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MANAGEMENT BRIEF

Variation in Bluegill Catch Rates and Total Length Distributions among Four Sampling Gears Used in Two Wisconsin Lakes Dominated by Small Fish

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Abstract
Many Bluegill *Lepomis macrochirus* populations are dominated by fish ≤125 mm total length (TL) that may be underrepresented when using standard sampling gears. To identify efficient sampling methods for these populations, we compared catch per unit effort (CPUE) and TL frequency distributions of Bluegill captured in cloverleaf traps, boat electrofishing, mini-fyke nets, and beach seine hauls from two northern Wisconsin lakes supporting populations dominated by fish ≤125 mm TL. Mean Bluegill CPUE ranged from 41 (SE = 11) fish per cloverleaf trap lift to 16 (SE = 8) fish per beach seine haul. Cloverleaf traps generally captured smaller Bluegill relative to other gears and were the only gear to consistently capture Bluegill ≤80 mm TL. Conversely, boat electrofishing captured the widest TL range of Bluegill, and fish ≥80 mm TL composed a greater proportion of catch (37%) relative to other gears. With few exceptions, the effort required to detect 10% or 25% changes in Bluegill CPUE was >100 units of effort regardless of lake, sampling gear, or month. Furthermore, there was no consistency between lakes or months in terms of which sampling gear required the fewest number of samples to detect a 50% change in CPUE. Estimated units of effort needed to detect 10% or 25% changes in mean Bluegill TL were ≤16 for all sampling gears on the lake with consistently higher CPUE (i.e., more fish to measure per unit). In the lake with lower CPUE, cloverleaf traps consistently required less effort to detect changes in mean TL. We note that comparing sample size requirements among gears is not straightforward because gears are sampling differing segments of the Bluegill population. Our study emphasizes the importance of evaluating gear biases and sampling efficiency so that fisheries managers can develop suitable sampling protocols.

Bluegill *Lepomis macrochirus* support important harvest-oriented recreational fisheries across North America (Coble 1988; Drake et al. 1997; Gaeta et al. 2013). Low size structure of Bluegill populations, where relatively few fish ≥125 mm total length (TL) are present, is a common occurrence in many lakes (e.g., Schneider 1999; Rypel 2015). Furthermore, regional assessments have suggested that Bluegill size structure is decreasing over time (Beard and Kampa 1999; Rypel et al. 2016). Changes in Bluegill size structure can occur for a variety of reasons, including harvest (Coble 1988; Schneider 1999; Rypel 2015), environmental factors (Paukert et al. 2002; Schultz 2008; Hoxmeier et al. 2009; Bevil and Weber 2018), lake morphometrics (Schultz 2008), and density-dependent interactions (Walters and Post 1993; Tomcko and Pierce 2005). Therefore, sampling protocols that do not adequately

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sample Bluegill ≤125 mm TL (stock length; Gabelhouse 1984) may not collect data that are representative of the entire population and may need to include an additional sampling gear to effectively sample populations with large numbers of small individuals.

Bluegill populations are commonly sampled during the spring or early summer using gears such as fyke nets (Cross et al. 1995; Beard and Kampa 1999; Miranda and Boxrucker 2009), boat electrofishing (Simpson 1978; Rypel 2015), or a combination of both (Schultz and Haines 2005; Ruetz et al. 2007). In Wisconsin, long-term fyke net and boat electrofishing survey data indicate that statewide Bluegill assessments are now composed primarily of boat electrofishing survey data compared with historic collections where multigear approaches were used (Rypel et al. 2016). Bluegill relative abundance and mean TL estimates were significantly different between small-mesh fyke nets (1.2-m × 0.9-m frames, 4-mm mesh [bar measure], 7.2-m-long lead line) and boat electrofishing conducted in Muskegon Lake, Michigan, which suggests that the two gears provided complementary information on Bluegill populations (Ruetz et al. 2007). However, both small-mesh fyke nets and boat electrofishing predominantly collect Bluegill ≥125 mm TL (Schultz and Haines 2005; Ruetz et al. 2007; Flammang et al. 2016) and likely underestimate the relative abundance of smaller Bluegill that represent the majority of fish in many populations. In some instances, beach seines have been used in combination with gears that capture large Bluegill in greater numbers to obtain a more complete representation of populations (e.g., Weaver et al. 1993; Pierce et al. 2001; Clark et al. 2007), but size-dependent seine avoidance (Lyons 1986; Bayley and Herendeen 2000) and obstructions to sampling (e.g., woody habitat or dense aquatic macrophytes; Bonar et al. 2009) can limit effectiveness. Ultimately, catchability in any sampling gear will vary in relation to fish size, and available evidence suggests that smaller Bluegill are likely underrepresented in standard electrofishing and fyke net assessments.

Cloverleaf traps are considered an effective capture technique for juvenile fish and have been used to sample age-0 Bluegill, Common Carp *Cyprinus carpio*, and Yellow Perch *Perca flavescens* (Jolly et al. 2010; Weber and Brown 2012; Carl et al. 2016). Bluegill primarily use complex littoral habitats throughout their life (Mittelbach 1981; Werner and Hall 1988; Paukert and Willis 2002), which are difficult to sample using other gears (e.g., beach seines or mini-fyke nets), but cloverleaf traps have effectively sampled fish occupying these habitats (e.g., Weber and Brown 2012). In lakes or regions where Bluegill populations have low size structure and slow growth (e.g., Wisconsin; Rypel 2015), cloverleaf traps could be effective for sampling Bluegill populations since a larger proportion of a population could be more vulnerable to the trap. However, whether cloverleaf traps provide unique or redundant information on Bluegill populations compared with other commonly used sampling gears remains relatively unknown.

Size selectivity of sampling gears and the underrepresentation of small Bluegill in population assessments can inhibit accurate evaluations of Bluegill populations with low size structure if selectivity is not accounted for or multigear approaches are not used (e.g., Clement et al. 2014). Furthermore, the extent to which seasonal fluctuations in surface water temperature affect Bluegill capture rates or TL distributions for populations with low size structure remains unknown. Thus, the goal of this study was to determine the most appropriate gear or gear combinations and month of deployment to sample Bluegill populations with low size structure to provide insights to fisheries managers conducting assessments. We evaluated temporal and gear-specific trends in Bluegill catch rates and cumulative TL frequency distributions among cloverleaf traps, boat electrofishing, mini-fyke nets, and beach seines in two Wisconsin lakes, where Bluegill size structure was dominated by fish ≤ 125 mm TL. Additionally, we estimated the number of samples, or operational effort, needed to detect predetermined changes in monthly mean Bluegill catch per unit effort (CPUE) and TL among gears to determine sampling efficiency of gears.

METHODS

Study lakes and design.— During 2017, Bluegill were collected from McDermott and Sandy Beach lakes located in southeastern Iron County in northern Wisconsin. McDermott Lake has a surface area of 33.1 ha and a mean depth of 3.0 m, while Sandy Beach Lake has a surface area of 44.5 ha and a mean depth of 2.1 m. During 2011 and 2012, Bluegill catch rates in standardized Wisconsin Department of Natural Resources (WDNR) boat electrofishing surveys in Sandy Beach Lake were 283 fish/h compared with 815 fish/h in McDermott Lake. Bluegill ≤ 125 mm TL were abundant in both lakes (Z. Lawson, WDNR, unpublished data). Both lakes include a variety of substrates (e.g., rock, gravel, and sand) and areas of submerged and emergent vegetation.

Currently, standardized WDNR statewide surveys of inland lakes consists of early summer (water temperature range = 13.0–21.0°C) boat electrofishing surveys or optional mid-summer (18.3–26.7°C) mini-fyke net surveys where Bluegill population demographic data are obtained (Simonson et al. 2008). To encompass this range of water temperatures, Bluegill were sampled once per month during months when lake surface water temperatures were ≥13.0°C at both lakes (June–September). Both lakes were sampled with all four gears during a 1-week period within each month. Lakes were sampled on consecutive nights within each 1-week period, and only one randomly chosen gear type was employed per night.

Sampling.— All of the sampling gears sampled shallow, shoreline habitats (0–5 m from the bank and depths ≤2 m) and were deployed in fixed locations throughout each lake following standard approaches (Bonar et al. 2009). Fixed sampling locations were evenly distributed along the shoreline of the lake, and all gears were deployed in similar habitat types. Eight 10-min nighttime boat electrofishing (Wisconsin-style; AC; 2.0–3.0 amps, 200–350 V, 25% duty cycle with two netters) transects were conducted using two experienced dipnetters. Five mini-fyke nets (0.9-m × 0.61-m frames, 3.2-mm mesh [bar measure], 7.6-m-long lead, and a double throat) were deployed in areas where the net frames would be in 1.0–1.5 m of water, and leads were fixed onshore. Five cloverleaf traps (three lobed, height = 41 cm, 50 cm in diameter, 6.0-mm bar wire mesh with 12.7-mm-wide openings between lobes, and an attractant [liver]) were deployed in littoral habitats. Both mini-fyke nets and cloverleaf traps were set in early afternoon, fished overnight, and retrieved the following afternoon (approximately 24-h soak time), hereafter referred to as a net lift. Four (McDermott Lake) and five (Sandy Beach Lake) nighttime beach seine hauls (0.32-cm mesh, length = 18.3 m, height = 1.83 m) were conducted in nearshore areas free of obstructions (e.g., fallen trees, dense stands of aquatic macrophytes). The beach seine was deployed perpendicular to the shoreline and then pivoted around an anchor point onshore (e.g., quarter haul; Bonar et al. 2009). Nighttime beach seine hauls were used due to the higher capture efficiency of Bluegill at night within sites that contain vegetation when using beach seines (Holland-Bartel and Dewey 1997) and other common gears (e.g., boat electrofishing; Bennet and Brown 1969; Dumont and Dennis 1997). All Bluegill were counted and measured (TL; mm). Three temperature loggers (Onset HOBO models Water Temperature Pro U22-001) were deployed in shallow water (1.0–1.5 m deep) throughout each lake during the study period to record water temperature (°C).

Analyses.— Cloverleaf trap, mini-fyke net, and beach seine haul CPUE were calculated as the average number of fish captured per net lift or seine haul. Boat electrofishing CPUE was calculated as the number of fish captured per 10-min transect. Mean CPUE was calculated for each gear by month for each lake. Sampling gears represented a mix of passive and active techniques, and CPUE is not directly comparable among these gears. We used coefficients of variation (CV; [SD/mean CPUE] × 100) to describe relative variation in CPUE estimates among gears by month for each lake. In addition, to determine if water temperature affected catch rates in each lake, gear-specific relationships between mean monthly water temperature (°C) and mean monthly CPUE were evaluated using Pearson correlation coefficients. Normality and homoscedasticity of Bluegill CPUE were assessed a priori using normal quantile and residual plots; CPUE values were $\log_{10}$ transformed prior to the analysis.

Nonparametric Kolmogorov–Smirnov two-sample tests were used to evaluate the null hypothesis that cumulative frequency of Bluegill TL distributions did not differ between lakes. If the null hypothesis was rejected ($P \leq 0.05$), Kolmogorov–Smirnov two-sample tests were used to evaluate pairwise differences in TL distributions among gears within each month. Statistical significance was set at an α of 0.05, which were Bonferroni-corrected to maintain familywise error rates of 0.05. Statistical analyses were conducted using the Fisheries Stock Analysis package (version 0.8.19; Ogle 2016) in software version 3.2.0 (R Development Core Team 2016).

We estimated the minimum number of samples required to detect specified changes in mean Bluegill CPUE and TL across gear types and months in both lakes. A sample was defined as one unit of effort of an individual gear (see above for gear-specific definitions of a unit of effort). Detectable changes were considered to be 10, 25, and 50% changes in mean Bluegill CPUE and TL based on previous literature (e.g., Parkinson et al. 1988; Fischer and Paukert 2009; Sindt 2018). The sample sizes required to detect specified changes in mean CPUE and TL were estimated using the formula recommended by Campbell et al. (1995):

$$n = 2\left(t_{1-\alpha/2} + t_{1-\beta}\right)^2 / d^2,$$

where n is the estimated sampling effort, $t_{1-\alpha/2}$ is the t-distribution deviate for a two-sided test at a specified α, $t_{1-\beta}$ is the t-distribution deviate for given level of statistical power (1 – β), d is the specified effect size (±10, 25, or 50% of the observed mean) divided by the sample standard deviation in mean CPUE or mean TL for each gear at each lake. A significance level of $\alpha = 0.10$ was chosen compared with a conventional value of 0.05 since type I errors were deemed more important than type II errors (e.g., Parkinson et al. 1988; Dauwalter et al. 2010). A statistical power level of $1 - \beta = 0.80$ was used for all sample size estimates since power ≥ 0.80 is deemed acceptable in fisheries survey data (Wagner et al. 2013). When estimating the number of sample sizes required to detect changes in Bluegill mean TL, n would be interpreted as the number of Bluegill required to be measured. To estimate the number of samples, or gear deployments (similar to detecting changes in mean CPUE), required to detect changes in mean Bluegill TL, n was divided by monthly mean CPUE for each gear in each lake.

RESULTS

Data collected for this project are available in electronic format (Isermann 2019). Beach seine hauls were not conducted during the month of September due to inclement weather, but all other gears were deployed that month. A total of 4,635 Bluegill were captured across all gears in both McDermott (3,756 fish) and Sandy Beach (879 fish) lakes. Across both lakes, boat electrofishing captured the most Bluegill (1,732 fish), followed by cloverleaf traps (1,645 fish), mini-fyke nets (857 fish), and beach seines (401 fish). Catch per unit effort ranged from 1 to 82 fish/net lift, seine haul, or 10-min transect among gears and months (Table 1). Catch rates of Bluegill were highest using cloverleaf traps (mean ± SE = 41 ± 11 fish/net lift), followed by boat electrofishing (27 ± 12 fish/10 min), mini-fyke nets (22 ± 6 fish/net lift), and beach seines (16 ± 8 fish/haul). Bluegill CPUE was lowest during September for both cloverleaf traps and boat electrofishing, while CPUE was generally lower during either July (Sandy Beach Lake) or August (McDermott Lake) for mini-fyke nets. Bluegill CPUE using beach seines was lowest during June at Sandy Beach Lake and July at McDermott Lake. Across both lakes, mean daily water temperature during the weekly sampling periods ranged from 18.0°C to 23.5°C from June to September. Bluegill CPUE was not significantly related to mean monthly water temperature for cloverleaf traps, boat electrofishing, mini-fyke nets, or beach seines in either McDermott or Sandy Beach lakes (Pearson's r ranged from −0.92 to 0.90; all $P > 0.05$; Figure 1).

Mean Bluegill TL ranged from 49 to 125 mm across all gears, and mean TL was lower for three of the four gears in McDermott Lake compared with Sandy Beach Lake (Table 2; Figure 2). The TL distributions of Bluegill captured were different between McDermott and Sandy Beach lakes ($D = 0.144$, $P < 0.001$). In McDermott Lake, pairwise comparisons indicated that Bluegill TL frequency

TABLE 1. Total number (N) of Bluegill captured, mean ± SE CPUE (net lift or seine haul or catch per 10 min), and coefficient of variation (CV) in CPUE of Bluegill captured using cloverleaf traps, boat electrofishing, mini-fyke nets, and beach seine hauls from June to September 2017 at both McDermott and Sandy Beach lakes, Wisconsin.

Lake	Gear	Month	N	CPUE	CV
McDermott Lake	Cloverleaf trap	June	374	75 ± 19	57
	Cloverleaf trap	July	412	82 ± 33	88
	Cloverleaf trap	August	274	55 ± 14	57
	Cloverleaf trap	September	74	15 ± 7	111
	Boat electrofishing	June	490	61 ± 18	85
	Boat electrofishing	July	426	53 ± 10	104
	Boat electrofishing	August	658	82 ± 19	67
	Boat electrofishing	September	64	8 ± 3	78
	Mini-fyke net	June	209	42 ± 12	66
	Mini-fyke net	July	215	43 ± 16	82
	Mini-fyke net	August	89	18 ± 6	71
	Mini-fyke net	September	98	20 ± 6	65
	Beach seine	June	192	48 ± 11	46
	Beach seine	July	68	17 ± 4	49
	Beach seine	August	113	28 ± 10	71
Sandy Beach Lake	Cloverleaf trap	June	167	33 ± 11	77
	Cloverleaf trap	July	278	56 ± 20	81
	Cloverleaf trap	August	46	9 ± 5	119
	Cloverleaf trap	September	20	4 ± 2	113
	Boat electrofishing	June	26	3 ± 1	100
	Boat electrofishing	July	23	3 ± 1	140
	Boat electrofishing	August	31	4 ± 1	100
	Boat electrofishing	September	14	2 ± 2	68
	Mini-fyke net	June	17	3 ± 1	77
	Mini-fyke net	July	9	2 ± 1	72
	Mini-fyke net	August	181	36 ± 28	174
	Mini-fyke net	September	39	8 ± 4	107
	Beach seine	June	5	1 ± 1	141
	Beach seine	July	6	1 ± 1	137
	Beach seine	August	17	3 ± 3	178

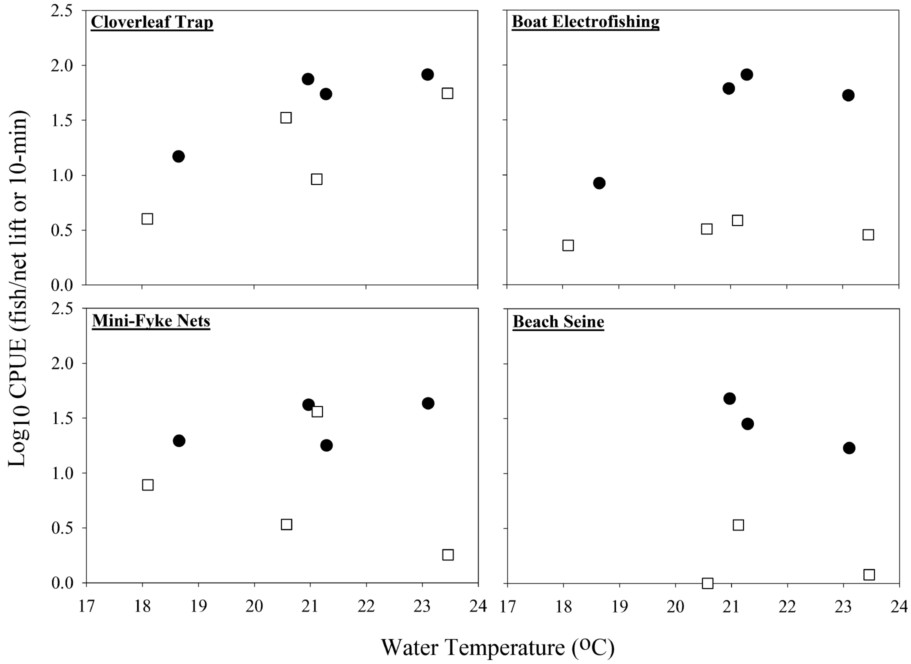

FIGURE 1. Relationship between Bluegill monthly CPUE (net lift or seine haul or catch per 10 min; $\log_{10}$ transformed) and mean monthly water temperature (°C) during June through September 2017 in both McDermott (black circles) and Sandy Beach (white squares) lakes. Beach seine hauls were not conducted during the month of September. All Pearson correlations (*r*) ranged from –0.92 to 0.90 (all $P > 0.05$).

TABLE 2. Total number (*N*) and mean ± SE, minimum, and maximum total length (mm) of Bluegill sampled with four gears from June to September 2017 at both McDermott and Sandy Beach lakes, Wisconsin.

			Total length		
Lake	Sampling gear	*N*	Mean ± SE	Minimum	Maximum
McDermott Lake	Cloverleaf trap	1,042	54 ± 0.3	35	115
	Boat electrofishing	1,455	76 ± 0.7	21	174
	Mini-fyke net	635	64 ± 1.0	24	140
	Beach seine	372	64 ± 1.5	21	187
Sandy Beach Lake	Cloverleaf trap	497	57 ± 0.6	26	107
	Boat electrofishing	92	125 ± 4.1	28	201
	Mini-fyke net	198	49 ± 2.6	21	210
	Beach seine	28	99 ± 6.2	24	176

distributions were different among all gears during June, July, and September (Table 3). During August, Bluegill TL frequency distributions were different among most pairwise gear comparisons; however, Bluegill TL distributions from mini-fyke nets were similar to cloverleaf traps and beach seines (Table 3). In Sandy Beach Lake, Bluegill TL frequency distributions were different between cloverleaf traps and all other gears within each month with the exception of mini-fyke nets during September (Table 3). Bluegill TL frequency distributions were similar between beach seines and both boat electrofishing and mini-fyke nets within each month, with the exception of mini-fyke nets during August (Table 3). Finally, Bluegill TL frequency distributions were different between boat electrofishing and mini-fyke nets during June, August, and September (Table 3).

Across lakes and gear types, the number of samples required to detect a change in mean Bluegill CPUE or TL increased as the desired detectable change decreased from 50% to 10%. For example, 400% more effort is required to detect a 25% change compared with a 50% change in mean Bluegill CPUE using boat electrofishing during June. The minimum number of samples required to detect a 10, 25, or 50% change in mean Bluegill CPUE was

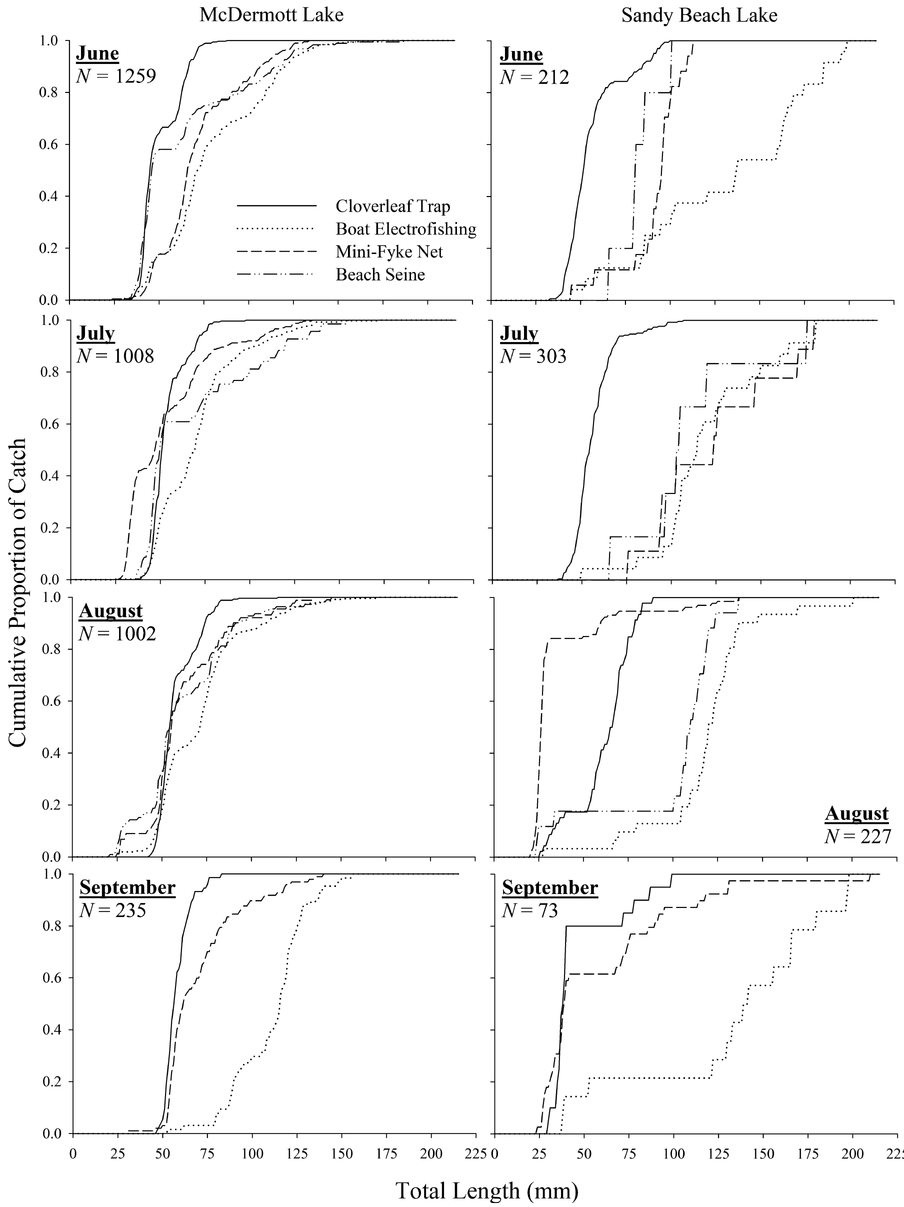

FIGURE 2. Cumulative frequency distributions and total number (N) of Bluegill collected from McDermott (left) and Sandy Beach (right) lakes during June through September 2017 using cloverleaf traps, boat electrofishing, mini-fyke nets, and beach seine hauls. Beach seine hauls were not conducted during the month of September.

achieved with as few as 19 beach seine samples in June or 19 boat electrofishing samples in July in McDermott Lake (Table 4). The minimum number of samples required to detect a 10, 25, or 50% change during August and September were achieved with as few as 24 cloverleaf trap and 32 mini-fyke net samples, respectively (Table 4). The minimum number of samples required to detect a 10, 25, or 50% change in mean Bluegill CPUE was higher in Sandy Beach Lake compared to McDermott Lake. The minimum number of samples required to detect a 10, 25, or 50% change was achieved with as few as 40 mini-fyke net samples in July (Table 4). Across all months, ≥ 40 boat electrofishing, cloverleaf trap, or mini-fyke net samples were required to detect a 10, 25, or 50% change in mean Bluegill CPUE (Table 4). Beach seines required more effort relative to other gears within each month to detect changes in mean Bluegill CPUE.

Detecting a 50% change in mean Bluegill TL yielded nonsensical results since the variability in mean TL was relatively small; therefore, we only estimated the minimum number of samples required to detect a 10% or 25% change. The minimum number of samples required to

TABLE 3. Kolmogorov–Smirnov test statistics (*D*) for pairwise comparisons of Bluegill total length frequency distributions from cloverleaf traps (CLV), boat electrofishing (EF), mini-fyke nets (FYKE), and beach seines (BS) within each month from McDermott and Sandy Beach lakes in northern Wisconsin. Beach seine hauls were not conducted during September; therefore, total length frequency distribution comparisons between seine hauls and other gears could not be evaluated. Bold italicized *P*-values denote significant differences (α = 0.05).

Month	Test statistic	CLV–EF	CLV–FYKE	CLV–BS	EF–FYKE	EF–BS	FYKE–BS
				McDermott Lake			
June	*D*	0.549	0.489	0.242	0.160	0.405	0.408
	P	***<0.001***	***<0.001***	***<0.001***	***0.008***	***<0.001***	***<0.001***
July	*D*	0.450	0.417	0.277	0.413	0.321	0.379
	P	***<0.001***	***<0.001***	***0.002***	***<0.001***	***<0.001***	***<0.001***
August	*D*	0.345	0.182	0.247	0.258	0.204	0.126
	P	***<0.001***	0.142	***<0.001***	***<0.001***	***0.005***	1.000
September	*D*	0.955	0.355		0.741		
	P	***<0.001***	***<0.001***		***<0.001***		
				Sandy Beach Lake			
June	*D*	0.767	0.762	0.819	0.625	0.667	0.624
	P	***<0.001***	***<0.001***	***<0.001***	***<0.001***	0.303	0.595
July	*D*	0.904	0.943	0.857	0.246	0.362	0.389
	P	***<0.001***	***<0.001***	***<0.001***	1.000	1.000	1.000
August	*D*	0.871	0.762	0.824	0.900	0.404	0.771
	P	***<0.001***	***<0.001***	***<0.001***	***<0.001***	0.332	***<0.001***
September	*D*	0.786	0.210		0.709		
	P	***<0.001***	1.000		***<0.001***		

TABLE 4. Minimum number of samples required to detect a 10, 25, or 50% change in mean Bluegill CPUE (fish per net lift or seine haul or catch per 10 min) at McDermott and Sandy Beach lakes among months (June–September; α = 0.10; 1 − β = 0.80). Beach seine hauls were not conducted during the month of September.

	McDermott Lake				Sandy Beach Lake			
% Change	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
				Boat electrofishing				
10	1,114	482	691	1,344	1,562	3,044	1,549	1,454
25	178	77	111	215	250	487	248	233
50	45	19	28	54	62	122	62	58
				Cloverleaf trap				
10	608	1,476	612	2,338	1,108	1,247	2,659	2,419
25	97	236	98	374	177	199	426	387
50	24	59	24	94	44	50	106	97
				Mini-fyke net				
10	828	1,266	949	800	1,111	991	5,741	2,148
25	132	203	152	128	178	159	918	344
50	33	51	38	32	44	40	230	86
				Beach seine				
10	467	528	1,114		3,777	3,541	6,011	
25	75	84	178		604	567	962	
50	19	21	45		151	142	240	

detect a 10% or 25% change in mean Bluegill TL was achieved with one sample using any gear in McDermott Lake across months (Table 5). To detect a 10% change in mean Bluegill TL in McDermott Lake, the minimum number of samples required was achieved with as few as two boat electrofishing samples in August. The minimum number of samples required to detect a 10% or 25% change in mean Bluegill TL was higher in Sandy Beach Lake compared to McDermott Lake. The minimum number of samples required to detect a 10% or 25% change in mean Bluegill TL was achieved with as few as one cloverleaf trap sample in June and July or two cloverleaf trap or mini-fyke net samples in August in Sandy Beach Lake (Table 5). In September, the minimum number of samples required to detect a 10% or 25% change was achieved with as few as 10 cloverleaf trap samples in Sandy Beach Lake (Table 5).

DISCUSSION

Our study contributes to the expanding body of literature evaluating and refining Bluegill sampling methodologies (e.g., Schultz and Haines 2005; Koch et al. 2014; Flammang et al. 2016). Our results support previous literature stating that Bluegill sampling designs should consider the use of multiple sampling gears to adequately sample the entire population (Schultz and Haines 2005; Ruetz et al. 2007); however, our results suggest that assessments of Bluegill populations with low size structure are likely to underestimate the abundance of small fish that likely compose a greater proportion of the entire population. Bluegill CPUE was highest in cloverleaf trap surveys and substock-length Bluegill (fish ≤ 80 mm TL; Gabelhouse 1984) accounted for a greater proportion of cloverleaf trap catch relative to other gears, suggesting that other gears do not efficiently sample smaller Bluegill.

TABLE 5. Minimum number of samples required to detect a 10% or 25% change in mean Bluegill total length (mm) at McDermott and Sandy Beach lakes among months (June–September; $\alpha = 0.10$; $1 - \beta = 0.80$). Sample sizes for cloverleaf traps, mini-fyke nets, and beach seine hauls represent the number of individual lifts or hauls; sample sizes for boat electrofishing are the number of 10-min transects. Beach seine hauls were not conducted during the month of September.

	McDermott Lake				Sandy Beach Lake			
% Change	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
Boat electrofishing								
10	3	3	2	5	53	31	22	99
25	<1	<1	<1	1	8	5	3	16
Cloverleaf trap								
10	1	<1	1	1	3	1	9	63
25	<1	<1	<1	<1	<1	<1	2	10
Mini-fyke net								
10	3	6	10	6	14	71	15	74
25	<1	1	2	1	2	11	2	12
Beach seine								
10	6	16	9		44	154	50	
25	1	3	1		7	25	8	

Furthermore, seasonal fluctuations in surface water temperature were not correlated with Bluegill CPUE for any gear, but within-month variability in catch (i.e., variability in catch among net lifts or seine hauls or 10 min of electrofishing each sampling session) led to highly variable sample sizes needed to detect predetermined changes in mean Bluegill CPUE or TL across months. Consequently, we suggest that managers consider the associated biases and sampling effort required by each gear when designing and performing assessments of Bluegill populations with low size structure. We suggest that other management agencies could benefit from an evaluation of Bluegill sampling protocols to ensure that the data obtained from such protocols accurately reflect Bluegill populations present within their systems.

We did not estimate the actual size structure of Bluegill populations in either lake and therefore do not know the true selective biases associated with each gear. Mean back-calculated length-at-age 1 for Bluegill collected from both McDermott and Sandy Beach lakes was 48 mm and 66 mm, respectively (C. J. Sullivan, unpublished data), and is approximately 74 mm across North America (25th percentile of mean length-at-age 1; Jackson et al. 2008), suggesting that Bluegill populations sampled herein are slower growing and slow growth likely extends the time to recruitment for a variety of sampling gears. Early in life or at these small sizes, Bluegill generally select for densely vegetated and complex habitats (Crowder and Cooper 1982; Gotceitas and Colgan 1987; Collingsworth and Kohler 2010). Both lakes were shallow (mean depth ≤ 3.0 m) and contained emergent and submerged vegetation in the littoral zones that could serve as primary habitat for Bluegill populations with low size structure. Cloverleaf traps are commonly deployed in vegetated areas (e.g., Weber and Brown 2012; Carl et al. 2016), but these habitats are unable to be successfully sampled using other gears such as boat electrofishing (e.g., Serafy et al. 1988), mini-fyke nets, and beach seines (e.g., Bonar et al. 2009). Although overly abundant complex habitats did not hinder sampling throughout this study, we encountered some difficulties with gear-specific site selection (e.g., beach seines). Further, effective immobilization of fish using boat electrofishing is related to body size (Dolan and Miranda 2003) as larger fish are more susceptible to immobilization than smaller fish (e.g., Anderson 1995). In our study, boat electrofishing captured the highest proportion (2.5% of total catch in both lakes) of quality-length Bluegill (≥150 mm TL; Gabelhouse 1984) compared to beach seines (1.0%), mini-fyke nets (0.003%), and cloverleaf traps (zero catch). This ability of boat electrofishing to capture quality-length Bluegill is well documented (e.g., Pierce et al. 2001; Ruetz et al. 2007; Flammang et al. 2016), but its inability to capture small Bluegill highlights the utility of other gears (e.g., cloverleaf traps). Consequently, our findings align with previous studies suggesting that the representation of the entire fish population is strongly dependent upon sampling protocols.

Sampling gears should also provide precise estimates of relative abundance and length distribution with minimal sampling effort (Colvin 2000). Several studies have estimated the sampling effort needed to achieve specified levels of precision for metrics used to describe Bluegill populations and populations of other closely related species (Hardin and Connor 1992; Koch et al. 2014; Flammang et al. 2016). Conversely, no published studies have evaluated and compared the sampling effort required to detect changes in mean CPUE and TL of Bluegill populations using the gears we assessed or for populations with low size structure. In the lake-rich regions of the upper Midwest, utilizing > 40 gear deployments per lake to detect changes in either mean Bluegill CPUE or TL may require more financial or time commitments than desired. However, it is unknown if other methods are more efficient for obtaining estimates of mean Bluegill CPUE and TL for populations with low size structure. Maximizing the amount of gear deployments per sampling occasion during months when the estimated number of samples needed to detect a predetermined change is lowest (e.g., eight 10-min boat electrofishing transects per sampling occasion during July) would reduce the number of site visits required and lead into possible investigations of smaller changes in mean CPUE or TL able to be detected (e.g., <50%) from population surveys. Thus, our evaluation of the sampling efficiency of specific gears can aid fishery managers in identifying labor-efficient sampling methods for Bluegill populations with small size structure.

Cloverleaf traps have been used to capture age-0 and juvenile Yellow Perch (Brown and St. Sauver 2002) and Common Carp (Carl et al. 2016) as well as age-0 Bluegill (Weber and Brown 2012; Kaemingk et al. 2013), but this is the first study to evaluate cloverleaf traps for their relative abilities to sample Bluegill populations in littoral areas of Midwestern lakes. Cloverleaf trap openings are relatively small (12.7 mm), resulting in the inability of large Bluegill to swim through trap openings and be captured (few Bluegill >100 mm TL were caught); therefore, cloverleaf traps are unlikely to adequately sample entire populations. However, cloverleaf traps captured substock-length fish more commonly (98.5% of total catch <80 mm TL) compared with the other gears and at a higher catch rate. Additionally, the decreased effort in labor for cloverleaf traps (<30 s; Mangan et al. 2005; Carl et al. 2016) relative to the other gears used herein (>300 s for deployment and retrieval; Collins et al. 2017), the ability to be deployed in areas hard to sample with other gears (e.g., complex habitats), and the minimal investment cost per trap (~$150/trap) suggests that cloverleaf traps provide a cost- and time-efficient gear for sampling substock-length Bluegill.

Management Implications

Most sampling gears used in fishery surveys have inherent biases that can hinder accurate quantification of fish population structure (e.g., Jackson and Bauer 2000; Ruetz et al. 2007; Bonar et al. 2009) and potentially result in inappropriate management decisions. Across the Midwest, fisheries biologists primarily use boat electrofishing surveys or fyke net surveys in the spring to early summer to sample Bluegill populations and collect data to derive population metrics (Schultz and Haines 2005; Simonson et al. 2008; Rypel et al. 2016). Our study indicated that assessing Bluegill populations with low size structure using a single gear (e.g., boat electrofishing) is likely to underestimate the abundance of smaller fish and limit the ability to detect significant changes in mean CPUE or TL of populations, indicating that more sampling effort will be required to collect and monitor populations. Furthermore, our results suggest that detecting changes in mean Bluegill CPUE and TL is convoluted because the gears are sampling differing subsets of the Bluegill population and suggests that alternative sampling methods should be used to capture fish of all sizes. Thus, our results support previous literature suggesting that multigear approaches are necessary to sample a fish population (Ruetz et al. 2007; Clement et al. 2014; Koch et al. 2014). To sample Bluegill populations with low size structure in lakes, we suggest incorporating both boat electrofishing surveys and either mini-fyke nets or beach seine hauls into sampling protocols depending on population density. Using a combination of these gears for Bluegill population assessments would allow for higher capture rates and a better representation of the Bluegill population size structure while reducing the amount of sampling effort required when attempting to assess populations.

Due to their inabilities to capture stock-length Bluegill, cloverleaf traps should be used for objective-specific population assessments. For example, cloverleaf traps could be used to assess substock-length Bluegill but should not be used to generally assess Bluegill populations (e.g., changes to adult density). Furthermore, density-dependent interactions can decrease the size structure of Bluegill populations (Wiener and Hanneman 1982; Walters and Post 1993). Low size structure within Bluegill populations associated with high density and slow growth ultimately provides poor angling quality. Consequently, fisheries managers attempt to maintain an appropriate balance among population density, growth rate, and size structure through various management actions. In certain situations, cloverleaf traps may provide an alternative for reducing abundances of small, more numerous Bluegill compared with the stocking of predators (Otis et al. 1998; Schneider and Lockwood 2002; Tomcko and Pierce 2005), altering harvest regulations (Coble 1988; Rypel 2015), or altering habitats (Crowder and Cooper 1982; Webb et al. 2016).

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