5 mm; n = 112). Similarly, mean lengths of Largemouth Bass ≥ 305 mm TL caught with spring electrofishing at Lake Minnetonka, Minnesota, also exceeded mean lengths of bass caught by tournament anglers in June (Ebbers 1987). Because the weigh-in occurred at the end of the tournament, repeat measurements of fall- or spring-marked and unmarked bass were not possible.

This tournament provided an efficient method for capturing Largemouth Bass compared to ice-out trap netting and spring electrofishing. The 56 tournament anglers weighed in 112 Largemouth Bass ≥ 300 mm that were measured and examined for fall and spring fin-clips in one day. Conversely, ice out trap netting (~ 23 nets lifted per day) yielded an average of 32 Largemouth Bass ≥ 300 mm per day and six spring electrofishing circuits of the lake yielded an average of 44 per day. Similar to *C-electrofishing* and *C-open water angling* estimates, assumptions for unbiased *C-ice out trap net* and *C-tournament* were probably met. A culvert connects Lake Marion and an adjacent shallow lake prone to annual winterkills; thus, emigration of some marked bass was possible but improbable.

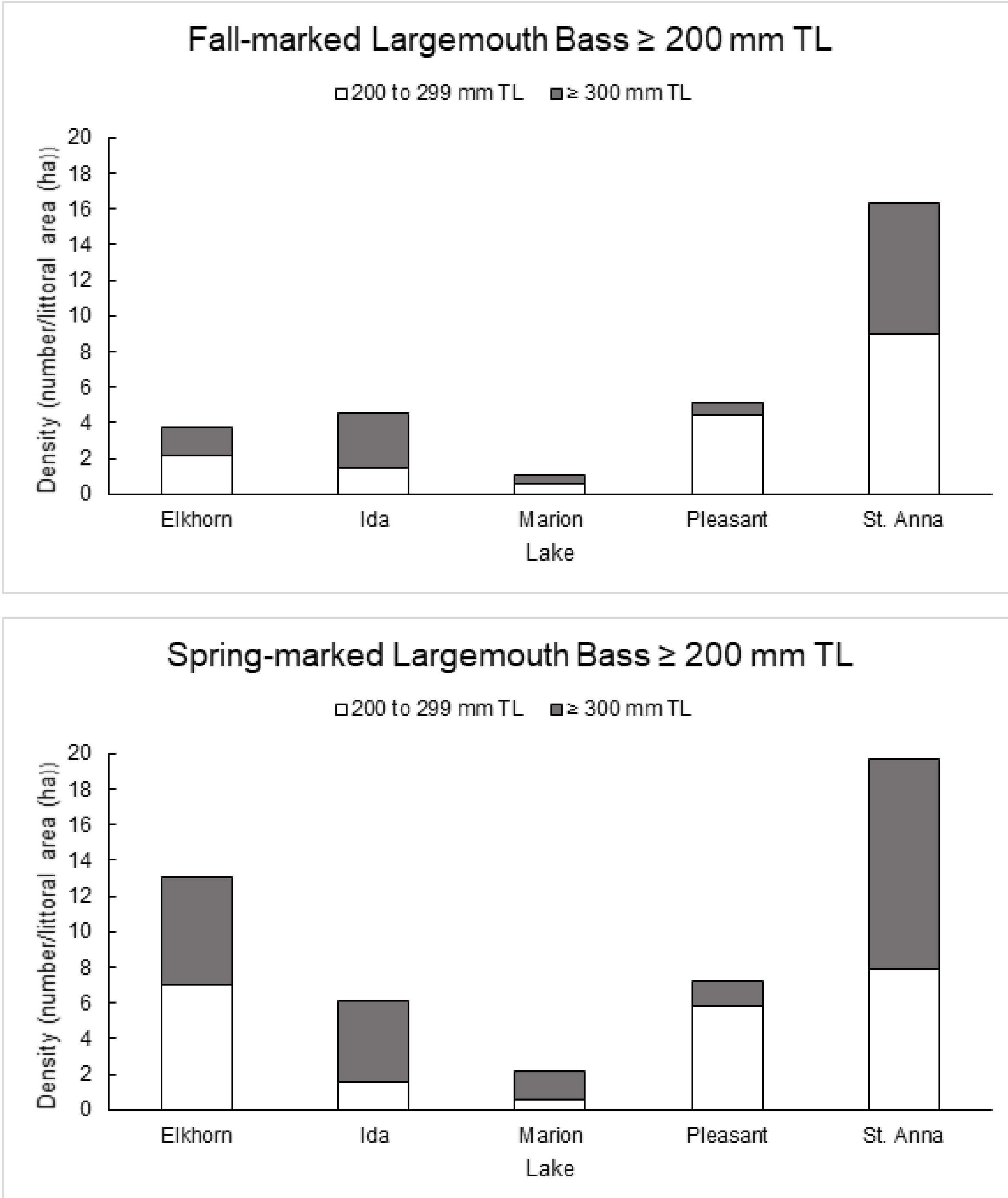


FIGURE 2. Density (number/ ha of littoral area (area of lake where depths < 4.6 m)) of fall-marked Largemouth Bass ≥ 200 and ≥ 300 mm TL in fall and spring-marked Largemouth Bass ≥ 200 and ≥ 300 mm TL in spring for estimating population size in five Minnesota lakes.

Black Crappie: C-ice angling vs. C-trap net

Ice angling appeared to be a useful recapture method for estimating fall population size of Black Crappie in most but not all study lakes. As expected, ice angling for Black Crappies was not observed at Richardson Lake during the winter following fall trap netting. However, ice angling was also seldom observed at Little Swan Lake where only one harvested Black Crappie was measured during two winters. Ice angling occurred during each winter at the other six lakes, and four to 52 on-ice visits were made per lake when ice angling activity occurred.

Despite consistent fall and spring trap netting effort, *C-trap net* estimates of Black Crappie ≥ 200 mm could not be made at all of the study lakes. *C-trap net* estimates of Black Crappie were not made in either fall at Ida Lake and were not made in fall 1996 at Lake Marion because $R < 4$. However, *C-trap net* estimates were made at the other lakes during each year when estimates were attempted (Table 4). Densities of marked Black Crappies were very low (< 0.3/ha) at Lake Marion during fall 1996 (Figure 3), but daily sample sizes of *C-trap net* (< 8 per day) were low during both springs at Lake Ida (Figure 4).

TABLE 4. Fall Chapman-Petersen estimates of population size (95% confidence limits) of Black Crappie ≥ 200 mm TL in seven Minnesota lakes marked by fall trap netting and recaptured with either ice angling (*C-ice angling*) or spring trap netting (*C-trap net*).

Lake (year)	*C-ice angling*	*C-trap net*
Dog (1999)	1,394 (692-3052)	1,263 (627-2,764)
Dog (2000)	1,808 (807-4,521)	1,693 (841-3,705)
Erie (1997)	17,706 (10,039-34,169)	24,921 (14,130-48,093)
Erie (1998)	4,211 (1,989-9,718)	7,233 (5,120-10,577)
French (1998)		6,534 (4,394-10,155)
Ida (1999)		
Ida (2000)		
Marion (1996)		
Marion (1997)	68,266 (30,475-170,666)	30,341 (16,763-60,682)
Richardson (2000)		23,465 (18,839-30,070)
Swan (1996)	80,263 (63,403-101,529)	79,150 (67,049-94,903)
Swan (1997)	8,838 (6,461-12,576)	11,569 (9,545-14,323)

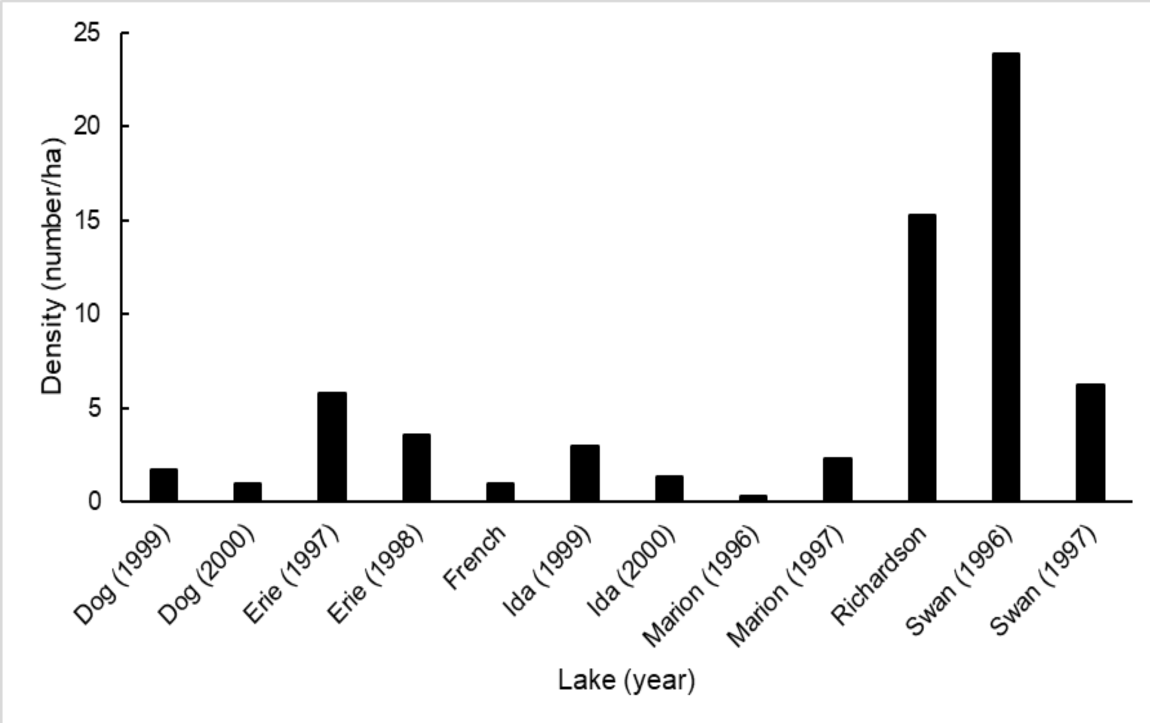


FIGURE 3. Density (number/ha) of fall-marked Black Crappie ≥ 200 mm TL during fall in seven Minnesota lakes in one year or two consecutive years for estimating population size.

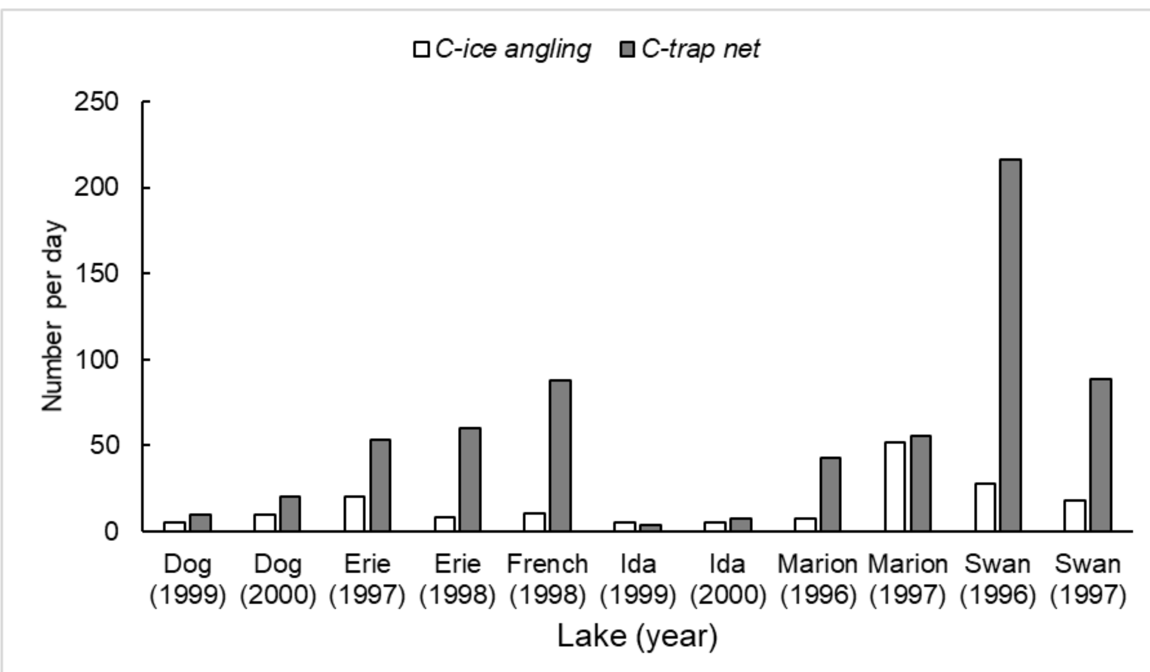


FIGURE 4. Number of Black Crappie ≥ 200 mm TL per day of ice-angling (*C-ice angling*) and spring trap netting (*C-trap net*; 9 trap nets per day) examined for fall fin-clips in six Minnesota lakes in one year or two consecutive years.

C-ice angling estimates of Black Crappie ≥ 200 mm were made for both falls at Dog, Erie, and Swan lakes, and for one fall at Lake Marion, and *C-ice angling* estimates did not differ significantly from *C-trap net* estimates (Table 4). *C-ice angling* and *C-trap net* estimates at Dog Lake were within 10% of each other during both years, and *C-ice angling* and *C-trap net* estimates at Swan Lake in 1996 were nearly identical (Table 4). At Lake Erie, *C-ice angling* estimates were 28 to 42% lower than *C-trap net* estimates during both years, and the *C-ice angling* estimate at Swan Lake in 1997 was 24% lower than the *C-trap net* estimate (Table 4). Conversely, the *C-angling* estimate at Lake Marion in 1997 was 2.2 times higher than the *C-trap net* estimate. Comparisons of mean lengths of Black Crappie ≥ 200 mm in *M-trap net*, *C-trap net*, and *C-angling* suggested that angling, fall trap netting, and spring trap netting oftentimes sampled different portions of Black Crappie populations but not consistently among lakes or between population estimates within lakes (Table 5).

Trap netting in spring was usually more effective than ice angling for capturing Black Crappies; however, angling and spring trap netting were similarly effective at Lake Ida and at Lake Marion in 1997 (Figure 4). Because all Black Crappies in *C-ice angling* were harvested, all individual crappies were examined for fin-clips only once. However, it was possible that multiple recaptures of the same fall-marked and unmarked crappies could have occurred in late spring trap net samples (see Implications and Recommendations).

TABLE 5. Mean total lengths (± 95% confidence limits) of Black Crappie ≥ 200 mm TL fin-clipped in fall (*M-trap net*), harvested by anglers during winter (*C-ice angling*), and captured in spring trap nets (*C- trap net*) in seven Minnesota lakes (sample size in parentheses).

Lake (year)	*M-trap net*	*C-ice angling*	*C- trap net*
Dog (1999)	223 ± 10 (65)	211 ± 3 (98)	229 ± 7 (133)
Dog (2000	219 ± 10 (37)	212 ± 2 (227)	223 ± 4 (311)
Erie (1997)	219 ± 1 (428)	223 ± 1 (453)	220 ± 1 (638)
Erie (1998)	243 ± 2 (265)	248 ± 4 (94)	247 ± 1 (842)
French (1998)	232 ± 4 (132)	225 ± 3 (94)	224 ± 1 (1,229)
Ida (1999)	228 ± 4 (95)	227 ± 6 (31)	224 ± 5 (59)
Ida (2000)	218 ± 5 (42)	218 ± 6 (36)	220 ± 3 (115)
Marion (1996)	213 ± 5 (48)	207 ± 3 (31)	213 ± 1 (603)
Marion (1997)	223 ± 1 (388)	223 ± 1 (882)	220 ± 1 (783)
Richardson (2000)	210 ± 1 (688)		209 ± 1 (2,417)
Swan (1996)	209 ± 1 (3,322)	212 ± 1 (1,461)	213 ± 1 (3,024)
Swan (1997)	244 ± 1 (866)	249 ± 1 (365)	245 ± 1 (1,240)

Assumptions for unbiased Chapman-Petersen estimates were met or likely met in each lake (Ricker 1975). Fin-clips did not regenerate during the span of this study; thus, assumptions of no loss of marks and all marks being recognizable were met. Growth of Black Crappies in all lakes between fall and spring was negligible; thus, no recruitment occurred. Furthermore, Black Crappies < 200 mm were also marked and examined for marks; thus, proportions marked to unmarked crappies that could have recruited would be the same as those longer than 200 mm. Dog, Erie, and Swan lakes lacked inlets or outlets suitable for fish migration; thus, no emigration of marked crappies and no immigration of unmarked crappies occurred at these lakes. Lake Marion is connected to a very shallow wetland that frequently winterkills; thus emigration of marked crappies was possible. Because of high water levels, Richardson Lake was connected to Dunns Lake in spring, which also supported a Black Crappie population. Thus, emigration of marked crappies and immigration of unmarked crappies was possible in spring. However, relative differences between FF and FS estimates at Richardson Lake were similar to relative differences in FF and FS estimates at Dog, Erie, and Swan lakes (McInerny and Cross 2005); thus, bias of C-trap net and C-open water angling in spring caused by emigration of marked crappies and immigration of unmarked crappies appeared minimal. Unequal mortality between marked and unmarked crappies was also possible; however, no dead marked crappies were observed in fall. Unless disproportionately higher mortality of marked crappies occurred after ice angling ended and before spring trap netting began, effects of unequal mortality between marked and unmarked crappies would have been the same for *C-trap net* and *C-ice angling.*

Black Crappie: C-open-water angling vs. C-trap net

The single *C-open water angling* population estimate of Black Crappie ≥ 200 mm made with the fall mark/fall recapture design (FF estimates) at Richardson Lake was 12,815 (95% CL = 5,721-32,038), about 55% of the *C-trap net* estimate made with the fall mark/spring recapture design (FS estimates) at this lake (Table 4). One to two anglers per boat caught 92 (88% were harvested) crappies ≥ 200 mm (214 ± 2 mm TL) in four trips, and total lengths were slightly longer than those in *M* or *C-trap net* (Table 5). The *C-open water angling* estimate also did not differ from the FF estimate made with marking and recapture with trap net catches only (15,574; 95% CL = 10,231-32,600; McInerny and Cross 2005). McInerny and Cross (2005) found that FF estimates of Black Crappie ≥ 200 mm were consistently lower than FS estimates among these study lakes. Positive bias in FS estimates would occur if mortality of marked crappies exceeded mortality of unmarked crappies; however, odds were low that fall-marked Black Crappie showed disproportionately lower survival than unmarked crappies. McInerny and Cross (2005) found that estimates made with two different spring mark-spring recapture designs did not differ even though the recapture period of one was 3-4 weeks after the other, suggesting that mortality of marked and unmarked crappies did not differ. Negative bias in FF estimates would occur if an offshore segment of the Black Crappie population was not vulnerable to either trap netting or angling. Van den Avyle (1976) found in an Iowa impoundment that an offshore portion of a Largemouth Bass population was not vulnerable to capture with shoreline electrofishing in fall, but that portion was vulnerable to capture in spring.

Spring open-water angling at Dog Lake in 2000 and at Richardson Lake failed to capture enough fall-marked Black Crappies to estimate fall population size at either lake. The low density (2.2/littoral ha) of fall-marked Black Crappies in fall coupled with low sample size (76 crappies in 11 trips) of *C-open-water angling* contributed to the failed population estimate at Dog Lake. Even though density of fall-marked crappies at Richardson Lake exceeded 38/littoral ha at the time of marking, sample size (108 crappies in 10 trips) of *C-open water angling* also appeared low because overwinter mortality of fall-marked and unmarked crappies probably occurred. Because only one fall-marked Black Crappie was recaptured at Dog and Richardson lakes, presumably at least four times the angling effort would have been needed to meet the minimum recapture requirement for estimating fall population size.

Spring open-water angling captured enough spring-marked crappie to estimate population size of Black Crappie at Richardson Lake, but less than four spring-marked crappies were recaptured at Dog Lake in 2000. On the other hand, spring estimates were made with *C-trap net* in both lakes. At Dog Lake, density of spring-marked crappies at large was low (1.8/ha of littoral area), and *C-open water angling* was composed of shorter (215 ± 8 mm TL; n = 76) crappies than in *M* (230 ± 11 mm TL; n = 52) or in *C-trap net* (231 ± 10 m TL; n = 95). Additionally, trap netting caught only 2.3 times more Black Crappies at Dog Lake than open-water angling per day; thus doubling or tripling the number of angling parties or trips could have resulted in a population estimate (Figure 5). Most (86%) Black Crappies at Dog Lake were harvested; thus, odds were low that individuals were examined for fin-clips more than once. At Richardson Lake, the *C-open water angling* estimate (6,466; 95% CL = 4,384-9,949) and *C-trap net* estimate (6,426; 95% CL = 5,737-7,248) were essentially identical. Furthermore, total lengths of Black Crappies in *M* (209 ± 1 mm TL; n = 1,427), *C-open water angling* (210 ± 2 mm TL; n = 108) and *C-trap net* (208 ± 1 mm TL; n = 1,267) were similar. Trap netting captured 32 times more Black Crappies per day than open-water angling at Richardson Lake (Figure 5), but the very high density of spring-marked crappies at large (79.3/ha of littoral area) negated the need for a large *C-open water angling* sample. Most (66%) of the Black Crappies in *C-open water angling* also were released, but because the overall sample size was low, odds were also low that repeat catches of some crappies occurred. Similar to *C-ice angling*, assumptions for unbiased *C-open water angling* estimates were probably met.

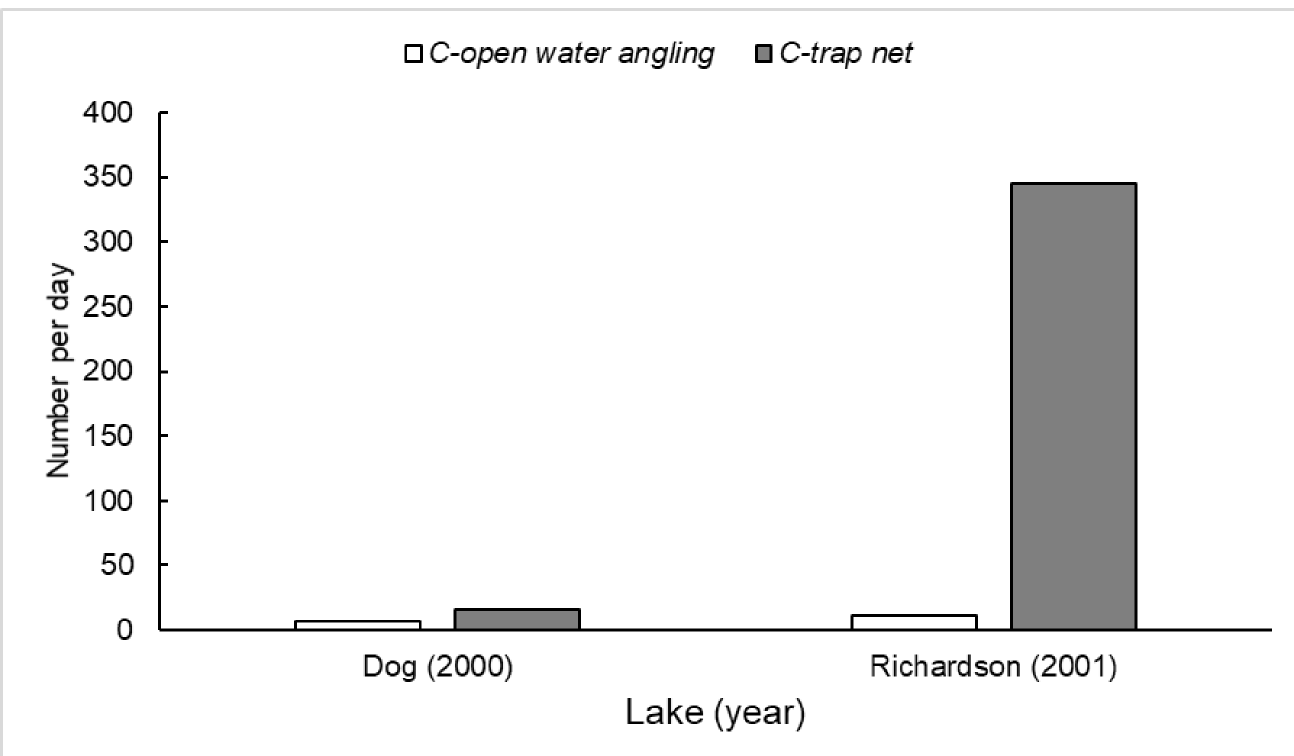


FIGURE 5. Number of Black Crappie ≥ 200 TL per day of open-water angling (*C-open water angling*) and spring trap netting (*C-trap net*; 9 trap nets per day) examined for spring fin-clips in two Minnesota lakes.

IMPLICATIONS AND RECOMMENDATIONS

We could not determine which method of estimating population size of Largemouth Bass or Black Crappie was least biased because actual population size was not known. Therefore, we cannot conclude if using the same or different gears provided the least biased estimates. However, the combination of ice-out trap netting, electrofishing, and tournament catches appeared promising for estimating population size of Largemouth Bass. Conversely, because biases associated with *C-electrofishing* and *C-open water angling* could differ, comparisons of population estimates of Largemouth Bass within or among lakes appear most meaningful if methods of marking and recapture are the same (i.e. compare *C-electrofishing* estimates with *C-electrofishing* estimates or compare *C-open water angling* estimates with *C-open water angling* estimates). For Black Crappie, *C-ice angling* and *C-trap net* provided similar fall estimates and *C-open water angling* and *C-spring trap net* provided similar spring estimates when the densities of marked fish at large were relatively high (24/ha in fall 1996 at Swan Lake; 79/ha of littoral ha in spring 2001 at Richardson Lake). Thus, apparent inconsistencies between *C-ice angling* and *C-trap net* could be associated with insufficient sample sizes rather than actual biases between the two capture methods.

Inserting individually-unique tags into Largemouth Bass and Black Crappie could have helped identify biases and explain potential differences and similarities among population estimates. Various closed- and open-population models could then be applied to identify potential biases and provide a better estimate of population size than the combination of batch-marking and either Chapman-Petersen or modified Schnabel estimates (Otis et al. 1978; Williams et al. 2002; Link and Barker 2005). Other than previously mentioned population estimates in the four Carver County lakes, no mark-recapture estimates of population size of either species have been made utilizing individual capture histories. Ebbers (1987) reported marking Largemouth Bass with individually numbered Monel jaw tags but did not evaluate individual capture histories. We did attempt to approximate capture histories of individual Largemouth Bass in *C-electrofishing* estimates by using total length at capture as unique marks (growth of Largemouth Bass is negligible between marking and recapture in all designs), but we found too much random measurement error to accurately estimate individual capture probabilities among consecutive electrofishing circuits. Lastly, if alternate gears are used to estimate population size, uniquely marking all captured and examined fish ensures that individual fish are not counted more than once when the Chapman-Petersen estimator is used; multiple recaptures of the same fish could cause negative bias in estimates and narrow confidence limits; whereas, multiple captures of unmarked crappies could cause positive bias in estimates (Williams et al. 2002).

Because angling by individuals (not tournaments) was less efficient in capturing target species than electrofishing for Largemouth Bass or trap netting for Black Crappie, staff either need to ensure enough fish are marked or they need to expend additional angling effort so that enough marked fish are recaptured for estimating population size. This study suggested that densities of fall-marked Largemouth Bass ≥ 200 mm should be at least four bass/littoral ha and densities of marked Largemouth Bass ≥ 300 mm needed to be at least two bass/littoral ha at the time of marking in order to recapture a minimum of four marked bass with the same open-water angling effort done in this study. Except for Largemouth Bass > 300 at Pleasant Lake, densities of spring-marked bass in this study were adequate. For Black Crappie ≥ 200 mm, densities of fall-marked crappies needed to exceed 20/ha (density = 24/ ha at Swan Lake in 1996) in order to estimate population size via *C-ice angling*, but densities of spring-marked crappies should exceed 70/ha of littoral area in order to recapture four marked crappies with the same open water angling effort in spring. Otherwise, additional angling effort would be needed. Alternatively, when biologists can make a reasonable guess at the size of the targeted population, sample sizes for marking and recapture for both species can be estimated by using figures in Robson and Regier (1964).

Although not mentioned in the Introduction, we also attempted beach seining as an alternate capture gear for Largemouth Bass because very large seines (> 350 m long; 2 to 6 m deep; pulled with motorized winches) captured sufficient numbers of bass to estimate population size in Minnesota lakes (Maloney et al. 1962; Newburg 1969). However, our attempts (four to five hauls per lake) with the only available, but smaller seine (50.3 m long and 4.3 m deep; pulled to shore by hand) failed to capture enough Largemouth Bass to make population estimates in five lakes (32 to 329 ha) in Kandiyohi, Meeker, and Wright counties (MNDNR unpublished data). We estimated that an average of 81 (range = 14 to 235) additional hauls with this seine would have been needed to capture the same number of Largemouth Bass ≥ 200 mm caught with spring electrofishing in these same lakes.

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