PRECISION AND ACCURACY OF LOW-FREQUENCY ELECTROFISHING FOR SAMPLING RESERVOIR FLATHEAD CATFISH *PYLODICTIS OLIVARIS* POPULATIONS

By

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Bachelor of Science in Biology

Baldwin Wallace University

Berea, Ohio

2017

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 2021

PRECISION AND ACCURACY OF LOW-FREQUENCY ELECTROFISHING

FOR SAMPLING RESERVOIR FLATHEAD CATFISH PYLODICTIS OLIVARIS POPULATIONS

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Date of Degree: July, 2021

Title of Study: PRECISION AND ACCURACY OF LOW-FREQUENCY ELECTROFISHING FOR SAMPLING RESERVOIR FLATHEAD CATFISH *PYLODICTIS OLIVARIS* POPULATIONS

Major Field: NATURAL RESOURCE ECOLOGY AND MANAGEMENT

Abstract: Flathead Catfish *Pylodictis olivaris* are popular among anglers, however; information about sampling Flathead Catfish is limited. Low-frequency electrofishing (LFE; < 30 pulses per second [pps]) is the most commonly used method for sampling Flathead Catfish. Therefore, the precision, optimal sampling duration, and accuracy of LFE sampling for Flathead Catfish was evaluated. CPUE (all sizes combined, $CPUE_{Total}$; fish over 610 mm TL, $CPUE_{610}$; and fish over 710 mm TL, $CPUE_{710}$) was highest from May-September when the water temperature was $\geq$23°C. Precision estimates (relative standard error, RSE) were not significantly impacted by water temperature but varied by month. $CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$ and their precision estimates did not significantly differ between 5-, 10-, and 15-minute samples. At warmer temperatures (i.e., >23° C), 15-minute samples only required 10-16 samples whereas 5-minute samples required 14-23 samples to achieve RSE = 25. Using a known Flathead Catfish populations (i.e., fish marked in Lake Carl Blackwell, Lake McMurtry, and Boomer Lake with operculum Carlin Dangler tags), I calculated capture probabilities with a Cormack Jolly Seber model. LFE is size biased but the bias varied among lakes. Capture probability decreased as fish length increased in Lake Carl Blackwell and Lake McMurtry and increased as fish length increased in Boomer Lake. Capture probability was the highest in July for Lake Carl Blackwell and Boomer Lake and August for Lake McMurtry. Capture probability was highest when the water temperature was $\geq$26°C in both Lake Carl Blackwell and Lake McMurtry, but temperature was not in the top models from Boomer Lake. The probability of a fish surfacing in wetlab trials was inversely related to the power applied to the fish indicating that low power application is most successful for Flathead Catfish LFE. Only 9.8% of fish surfaced in the trials suggesting that only some fish exhibit a surfacing response when exposed to LFE. I recommend sampling Flathead Catfish in July and August when the water temperature is $\geq$26°C as this sampling design will maximize catch rates, have high precise and minimize the size bias during the sampling season.

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CHAPTER I

OPTIMAL SAMPLING DURATION AND PRECISE ABUNDANCE AND SIZE-STRUCTURE ESTIMATION OF FLATHEAD CATFISH USING LOW-FREQUENCY ELECTROFISHING IN RESERVOIRS

Abstract

Many management agencies do not have a standardized sampling protocol for Flathead Catfish *Pylodictis olivaris*, primarily because information on sampling Flathead Catfish in lentic environments is lacking. Specifically, the effect of sampling duration, temperature and season on precision of low-frequency electrofishing (LFE) catch rate and size structure metrics is unknown. The goal of this study was to determine the water temperature and month of the year when the catch rates from LFE were highest and most precise for different size classes of Flathead Catfish and to find the optimal sampling duration (5-, 10-, or 15-minute samples) for Flathead Catfish LFE samples. CPUE (all sizes combined, $CPUE_{Total}$; fish over 610 mm TL, $CPUE_{610}$; and fish over 710 mm TL, $CPUE_{710}$) was calculated from a range of temperatures and seasons. $CPUE_{Total}$, $CPUE_{610}$ and $CPUE_{710}$ had the highest catch rates from May-September when the water temperature was $\geq$23°C. Precision estimates (relative standard error, RSE [also called

coefficient of variation of the mean]) were not significantly impacted by water temperature but were by month. N_{RSE25} was lowest when the water temperature >20°C from months May – September. $CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$ and their precision estimates did not significantly differ between 5-, 10-, and 15-minute samples, suggesting any sample duration would produce similar abundance estimates. Flathead Catfish CPUE from mobile LFE was compared across 5-, 10- and 15-minute samples taken monthly to collect fish from a range of temperatures and seasons. Sampling when water temperature is $\geq$26°C and taking at least 25 5-minute samples will typically obtain precise CPUE estimates (RSE < 25) with relatively high and consistent catch rates.

Introduction

The three largest North American catfish species (Channel Catfish *Ictalurus punctatus*, Blue Catfish *Ictalurus furcatus*, and Flathead Catfish *Pylodictis olivaris*) have increased in popularity with anglers and managers over the last few decades, leading to an increase in research related to the management of these species (Montague and Shoup *in press*; Porath et al. *in press*). However, there are still significant information gaps in the ictalurid sampling literature (Brown 2007; Bodine et al. 2013; Montague and Shoup *in press*), primarily because there is insufficient information about how to efficiently, accurately, and precisely sample these species (Brown 2007). Flathead Catfish are the least-studied of these three ictalurid species and are in greatest need of gear performance studies (Bodine et al. 2013; Montague and Shoup *in press*). Gear performance studies can help quantify gear biases and the conditions under which precision varies for particular sampling gears, allowing for the development of standardized protocols to minimize these biases and maximize sample precision, which will better equip researchers to manage and conduct research on these species.

Low-frequency electrofishing (LFE, 15 pps) is the most efficient and widely used Flathead Catfish sampling gear (Brown 2007; Bodine et al. 2013), however, many agencies do not have an LFE sampling protocol for Flathead Catfish and typically use a modified predator approach (Vokoun and Rabeni 1999) that focuses on catching the most fish possible. Although selecting a gear with high sampling efficiency (i.e., high catch per unit effort; CPUE) is helpful for some fishery metrics (e.g., where fish are needed for age analysis), it does not ensure that catch rates accurately reflect population sizes or size structures, nor will it ensure adequate precision of any fishery metrics. Low-precision data cannot detect meaningful but small changes in population metrics. It is therefore critical to evaluate the quality of data produced by LFE to further guide its use as a sampling tool for Flathead Catfish. Factors affecting precision (e.g., sample duration, season when samples are taken, etc.) of data collected on Flathead Catfish by LFE are unknown, making it difficult to know how best to use this gear to obtain quality data (Quinn 1986; Cunningham 2000; Cunningham 2004). Further, it is important to determine the conditions under which LFE Flathead Catfish data are consistent such that changes in measured values reflect changes in the population rather than changes in the sampling conditions.

Determining and using the optimal sampling duration allows quality data to be obtained with maximum efficiency, saving time and money or provide superior data quality for the same amount of time/effort expended. For example, for lentic Blue Catfish populations, 5-minute samples increase the spatial coverage of samples relative to taking half as many 10-minute samples, which ultimately leads to quality data with less time (and therefore money) expended on sampling (Shoup and Bodine *in press*). However, it is possible that longer samples produce more consistent catch rates for other species with lower catch rates (i.e., Flathead Catfish) such that fewer but longer-durations samples can be used to achieve the same precision with less time. Unless precision of different sample durations is considered, these tradeoffs cannot be evaluated and optimized. The optimal sampling duration for sampling Flathead Catfish with LFE has yet to be quantified. However, given their lower catch rates (25^{th} percentile = 19, 75^{th} percentile = 62 fish/hour; Bodine et al. 2013), Flathead Catfish may require samples longer than 5-minutes to achieve adequate precision, given the high frequency with which no fish are encountered in a 5-minute sample. Further, it is important to know how many samples are needed to achieve reasonable precision (i.e., relative standard error (RSE) $\leq$ 25). Collecting too few samples is a waste of time because it does not provide usable data (i.e., low-precision data that cannot adequately detect changes in the population), but collecting more samples than needed wastes time and resources.

It takes 30-90 seconds in the electric field before Flathead Catfish exhibit a surfacing response (Cunningham 2000; Bodine et al. 2013; Chapter 2), and presumably it could take several more seconds or even a minute for a fish to swim to the surface. Therefore, it is possible that different sizes of Flathead Catfish inhabit different depths and could surface at different times (i.e., taking longer for deeper fish to surface), potentially making samples of different duration produce different size-specific catch rates. Therefore, it is possible that short-duration samples could lead to size bias if fish of different sizes require different amounts of time before they surface (Shoup and Bodine *in press*). Thus, there is a need to evaluate if catch rates of all size classes are similar between shorter and longer sampling durations.

Seasonality, which correlates with temperature but also affects biological changes in fish over the course of a year (e.g., spawning), can also affect sampling precision and should be considered when attempting to design precise sampling protocols. For example, LFE of Flathead Catfish in rivers is most precise when taken in the summer months at temperatures between 16 and 30°C (CV=0.34-0.36; Travnichek 2011). Seasonal or temperature-based precision has yet to be quantified for LFE for Flathead Catfish in reservoirs, so it is unknown which season produces the best data.

LFE is the most efficient gear used to sample Flathead Catfish populations, but the optimal sampling duration, temperature and season for collecting precise data in lentic environments are unknown. Specifically, the goals of my study are to: 1) determine the effect of temperature and month (season) on the magnitude and precision of CPUE (all sizes combined, $CPUE_{Total}$; fish over 610 mm TL, $CPUE_{610}$; and fish over 710 mm TL, $CPUE_{710}$) of Flathead Catfish; 2) determine the number of samples required to achieve RSE $\leq$ 25 (RSE_{25}) for $CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$; and 3) determine the effect of sample duration (5-, 10-, and/or 15-minute samples) on the magnitude and precision of total catch rate ($CPUE_{Total}$), catch rate of preferred-sized fish ($\geq$ 610mm; $CPUE_{610}$; Gabelhouse 1984), and catch rate of memorable-sized fish ($\geq$ 710mm; $CPUE_{710}$; Gabelhouse 1984) of Flathead Catfish.

Methods

Sampling was conducted in three north-central Oklahoma reservoirs (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake). The reservoirs vary in size with Boomer Lake (Payne County, OK) being the smallest (102 ha), Lake McMurtry (Noble County, OK) being the intermediate (467 ha), and Lake Carl Blackwell (Payne County, OK) being the largest (1,364 ha). These reservoirs also have different habitat characteristics; Boomer Lake has its basin modified with a series of peninsula-shaped wing dykes with concrete or rip-rap substrate and little natural standing timber, Lake McMurtry primarily consists of natural habitat (flooded timber and natural rock outcroppings) with rip-rap only located along the dam, and Lake Carl Blackwell is a mix of anthropogenically modified and natural habitat.

Monthly LFE samples were collected during daylight hours from a 5.5-m long aluminum semi-V boat with the boat hull serving as the cathode and two Smith-Root SAA-6 anode arrays mounted at the end of 1.8-m fiberglass booms. Electrofishing power was produced by a 7.5 Smith-Root GPP electrofisher set to 15 pps DC current, 240-340 V, and the percent of range was adjusted based on water conductivity following the power tables of Bonar et al. (2009). Fish were collected by one dipnetter on the bow of the electrofishing boat (no chase boat, following the recommendation of Cunningham 2004). Lake Carl Blackwell and Lake McMurtry were sampled monthly from September 2019 – March 2021 and Boomer Lake was sampled monthly from March 2020 – June 2021. Due to technical problems, electrofishing samples were not collected in Lake McMurtry and Lake Carl Blackwell in August 2019 and from December 2019-February 2020.

Each reservoir's shoreline was divided into four distinct sections that were then sampled monthly using a stratified random design (reservoir section being the stratifying variable). Each section was further subdivided into 600-meter-long transects that were classified as the sampling sites. The starting section for a given sampling event was randomly selected from the un-sampled sections available at that time and the starting site within that section was also randomly selected. Sampling was performed in a counter-clockwise fashion within the section and when the end of the sampling section was reached, the boat was moved to the other end of the section and sampling continued until the starting point was reached (i.e., the entire section had been sampled). The electrofishing boat was operated slowly (1.3-2.9 kph) and close to the shoreline (<30 meters from shore). Each site was randomly assigned a sampling duration (5-, 10-, or 15-minute sample) and samples were separated $\geq$ 100 meters from each other to make sure there was no overlap of the electrical field with adjacent sites. Each captured fish was measured (TL, mm). Water temperature and conductivity were recorded at the start of each sampling site.

Analysis

Effect of Temperature and month on catch rates

I tested the effect of temperature and month on $CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$ using general linear mixed models (lmer() function of the lmerTest package (Bates et al. 2015) in R (R Core Team, 2019)). Temperature, month and their interaction were fixed effects and lake (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) was a random factor. Temperature was analyzed categorically using 3^{o} C bin size rather than treating temperature as a continuous variable because preliminary graphing of the data suggested multiple threshold temperatures existed and treating temperature as a continuous variable would assume smooth linear or curvilinear transitions between temperature ranges. I also tested the effect of temperature and month on the precision (RSE) of $CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$ using the above procedure, but with RSE rather than CPUE for each response variable. Relative standard error was calculated as RSE = 100 * SE/mean, where SE is standard error. In cases where model effects were significant, Tukey honestly significant difference test (using the glht function of the multcomp package (Hothorn et al. 2008) in R (R Core Team, 2019)) was used to test all pairwise combinations.

NRSE

The number of samples required to achieve RSE $\leq$ 25 was calculated using the methods of Dumont and Schlechte (2004). I separately analyzed each temperature bin (3°C) and month combination that had $\geq$15 samples. For each temperature and month combination, all samples of a given duration (5-, 10-, or 15-minutes) were resampled 1,000 times (with replacement) with each of several different sample sizes. From these resampled distributions, sampling effort required to achieve RSE $\leq$ 25 was determined at the empirical 80th percentile. I then compared the estimated sample sizes needed to achieve RSE $\leq$ 25 for each sample duration to see if more numerous short samples or fewer longer-duration samples were more efficient and to determine how temperature and month affect sample sizes needed to achieve target precision.

Sampling Duration

I wanted to determine if 5-, 10-, or 15-minute sampling duration produces similar catch rates. Therefore, I compared the CPUE (fish/hour) of each sampling duration (5-, 10-, and 15-minutes) using general linear models with a random effects for sites and lakes (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) using the lmer() function of the lmerTest package (Bates et al. 2015) in R (R Core Team, 2019). Separate models were used to assess differences in the CPUE of all Flathead Catfish ($CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$). Because the catch rates were highest and most precise above 23°C, I filtered the data so that only the data collected in water temperatures above 23°C were used.

Precision (relative standard error; RSE) of $CPUE_{Total}$, $CPUE_{610}$, and $CPUE_{710}$, was calculated from 5-, 10-, and 15-minute samples in order to test if longer duration samples provided better precision using general linear models with a random effects for sites and lakes (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) using the lmer() function of the lme4 package (Bates et al. 2015) in R (R Core Team, 2019). Separate models were used to assess differences in the RSE values of all Flathead Catfish ($CPUE_{Total}$), $CPUE_{610}$, and $CPUE_{710}$.

Separate length frequency histograms were created for each lake from pooled data sampled with each sampling duration (5-, 10-, or 15-minute samples) using 50-cm length bins. I used the fisher.test() function in R (R Core Team, 2019) to conduct a Fisher's exact test to determine if length frequencies from each sampling duration differed in each lake.

Results

Effects of Water temperature and month

Overall, I collected 1,853 fish during the study (958 from Lake Carl Blackwell, 743 from Lake McMurtry, and 152 from Boomer Lake). Water temperature and month had a significant effect on $CPUE_{Total}$ (temperature x month $F_{19, 3894.4} = 2.4$, $P < 0.01$; Figure 1), $CPUE_{610}$ (temperature x month $F_{19, 3860.3} = 3.52$, $P < 0.01$; Figure 2) and $CPUE_{710}$ (temperature x month $F_{19, 3882.5} = 3.78$ $P < 0.01$; Figure 3). $CPUE_{Total}$ was typically highest when the water temperature ranged from 23-31.9° C (i.e., generally, CPUE in this range was not significantly lower than the highest CPUE), but at any given temperature, catch rates still varied from month to month. Within-month variation was particularly pronounced for May and September where warmer temperatures had very high catch rates and cooler temperatures had noticeably lower catch rates. The month of May included several high-catch events for all fish sizes (Figures 1-3). Although sampling was conducted with similar effort each month, no fish of any size were caught when the water temperature was below 13°C (Figures 1-3). Similar catch rates of all three size classes of fish were observed from May once temperatures were above 26^{o} C through September until temperatures cooled below 26^{o} C.

Water temperature and month did not significantly affect precision (RSE) of $CPUE_{Total}$ (temperature x month $F_{19, 49.9}$= 0.55, P = 0.92; temperature $F_{9, 49.9}$ = 0.90, P = 0.53; month $F_{11,49.9}$ = 1.91, P = 0.06; Figure 4), $CPUE_{610}$ (temperature x month $F_{19, 50.1}$ = 0.65, P = 0.85, temperature $F_{9, 50.1}$ = 0.70, P = 0.71; month $F_{11, 50.3}$ = 1.00, P = 0.46; Figure 4), and $CPUE_{710}$ ($F_{19, 52}$ = 0.81, P =0.68, temperature $F_{9, 52}$ = 0.40, P = 0.93; month $F_{11, 52}$ = 2.20, P = 0.03; Figure 4). For $CPUE_{710,}$ the Tukey test on month effect did not identify any pairs of months with significantly different catch rates (all P > 0.11). Precision estimates could not be generated in the months of November- March because no fish were caught during those months (Figure 4).

NRSE

The number of samples needed to achieve RSE $\leq$ 25 ($N_{RSE=25}$) generally decreased as the water temperature increased and was typically somewhat lower for longer-duration samples (Table 1). At warmer temperatures, where CPUE was highest (i.e., >23° C), 15-minute samples only required 10-16 samples whereas 5-minute samples required 14-23 samples to achieve RSE = 25 (Table 1). Cool temperatures early and late in the year produced high $N_{RSE=25}$ estimates that would not be practical for most biologists/researchers.

Sampling duration

Catch rates did not differ between the 5-, 10-, and 15-minute sampling durations for $CPUE_{Total}$ ($F_{2, 524.7} = 0.16$, $P = 0.85$; Figure 5), $CPUE_{610}$ ($F_{2, 523.4} = 0.78$, $P = 0.46$; Figure 7), or $CPUE_{710}$ ($F_{2, 527.5} = 1.19$, $P = 0.31$, Figure 5). Precision also did not differ between the 5-, 10-, and 15-minute sampling durations for $CPUE_{Total}$ ($F_{2, 4} = 0.70$, $P = 0.55$; Figure 6), $CPUE_{610}$ ($F_{2, 4} = 1.10$, $P = 0.42$; Figure 6), or $CPUE_{710}$ ($F_{2, 4} = 4.94$, $P = 0.08$, Figure 6). Length frequencies also did not differ between the 5-, 10-, and 15-minute samples for $CPUE_{Total}$ at any of the three lakes (all P values ≥ 0.31; Table 2, Figures 7-9).

Discussion

Optimizing sample duration can improve efficiency such that agencies save time, money, and effort while still obtaining quality data useful for monitoring (Shoup and Bodine *in press*). My results indicate that conducting 5-minute samples provide similar data (i.e., catch rates and size-related metrics were not statistically different) to 10- or 15-minute samples with less cumulative time spent electrofishing to achieve target precision (RSE = 25). Although $N_{RSE=25}$ was lower using a 15-minute sample compared to a 5- or 10-minute samples, conducting 5-minute samples is still advantageous because they required less cumulative electrofishing time, and shorter duration samples allow for greater spatial coverage of the reservoir. For example, using 15-minute samples in the months of June-September took 10-18 samples to consistently obtain RSE $\leq$ 25, which is equivalent to 150-270 minutes of total sampling time. With 5-minute samples, 14-23 replicates were required to achieve RSE $\leq$ 25, but this equated to 70-115 minutes of total sampling time and also provided greater spatial coverage. In this example, travel time between samples was not considered, so longer samples may be more efficient in terms of time if travel time is considerable and the added spatial coverage is not considered advantageous.

Although precision of LFE was high from late May through early September (i.e., when water temperatures were > 20^{o}C), I found significant differences in $CPUE_{Total}$, $CPUE_{610}$ and $CPUE_{710}$ across this range of months, suggesting that sampling should take place over a narrower range of months to ensure catch rates do not vary appreciably as a result of gear bias. If sampling time were not standardized, the same lake could produce strongly different CPUE values that would make it appear that the population size had changed when in reality it was just seasonal variation. The month(s) with peak CPUE values for each size group of fish also differed. The greatest catch rate of large fish occurred in May (likely due to larger Flathead Catfish inhabiting shallow water to spawn as spawning occurs at temperatures of 19-24° C, Jackson 1999)) and the most fish were caught overall in September, relatively few large fish were caught in this month (possibly because larger Flathead Catfish move to deeper and cooler water post spawn and may have been out of range of the electrical field (Cunningham 2000)). Catch rates for all sizes of fish were statistically similar from May through September as long as water temperatures were above 26° C. In Chapter 2, I identified that LFE is size biased and has variable capture probabilities depending on the month and temperature when you sample. Therefore, to minimize size bias, the most accurate time to sample with LFE is in the months of July and August when the water temperature is ≥26° C. This coincides well with a period of high precision, so this is the time I recommend be used to sample Flathead Catfish with LFE to maximize accuracy and precision of data.

Water temperature is an important environmental cue that managers can use to determine when to sample Flathead Catfish populations and get the highest and most precise catch rates using LFE. Generally, catch rates decreased rapidly at water temperatures < 20° C and were highest when above 20-23° C, depending on the month. Several studies have similarly found that LFE for Flathead Catfish is more effective (higher catch rates) when the water temperatures were >20° C (Quinn 1984; Cunningham 2000; Bodine et al. 2013). My results also indicate samples are more precise at these warmer temperatures. For Blue Catfish, 18-28° C is the most effective water temperature to maximize catch rates and precision (Bodine and Shoup 2010). Therefore, if both species are collected at the same time, I recommend sampling when temperature is 20 – 28°C in the months of June – August to ensure both species are being sampled at optimal temperatures.

LFE sampling for both Blue Catfish (Justus 1996; Bodine and Shoup 2010) and Flathead Catfish (Quinn 1984) is ineffective during cold water temperatures (<16° C) and winter months (December-March). I also found LFE catch rates of Flathead Catfish declined rapidly when temperatures were < 21^{o} C, approached zero when temperatures were $\leq$ 18^{o} C, and were totally ineffective at temperatures < 13^{o} C. The ineffectiveness of LFE at colder water temperatures may be attributed to a physiological condition that makes Flathead Catfish unsusceptible to the electrical field at colder temperatures. Morris (2018) found that only a few Flathead Catfish exhibited a capture-prone response (i.e., surfacing) in a laboratory environment when electrofished in water temperatures of 13-17° C. However, this temperature range was still above the cold water threshold where I stopped collecting fish in the field. Alternatively, it is possible the inability to sample Flathead catfish at temperatures <13° C could also be caused by fish moving to deeper habitats in the winter months (> 4 m; Daugherty and Sutton 2005) and therefore, LFE may not be able to effectively shock fish to the surface while sampling along the shoreline.

It is important for fisheries managers to develop a sampling protocol that is efficient, precise, and accurate. LFE can provide data to indicate if relative changes occur by picking a sampling strategy where the bias is constant and looking at relative differences across systems or years. Based on my findings, I recommend 20, 5-minute samples anytime from May – September when the water is $\geq$ 26º C to optimize precision and prevent excessive variation in catch rates. Ten- or 15-minute samples will provide similar data quality, but at the cost of additional cumulative electrofishing time, and could be used when preferred (possibly because it minimizes travel time). However, these longer sample times do not allow as great a spatial coverage for a given amount of electrofishing time. However, sampling in May is recommended if obtaining maximum numbers of large fish is important (e.g., for age analysis).

Acknowledgements

Support for this manuscript was provided by the Natural Resource Ecology and Management Department at Oklahoma State University and USDA National Institute of Food and Agriculture, Hatch project number 1023034 and the Division of Agricultural Sciences and Natural Resources at Oklahoma State University. I also thank the numerous Oklahoma State University volunteers and graduate students for helping in field sampling. This research was conducted under Oklahoma State University's Institutional Animal Care and Use Committee's Protocol AG-19-9.

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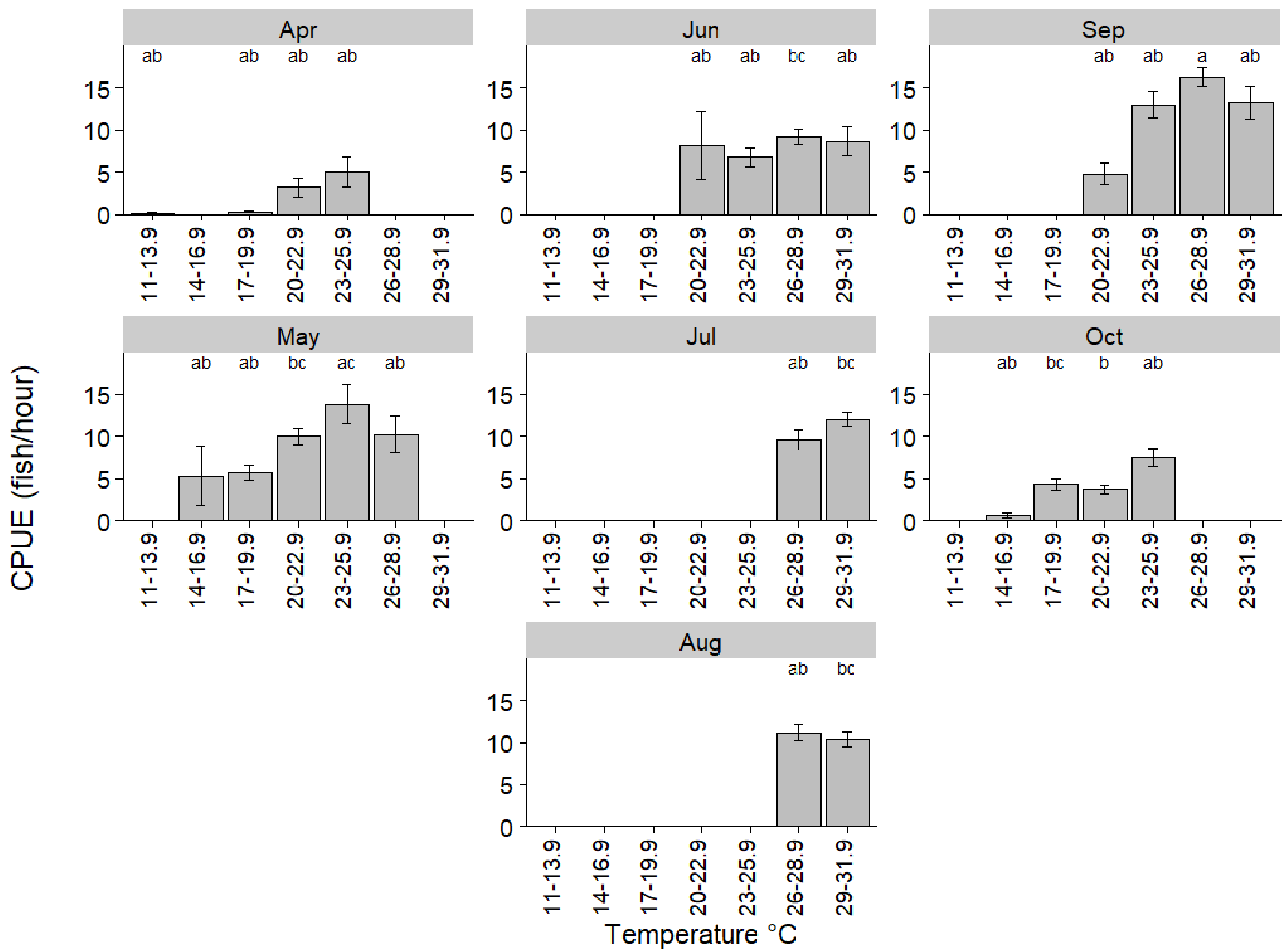
Table 1. The number of samples required to achieve relative standard errors ≤ 25 (N_{RSE25}) for low-frequency electrofishing samples of Flathead Catfish in 3 Oklahoma lakes at different water temperatures, months, and sampling durations (5-, 10-, or 15-minute samples). Blank cells indicate that no fish were sampled in that month and temperature combination, so N_{RSE25} could not be calculated.

Temperature °C	Apr			May			Jun			Jul			Aug			Sep			Oct		
	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
11-13.9																					
14-16.9																			191	201	190
17-19.9	136	147	144	46	20	17													29	24	23
20-22.9				21	14	14										21	19	18	66	25	17
23-25.9				18	14	14	23	19	12							21	17	14	18	14	14
26-28.9							19	16	15	15	19	16	17	15	11	14	16	13			
29-31.9										18	18	13	15	13	10	20	16	14			

Table 2. Results of the Fisher Exact test comparing 5-, 10-, and 15-minute low-frequency electrofishing samples for Flathead Catfish in Lake Carl Blackwell, Lake McMurtry, and Boomer Lake.

Lake	Sample Duration	Fisher's Exact P value
Lake Carl Blackwell	5 vs 10	0.31
Lake Carl Blackwell	5 vs 15	0.52
Lake Carl Blackwell	10 vs 15	0.63
Lake McMurtry	5 vs 10	0.41
Lake McMurtry	5 vs 15	0.69
Lake McMurtry	10 vs 15	0.83
Boomer Lake	5 vs 10	0.71
Boomer Lake	5 vs 15	0.99
Boomer Lake	10 vs 15	0.72



Apr
Jun
Sep
May
Jul
Oct
Aug
ab
bc
ac
a
b
15
10
5
0
11-13.9
14-16.9
17-19.9
20-22.9
23-25.9
26-28.9
29-31.9
CPUE (fish/hour)
Temperature °C

Figure 1. Catch rates of all size classes ($CPUE_{Total}$) of Flathead Catfish using low-frequency electrofishing from three Oklahoma Reservoirs (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) by temperature and month. The temperatures with no bars indicate no fish were captured. November through March are not pictured because no fish were caught in these months despite equal monthly sampling effort. Significant letters are above each bar to indicate which bars are significantly different. Error bars indicate $\pm$1 standard error.

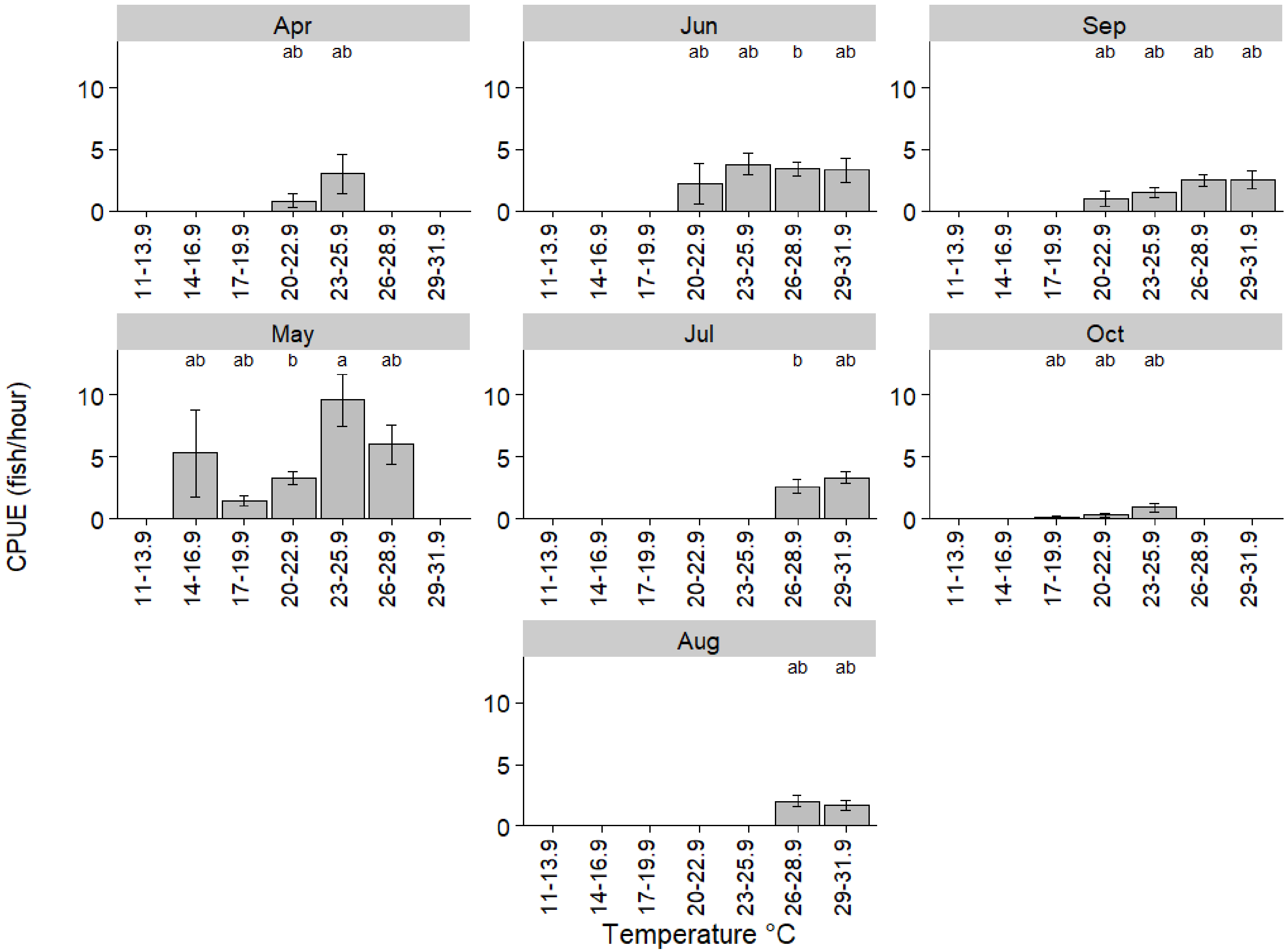
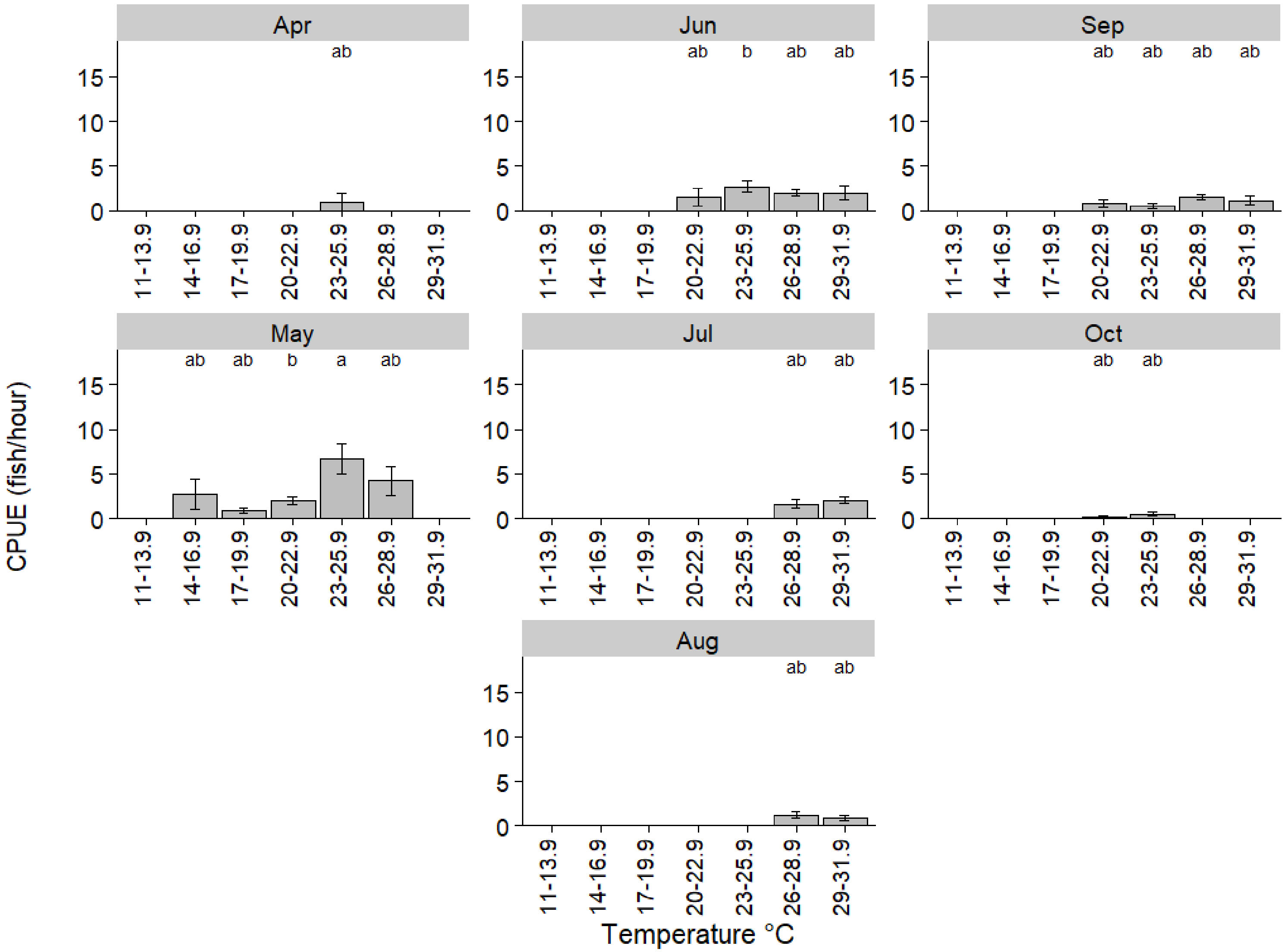

Apr
Jun
Sep
May
Jul
Oct
Aug
ab ab
ab ab b ab
ab ab ab ab
ab ab b a ab
b ab
ab ab ab
ab ab
0
5
10
11-13.9
14-16.9
17-19.9
20-22.9
23-25.9
26-28.9
29-31.9
CPUE (fish/hour)
Temperature °C

Figure 2. Catch rates of preferred-size ($\geq$ 610 mm TL; $CPUE_{610}$) Flathead Catfish using low-frequency electrofishing from three Oklahoma Reservoirs (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) by temperature and month. The temperatures with no bars indicate no fish were captured. November through March are not pictured because no fish were caught in these months despite equal monthly sampling effort. Significant letters are above each bar to indicate which bars are significantly different. Error bars indicate $\pm$1 standard error.



Apr
Jun
Sep
May
Jul
Oct
Aug
ab
ab b ab ab
ab ab ab ab
ab ab b a ab
ab ab
ab ab
ab ab
15
10
5
0
11-13.9
14-16.9
17-19.9
20-22.9
23-25.9
26-28.9
29-31.9
CPUE (fish/hour)
Temperature °C

Figure 3. Catch rates of memorable-size (≥710 mm TL; $CPUE_{710}$) Flathead Catfish using low-frequency electrofishing from three Oklahoma Reservoirs (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) by temperature and month. The temperatures with no bars indicate no fish were captured. November through March are not pictured because no fish were caught in these months despite equal monthly sampling effort. Significant letters are above each bar to indicate which bars are significantly different. Error bars indicate ±1 standard error.

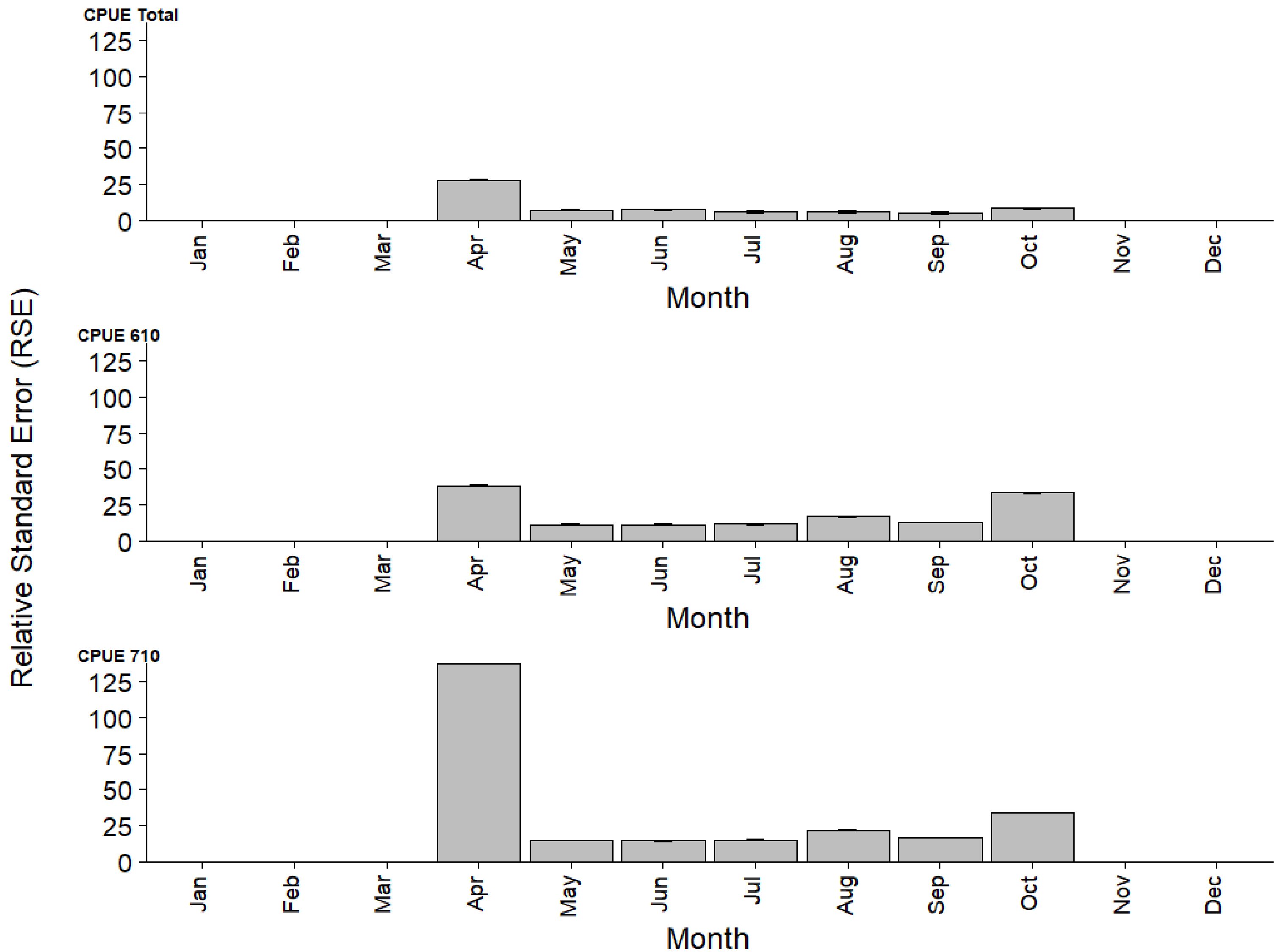

Relative Standard Error (RSE)
CPUE Total
CPUE 610
CPUE 710
125
100
75
50
25
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 4. Relative standard error of CPUE from all sizes of Flathead Catfish ($CPUE_{Total}$), preferred-length fish ($\geq$610 mm TL; $CPUE_{610}$), and memorable-length fish ($\geq$710mm TL; $CPUE_{710}$) of Flathead Catfish using low-frequency electrofishing from three Oklahoma Reservoirs (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake) by month. November through March are not pictured because no fish were caught in these months despite equal monthly sampling effort. Error bars indicate $\pm$1 standard error.

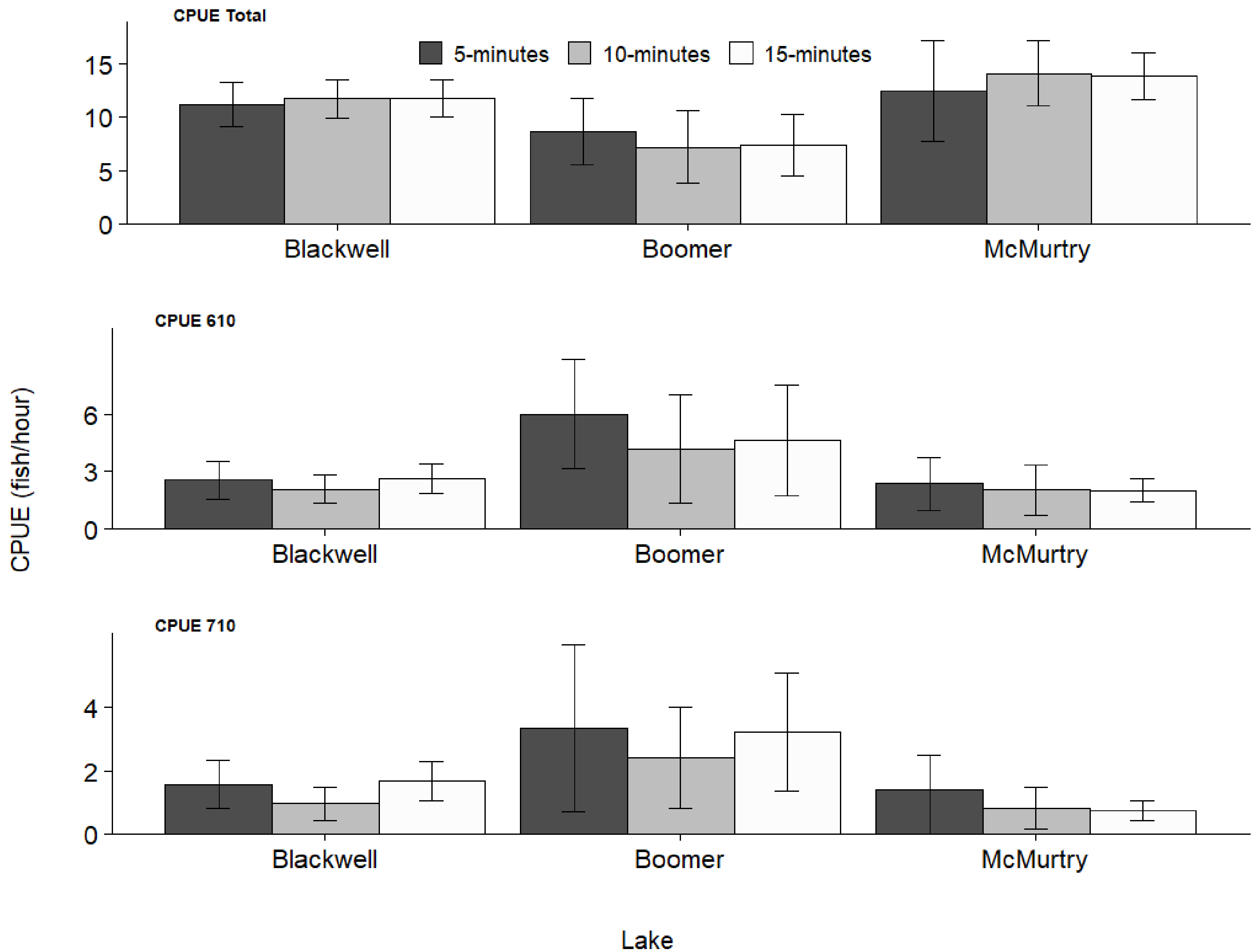

CPUE Total
5-minutes
10-minutes
15-minutes
15
10
5
0
Blackwell
Boomer
McMurtry
CPUE 610
6
3
0
Blackwell
Boomer
McMurtry
CPUE (fish/hour)
CPUE 710
4
2
0
Blackwell
Boomer
McMurtry
Lake

Figure 5. Mean catch rates from 5-, 10-, and 15-minute low-frequency electrofishing samples for Flathead Catfish in Lake Carl Blackwell, Lake McMurtry, and Boomer Lake for all sizes of Flathead Catfish ($CPUE_{Total}$), preferred-length fish ($\geq$610 mm TL; $CPUE_{610}$), and memorable-length fish ($\geq$710mm TL; $CPUE_{710}$). Error bars indicate $\pm$ 1 standard error.

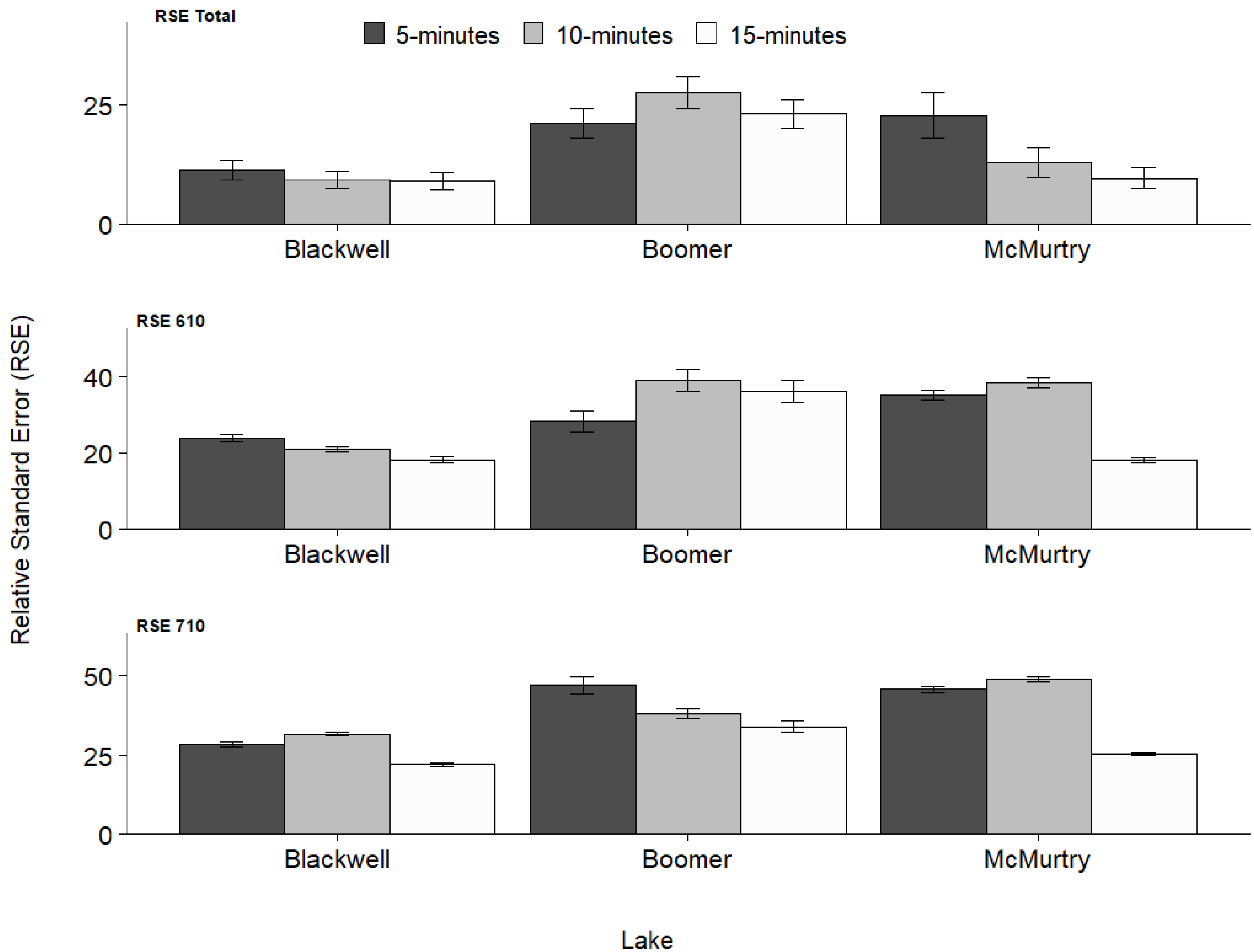

RSE Total
5-minutes
10-minutes
15-minutes
25
0
Blackwell
Boomer
McMurtry
RSE 610
40
20
0
Blackwell
Boomer
McMurtry
Relative Standard Error (RSE)
RSE 710
50
25
0
Blackwell
Boomer
McMurtry
Lake

Figure 6. Mean relative standard error from CPUE of 5-, 10-, and 15-minute low-frequency electrofishing samples for Flathead Catfish in Lake Carl Blackwell, Lake McMurtry, and Boomer Lake for all sizes of Flathead Catfish ($CPUE_{Total}$), preferred-length fish ($\geq$610 mm TL; $CPUE_{610}$), and memorable-length fish ($\geq$710mm TL; $CPUE_{710}$). Error bars indicate $\pm$ 1 standard error.

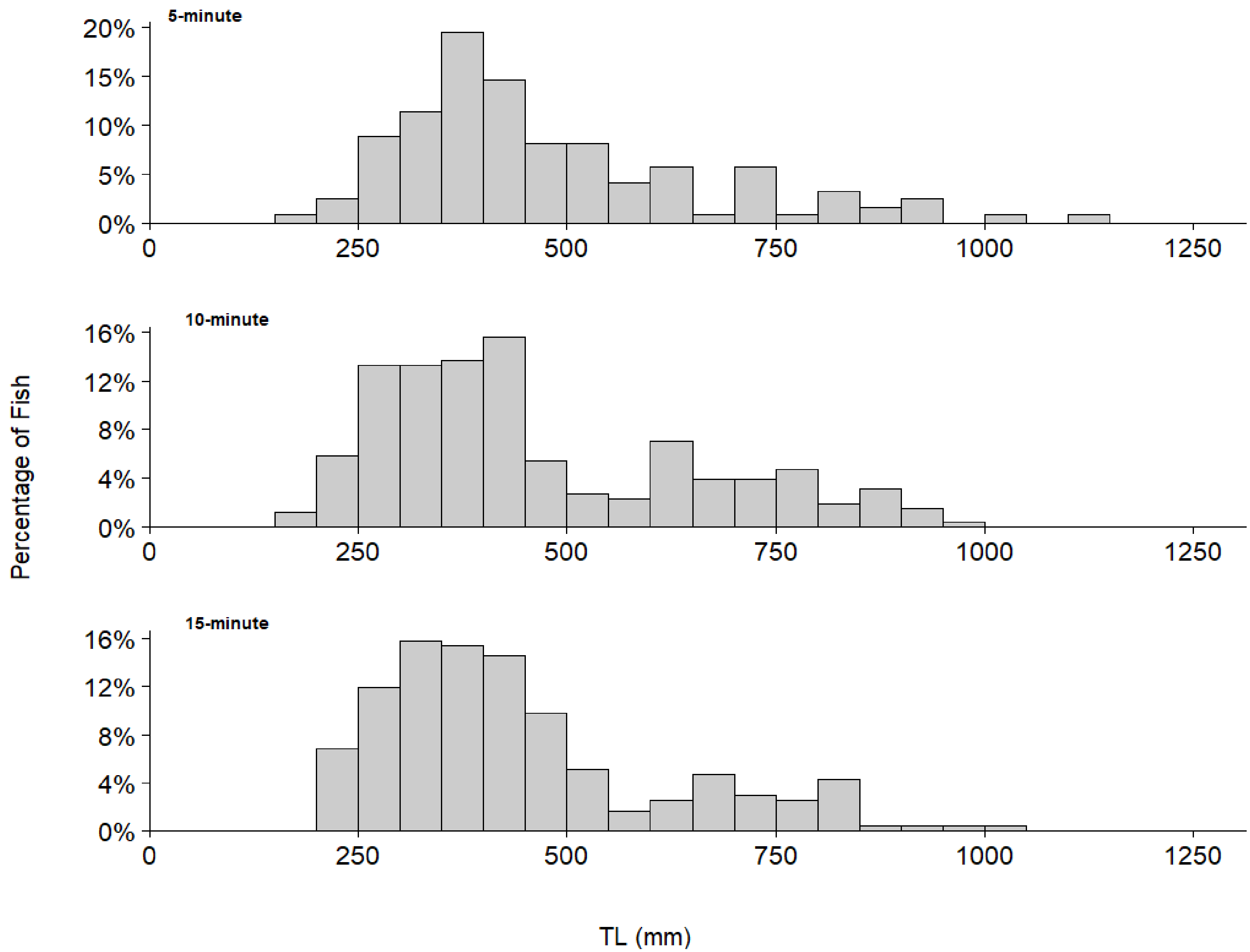

5-minute
20%
15%
10%
5%
0%
0
250
500
750
1000
1250
10-minute
16%
12%
8%
4%
0%
15-minute
Percentage of Fish
TL (mm)

Figure 7. Length frequency histograms of Flathead Catfish caught by low-frequency electrofishing in 5-, 10-, or 15-minute low-frequency electrofishing samples in Lake Carl Blackwell.

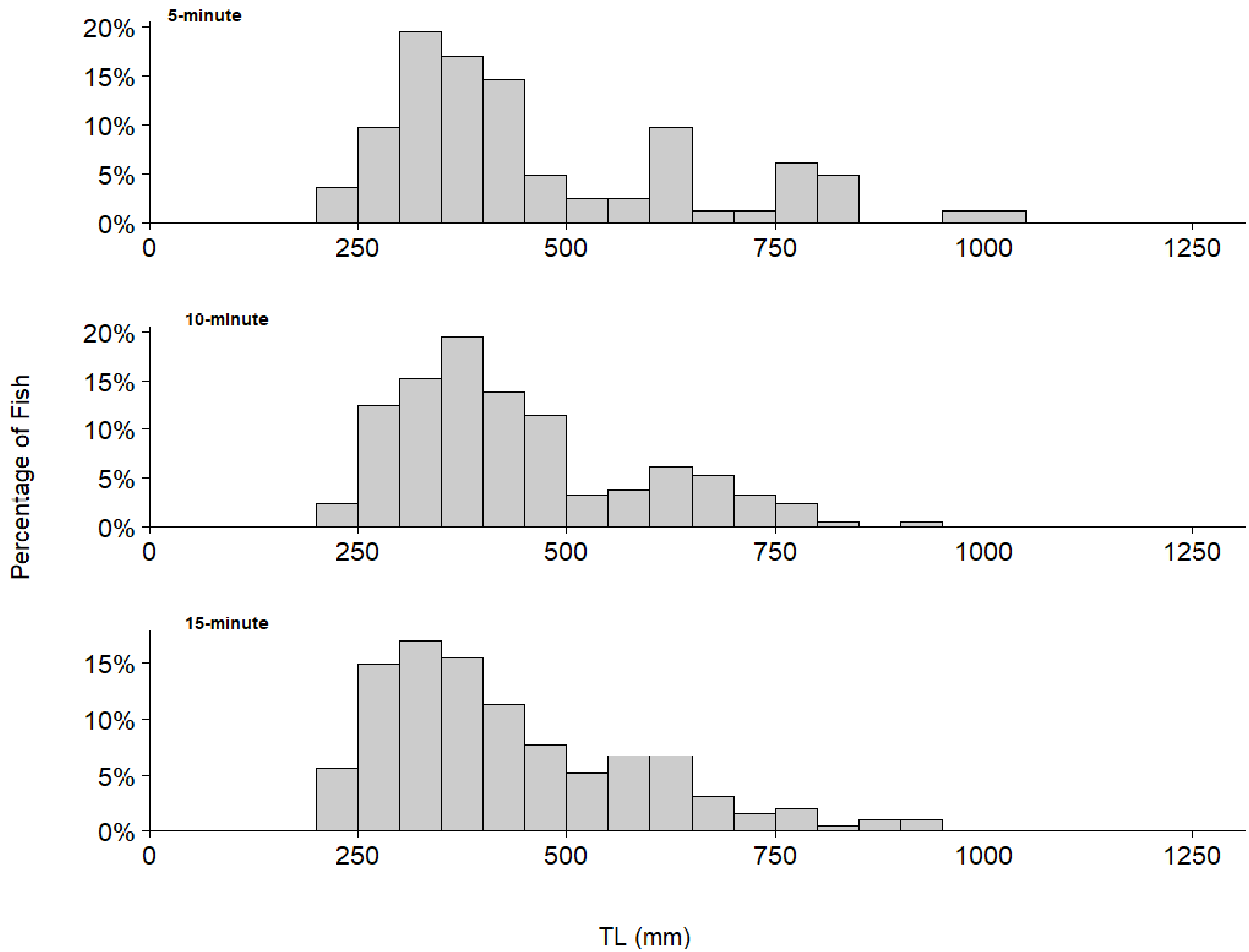

5-minute
10-minute
15-minute
20%
15%
10%
5%
0%
0
250
500
750
1000
1250
Percentage of Fish
TL (mm)

Figure 8. Length frequency histograms of Flathead Catfish caught by low-frequency electrofishing in 5-, 10-, or 15-minute low-frequency electrofishing samples in Lake McMurtry.

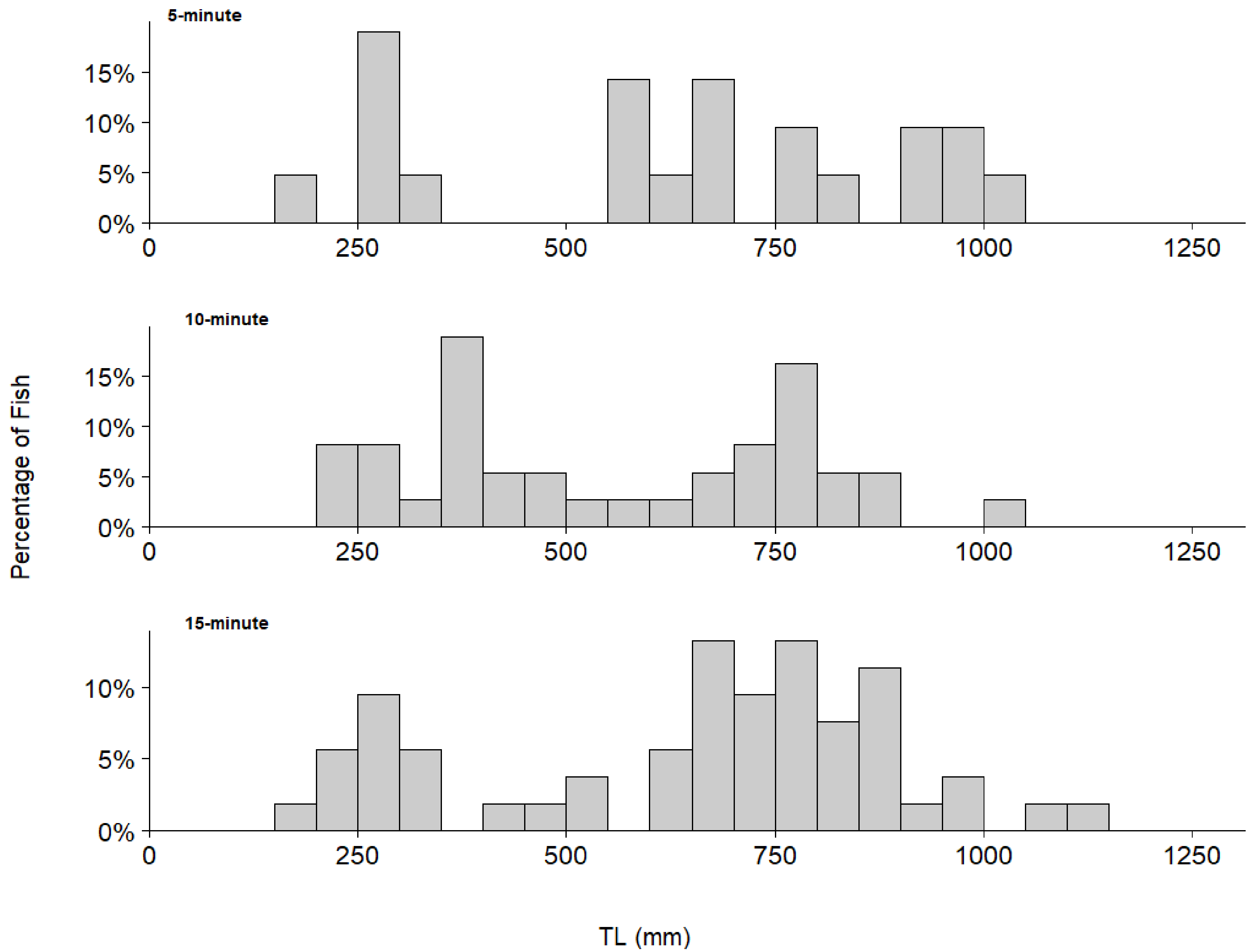

5-minute
10-minute
15-minute
Percentage of Fish
0%
5%
10%
15%
0
250
500
750
1000
1250
TL (mm)

Figure 9. Length frequency histograms of Flathead Catfish caught by low-frequency electrofishing in 5-, 10-, or 15-minute low-frequency electrofishing samples in Boomer Lake.

CHAPTER II

EFFECTS OF WATER TEMPERATURE, SEASON, AND ELECTROFISHING POWER DENSITY ON THE BIAS OF SIZE AND ABUNDANCE METRICS FROM LOW-FREQUENCY ELECTROFISHING FOR FLATHEAD CATFISH *PYLODICTIS OLIVARIS* IN RESERVOIRS

Abstract

Flathead Catfish *Pylodictis olivaris* are popular among anglers. Unfortunately, information about sampling Flathead Catfish is limited, making it difficult for management agencies to get accurate population data they need to properly manage this species. Research on the best method for sampling Flathead Catfish is needed. Low-frequency electrofishing (LFE; < 30 pulses per second [pps], commonly 15 pps) is the most commonly used method for sampling Flathead Catfish. Although the accuracy of this gear is unknown, many think it may be biased against fish > 600 mm, TL. To quantify the accuracy of LFE for Flathead Catfish, I created known populations by tagging Flathead Catfish in Lake Carl Blackwell (n=1,061), Lake McMurtry (n=835), and Boomer Lake (n=167) with numbered modified Carlin Dangler tags and calculated their

capture probabilities from recapture data with a Cormack Jolly Seber model. LFE is size biased but was variable among lakes. The capture probability decreased as fish length increased in Lake Carl Blackwell and Lake McMurtry and increased as fish length increased in Boomer Lake. Capture probability was the highest in July for Lake Carl Blackwell and Boomer Lake and August for Lake McMurtry. Capture probability was the highest when the water temperature was >26°C in both Lake Carl Blackwell and Lake McMurtry, but temperature was not an important factor in the top models from Boomer Lake. Wetlab electrofishing trials were conducted to determine the minimum power level needed to elicit a surfacing response by Flathead Catfish so power standardization can be used to ensure more consistent effort to make CPUE scale better with fish abundance. The probability of a fish surfacing was inversely related to the power applied to the fish (D_m) indicating that low power application is most successful for Flathead Catfish LFE, however, our trials only included power densities down to 2.2 $\mu W/cm^3$, which apparently is still above the power threshold for eliciting a capture-prone surfacing response in Flathead Catfish. Only 9.8% of fish surfaced in the experimental trials suggesting that not every fish exhibits a surfacing response when exposed to LFE. It took 59 seconds on average (range 38 – 85 seconds) for fish to exhibit a surfacing response. I recommend sampling in the months of July and August when the water temperature is ≥ 26°C as this sampling design will maximize catch rates, have high precise and keep size bias relatively constant during the sampling season. However, the inter-lake variation in size bias, and to lesser extent capture probability of all sizes of fish is concerning and further research is needed to see how comparable LFE data for Flathead Catfish are among lakes.

Introduction

Flathead Catfish, *Pylodictis olivaris*, are large, predatory fish that inhabits rivers, lakes, and reservoirs and are native to Mississippi, Missouri, Ohio, Tennessee, Arkansas, and Rio Grande river drainages (Jackson 1999, Fuller and Whelan 2018). Flathead Catfish are one of three ictalurid species in North America with large growth potential and are of particular interest for trophy sized angling (> 864 mm, TL; Arterburn et al. 2002; Vokoun and Rabeni 1999). Where introduced, Flathead Catfish also have the ability to negatively alter native fish communities due to their large sizes and piscivorous feeding behavior (Jackson 1999). Flathead Catfish have invaded the Atlantic slope drainages and the Great Lakes and their tributaries by authorized stockings, natural dispersal (aided by construction of canals and locks), and unauthorized releases (Fuller and Whelan, 2018). In general, Flathead Catfish grow faster in introduced populations, frequently out compete native fish assemblages, establish themselves as the apex predator, and have the ability to disperse long distances (Brown et al. 2005; Kwak et al., 2006; Schmitt et al., 2019). Because of their potential as a sport fish and the possible ecological harm they do where introduced, accurate sampling methods for assessing Flathead Catfish populations are a priority for fishery managers.

Obtaining accurate samples (i.e., representative of the true population) is imperative for sound fish management (Bodine et al. 2013). Inaccurate sampling data lead to erroneous fish population metrics. Therefore, gear performance studies are needed to develop unbiased standardized sampling protocols that can be used to accurately assess a fishery. Although there have been studies that compared the catch of Flathead Catfish from two or more gears to find the gear that captures the most fish per time spent in the field (sampling efficiency), no peer-reviewed literature exists evaluating sampling accuracy of abundance or size-related metrics for Flathead Catfish (Bodine et al. 2013). Gear bias has been a consistent concern of Flathead Catfish managers and researchers for over 2 decades (Michaletz and Dillard 1999; Brown 2007, Bodine et al. 2013; Montague and Shoup *in press*). Quantifying a gear's bias is also important because when gear bias is well characterized, it can often be accounted for (i.e., corrected) to provide more accurate data (Pierce et al. 1990; Bayley and Austen 2002; Shoup and Ryswyk 2016).

Low-frequency electrofishing (LFE; < 30 pulses per second [pps], commonly 15 pps) is used by more management agencies (49%) than any other method for sampling Flathead Catfish (Brown 2007) because it is highly efficient (i.e. catch/gear-effort, Bodine et al. 2013), however, the accuracy of this gear is unknown. Anecdotal evidence suggests LFE may be biased against fish over 600 mm, TL (Brown 2007). Low-frequency electrofishing also results in an atypical response in Flathead Catfish whereby fish surface slowly (up to 90 seconds after first exposed to LFE) up to 100 m away from the shock boat, making them challenging to collect (Bodine et al. 2013, Cunningham 2000), which suggests that conventional high-frequency (i.e., 60 pps) electrofishing standards may not be applicable to LFE sampling for Flathead Catfish. The mechanism underlying this unusual response is not known. Because LFE is widely used but poorly understood, there is a need to evaluate this gear with a known population size to determine the sampling conditions that produce the most accurate abundance metrics so standard sampling protocols for this species can be developed.

Catch rates and precision estimates of CPUE from LFE vary among months (Cunningham 2000; Chapter 1), so it is important determine when the CPUE of LFE most accurately reflects population structure. If LFE is inaccurate at indexing fish abundance, then LFE catch rates, no matter how precise, are not useful. In chapter 1, I found that catch rates are high and consistent when water temperature was ≥23°C across all size classes. However, catch rates of certain size classes varied among months, with September having the highest catch rates overall, but May exhibiting the highest catch rates for larger size fish (≥ 610 mm TL) (Chapter 1). This suggests size-based metrics will vary seasonally and it is unclear which month, if any, actually represents the true size structure of the sampled population.

Standardized sampling is important because it generates data that can be directly compared temporally and spatially (Bonar and Hubert 2002). Standardization requires assessing a gear's performance across a set of conditions to see which conditions produce the most accurate sample, or at least when the biased sample metrics are consistent enough that they can still precisely index population changes in a relative sense. One factor that must be accounted for when standardizing high-frequency electrofishing is the concept of power (Bonar et al. 2009). The power density generated by an electrofisher determines the volume of water around the electrodes in which fish are immobilized. Therefore, standardizing electrofishing power output is important because it makes catch per unit effort (CPUE) more consistent (i.e., consistently immobilizes fish from a standardized volume of water) and when agencies use the same power standardization (including adjustments for changes in conductivity), changes in CPUE reflect population changes rather than changes in the gear's effectiveness (Burkhardt and Gutreuter 1995; Bayley and Austen 2002). To pick an appropriate power standardization level, the power threshold needed to effectively immobilize Flathead Catfish should be determined.

The goal of this study is to provide a gear performance evaluation of LFE that evaluates how season, water temperature, and the power density applied to the fish affect the "surfacing response" (fish swimming on the surface of the water for $\leq$2 seconds and able to be dipnetted) of Flathead Catfish to provide information needed to develop a standard sampling approach that maximizes accuracy of size-specific abundance metrics for this species. Specifically, I sought to (1) determine if LFE produces accurate size-specific abundance estimates across all seasons; and (2) find the minimum power threshold needed to elicit a surfacing response of Flathead Catfish.

Methods

Field Study

I conducted a capture-recapture study in three north-central Oklahoma reservoirs (Lake Carl Blackwell, Lake McMurtry, and Boomer Lake; Table 1) that historically have had moderate to high LFE CPUE for Flathead Catfish. The reservoirs vary in size with Boomer Lake being the smallest (102 ha), Lake McMurtry being intermediate (467 ha), and Lake Carl Blackwell being the largest (1,364 ha). These reservoirs also have different habitat characteristics; Boomer Lake has mainly anthropogenically modified habitats (basin shaped by bulldozer with a series of peninsula-shaped wing dykes that have concrete or rip-rap covering and little natural standing timber or vegetation), Lake McMurtry primarily consists of natural habitat (flooded timber and natural rock outcroppings), and Lake Carl Blackwell is a mix of anthropogenically modified and natural habitat.

Each reservoir's entire shoreline was sampled monthly using a stratified random design. Each reservoir was divided into 4 distinct sections (strata) that were sampled at least once per month. Lake Carl Blackwell was sampled from May 2019-February 2021, Lake McMurtry was sampled from June 2019-February 2021, and Boomer Lake was sampled from May 2020-June 2021. Due to technical problems, electrofishing samples were not collected in Lake McMurtry and Lake Carl Blackwell in August 2019 and from December 2019-February 2020.

During each sampling event, sampling was conducted with LFE (using a Smith-Root 7.5 GPP electrofisher with 15 pps DC current, 240-340 V, with percent of range adjusted based on water conductivity following the power tables of Bonar et al. 2009) during the daylight hours with one dipnetter on the bow of the electrofishing boat (no chase boat, as recommended by Cunningham 2004). The electrofishing boat was a 5.5-m long semi-V aluminum boat with the boat hull serving as the cathode and two Smith-Root SAA-6 anode arrays mounted at the end of 1.8-m fiberglass booms spread 2 m apart as the anodes. When sampling, the electrofishing boat was operated slowly (0.8-1.8mph) and close to the shoreline (<30 m from shore). Fifteen-minute samples were conducted and adjacent samples were separated by 100 meters to ensure no overlap of the electrical field between samples. Water temperature and conductivity were recorded for each sampling event.

Each fish was measured (TL, mm), and fish > 230-mm TL were tagged with modified Carlin dangler tags installed in the operculum between the preopercle and opercule bones. The Carlin dangler tags consisted of a stainless steel wire (0.81 mm diameter) and stainless steel metal charm (5 x 12 mm) that had unique 4-digit code engraved. Each fish also received a left pelvic fin clip and a second tag on the opposing operculum was applied to a subset of fish to quantify tag loss throughout the study. Additional Flathead Catfish were collected and marked using gill nets (n=45), juglines (n=1), hoop nets (n=5), rod and reel (n=3), and high frequency electrofishing (n=4) to mark as many fish as possible early in the study.

Analysis

Accuracy: Capture Probability

I used separate Cormack Jolly Seber (CJS) capture-recapture models for each lake to estimate the capture probabilities (*p*; the probability that a Flathead Catfish was encountered during sampling occasion *i* where *i* is the full monthly sample of all four strata of the lake) and apparent survival (Phi (Φ); the probability that an individual Flathead Catfish survives in the study system with tag intact throughout the duration of the study) (Cormack 1964; Jolly 1965; Seber 1965; Lebreton 1992). I created encounter histories for 22 sampling occasions for Lake Carl Blackwell, 21 sampling occasions from Lake McMurtry, and 14 sampling occasions for Boomer Lake. Time (i.e., each monthly sampling occasion), fish TL, and surface water temperature (ctemp) were tested to see if they had a significant impact on Flathead Catfish capture probabilities. Fish length and temperature were centered and scaled in the CJS analysis to make their impacts comparable for model selection (i.e., to prevent fish lengths from having larger effects than temperature due to the larger range of values observed for fish length). All analyses were performed in MARK through RMark (Laake, 2013; R Core Team 2020). I tested 8 different models with various combinations of the 4 variables described above (Table 2). I used AIC_C to select my top model(s) from the CJS analysis for each lake and selected

≤ 2 ΔAICc as the threshold to determine similarly likely models. Capture probabilities (p) for three PSD length categories (stock size, 280 mm; preferred size, 610 mm; and trophy size, 910 mm; Gabelhouse 1984) were calculated from the top-ranked CJS model from each lake using the plogis function in the RMark package (Laake 2013).

Wetlab Study

Flathead Catfish were collected from Lake Carl Blackwell and Lake McMurtry using LFE and transferred to the Oklahoma State University Fisheries and Aquatic Ecology Wet Laboratory. Fish were held in a 1.83-m diameter round polypropylene tank filled with filtered tap water to a depth of 121 cm for $\geq$ 72 hours before undergoing electrofishing treatments. Fish were marked with individually numbered modified Carlin dangler tags as described in the field study methods. The wetlab room lighting was provided by windows and skylights following the natural diurnal cycle.

A test tank was constructed in a 2.69-m (long) x 0.56-m (wide) x 0.48-m (high) fiberglass tank with 2 metal plates (56 cm x 45.7cm, 0.32cm thick aluminum sheet) serving as the cathode and anode at either side that were 160 cm apart. The tank was filled with 41 cm of water. This produced a uniform power density across the entire tank. All trials were conducted with a Smith Root LR24 backpack electrofisher operating at 15 Hz pulsed DC current and 25% duty cycle . To increase resistance and allow lower power densities to be tested, I placed the anode of the backpack electrofisher at one end of a 1.83-m diameter polypropylene tank filled with 12 cm of water that had an AWG 10 wire with 0.38 cm of insulation removed on the other side of the tank that was attached to the anode plate in the test arena tank. This produced voltage gradients as low as 0.04 v/cm^2 in the test tank (i.e., at the 50V setting of the LR24 unit).

All fish were tested in two types of electrofishing trials (in random order) to determine minimum voltage threshold required to elicit the surfacing response characteristically observed when sampling Flathead Catfish with LFE. Trial type 1 was designed such that a constant voltage was randomly selected from a low (50-125V), medium (125-175V), or high (150-200V) voltage ranges and the fish was shocked at that setting for 2 minutes. Each fish was tested 3 times in this trial type to receive one voltage from each of the 3 voltage ranges. Trial type 2 consisted of testing each fish with a gradually increasing voltage range (increasing the LR24 voltages setting 50 volts higher every 30 seconds to test from 50 – 200 V) over a 2-minute trial. Each fish was only tested once in trial type 2. Water conductivity and water temperature were recorded at the start of each day of testing. Each fish was shocked a total of 4 times. Water temperatures during the experiment were 22 $\pm$3°C.

To begin a trial, a fish was dip netted from the holding tank and placed into the testing tank and given 10 minutes of acclimation time. The fish was then electroshocked for 2 minutes using one of the two above described trial types. After the trial, the fish was placed back in the holding tank and was not used again for at least 72 hours.

Two GoPro cameras were set at either side of the tank to record fish responses. Fish responses were categorized as surfacing (capture-prone response), non-capture prone response (all other changes to fish movement), or no response (no detectible change to fish behavior when electricity was applied), similar to the methods of Morris (2018). Surfacing was described as a fish swimming erratically at the surface of the water for at least 2 seconds and becoming immobilized (such that they could be dip netted). Non-capture prone responses recorded were muscle twitching, fast/slow swimming, and barbel movements. Fish that showed no response to the electrical current were classified as “no response”. For fish exhibiting a capture-prone response (swimming on the surface of the water), the time at which the behavior occurred was recorded.

Electrical measurements

Power treatments were applied based on available LR24 voltage settings (50-200V in 5 V increments). The peak voltage gradient ($\mathcal{E}$, V/cm) in the test tank was calculated as:

$$\mathcal{E} = V/160$$

(1)

where V is the peak voltage across the metal plates (160 cm was the spacing between plates). The power density applied to the water between the metal plates (D_a, μW/cm^3) was calculated as:

$$D_a = \varepsilon^2 * \mathrm{C}_w$$

(2)

where C_w is the ambient water conductivity (µS/cm) on the day of the trial. Finally, power applied to the fish (D_m, µW/cm^3) was calculated as:

$$\mathrm{D}_m = D_a \frac{\left(4\frac{C_f}{C_w}\right)}{\left(1+\frac{C_f}{C_w}\right)^2}$$

(3)

where C_f is the ambient conductivity of the fish (assumed to be 100 µS/cm), and D_a and C_w are as defined above.

Analysis

I tested to see if the power applied to the fish (D_m) significantly correlated with the frequency of fish surfacing or non-capture prone responses using generalized linear models. Specifically, models were constructed with a biniomial distribution and a “probit” link function in the glmer fuction of the lme4 package (Bates et al. 2015) in program R (R Core Team, 2021). Power applied to the fish was a fixed factor and fish ID was included as a random effect to account for repeated measurements on individual fish in the constant-voltage trials. I also used a frequency histogram to evaluate the frequency of fish that surfaced during each 10-second interval.

Results

Field study

A total of 2,063 unique fish was sampled with an additional 719 recaptures from all reservoirs throughout the study (Table 1); including 1,061 unique fish from Lake Carl Blackwell (315 recaptured), 835 unique fish from Lake McMurtry (351 recaptured), and 167 unique fish from Boomer Lake (53 recaptured) (Table 1). The capture probabilities varied among reservoirs, but were typically a function of fish size and time (and in some cases temperature) as detailed below.

Lake Carl Blackwell had two top models (≤2 ΔAICc units apart; Table 1). The model with the lowest AICc value included capture probability as a function of water temperature, fish length, and sampling occasion (time) (Table 2). The second best model included capture probability as a function of fish length and sampling occasion (time) (Table 2). Based on the top model, capture probability decreased as length increased (Table 3). The calculated apparent survival estimate (a metric that addresses the combination of mortality, tag loss, and fish leaving the system) was 94.0%. July was the month with the highest Flathead Catfish capture probabilities for the three length categories I considered (stock, preferred, and trophy PSD size classes). Capture probabilities in the month of August were only slightly lower than in July. Capture probabilities declined by a factor of approximately 2 – 5 at the same temperatures in adjacent months before and after these peak values in July and August, with the more extreme changes in early spring and late fall (Tables 4-6). April and October had very low capture probabilities even though fish were caught during these months (Tables 4-6). No fish were captured from November through March. The percent change in capture probability between stock- and trophy-size fish (i.e., difference between capture probabilities of stock and trophy fish divided by the capture probability of the size class with the largest value) was relatively consistent from May – October, indicating that trophy-size fish were 63-68% less likely to be captured as stock-size fish throughout the growing season.

Modeling results were almost the same for Lake McMurtry when compared with Lake Carl Blackwell. Lake McMurtry also had two models that were within ≤2 ΔAICc units of each other. The top model was the same as the top model identified for Lake Carl Blackwell (i.e., modeled capture probability as a function of water temperature, fish length, and sampling occasion (time); Table 2). The second best model (0.721 Delta AICc units) was similar to the second model identified for Lake Carl Blackwell except that it modeled capture probability as a function of water temperature (ctemp) and sampling occasion (time) instead of fish length and sampling occasion (Table 2). Based on the top model, capture probability decreased as length increased (Table 7). The calculated apparent survival estimate was 94.6%. August was the month with the highest Flathead Catfish capture probabilities for the three length categories I considered (stock, preferred, and trophy). Capture probabilities in July were only slightly lower than in

August. Capture probabilities in the months before July and after August again declined by a factor of 2 – 5 in adjacent months at the same temperatures, except that fairly similar capture efficiencies occurred in May and June. As with Lake Carl Blackwell, the monthly changes were most extreme in early spring and late fall (Tables 8-10). April and October had very low capture probabilities even though fish were caught during these months (Tables 8-10). No fish were captured from November through March. Like Lake Carl Blackwell, the percent change in capture probability between stock- and trophy-size fish was also relatively consistent from May – October in Lake McMurtry, but the magnitude of the size bias was considerably weaker. Trophy-size fish were 33-37% less likely to be captured as stock-size fish throughout the growing season.

The CJS modeling results at Boomer Lake were quite different from the other two lakes. Boomer Lake had two models within ≤2 ΔAICc units of the top model. The top model modeled capture probability as a function of sampling occasion (time) (Table 2). The second best model (1.86 ΔAICc) modeled capture probability as a function of length and sampling occasion (time) (Table 2)), however capture probability increased as length increased, which is the opposite pattern observed for the other two lakes (Table 11). The calculated apparent survival estimate was 99.9%. Similar to results from Lake Carl Blackwell, July was the month with the highest Flathead Catfish capture probabilities for all length categories (stock; 280 mm, preferred; 610 mm, and trophy; 910 mm). Capture probabilities typically varied by about 10-15% in adjacent months, but high values were not confined to summer as peaks in capture efficiency occurred in May and July (where capture efficiencies ranged 0.151 – 0.213) and were relatively low in all other months ($\leq$ 0.071; Table 12). Similar to the other lakes, April and October had very low capture probabilities even though fish were caught during these months (Tables 12). No fish were captured from November through March. Like the other two lakes, the percent change in capture probability between stock- and trophy-size fish was again relatively consistent from May – October, but Boomer Lake had the least size bias, with trophy-size fish were being 10-11% more likely to be captured as stock-size fish throughout the growing season.

Overall, capture probabilities were typically highest and most consistent at warmer temperatures during summer months (July-August). For example, Lake Carl Blackwell and Lake McMurtry both had capture probabilities around 0.1 – 0.2 for stock size fish in July – August (but capture probabilities of larger fish were lower and more variable between systems, reflecting the variable nature of size bias across lakes). Boomer Lake's capture probabilities in July (0.192 - 0.213) were also comparable to the other two lakes, but August values were considerably lower (0.063 – 0.071) at Boomer Lake. Boomer Lake also had consistently high capture probability in May (0.151- 0.167) but this was not the case at Lake Carl Blackwell (0.014 – 0.048) and Lake McMurtry (0.052 – 0.077).

Wetlab Study

Twenty-five fish exhibited a surfacing behavior in 256 trials (9.8%) (Table 13). Fish surfaced more frequently in the trial type 1 (increasing voltage; 23.4%) than in the trial type 2 (constant voltage; 5.2%; Table 13). Fish showed non-capture prone responses more frequently in trial type 1 (95.3%) than trial type 2 (85.9%; Table 13). The power density applied to the fish (D_m) was significantly related to the probability of surfacing ($F_{1, 190} = 4.05$, $P = 0.03$; Figure 1), and the probability of exhibiting a non-capture prone response ($F_{1, 190} = 4.05$, $P < 0.01$; Figure 2). Flathead Catfish showed a stronger surfacing response (higher number of fish surfacing) to lower power levels (Figure 1), but the opposite was true for non-capture prone responses (Figure 2). For Flathead Catfish that surfaced, it took between 38 and 85 seconds (59 seconds on average) for fish to exhibit this response (Figure 3).

Discussion

Sampling with LFE for Flathead Catfish produced variable capture probabilities depending on the size of fish, which creates a size bias. This size bias was consistent across months (i.e., did not vary by more than 5%), but differed strongly among lakes. In Lake Carl Blackwell and Lake McMurtry, LFE had higher capture probabilities for smaller fish (i.e. stock size) than larger fish (i.e. trophy size), confirming the anecdotal claims that LFE is biased against fish over 600 mm (Brown 2007). However, the magnitude of this pattern was roughly twice as strong at Lake Carl Blackwell compared to Lake McMurtry. Further, the capture probabilities in Boomer Lake where were in the opposite direction (large fish were slightly more likely to be captured than smaller fish). One possible explanation for this may be the overall shallower depths at Boomer Lake (average depth = 2.1 m, maximum depth = 6.7 m), suggesting that the larger fish in the bigger reservoirs may have been in deeper water where they were not as vulnerable to electrofishing (Chapter 1). However, other differences between reservoirs (e.g., water chemistry, differences in the type of cover available, etc.) could also have been involved. Regardless of the cause, this difference in size bias between reservoirs suggests it may be difficult to compare size structure among systems.

Although this is the first LFE accuracy study on Flathead Catfish, accuracy of size-based metrics from electrofishing for Channel Catfish *Ictalurus punctatus* is also variable in small lakes, being selective towards smaller fish (Santucci et al. 1999), but in larger reservoirs and rivers, Channel Catfish size structure was accurately sampled using electrofishing (Buckmeier and Schlechte 2009). Accuracy studies on LFE for Blue Catfish suggests there is no size bias (Buckmeirer and Schlechte 2009, Bodine and Shoup 2010), but Blue Catfish typically only occur in larger systems such as those where accuracy studies have been evaluated. It is possible Flathead Catfish size bias will be more consistent in reservoirs of the same size, but this hypothesis still needs evaluation.

Flathead Catfish capture probabilities varied among seasons and water temperatures for all size classes, but were typically highest and most consistent at warmer temperatures during summer months (July-August). Ultimately, July was the only month where capture probabilities were similar across all three lakes, and even then, capture efficiencies of the largest fish started to diverge between some lakes (i.e., Boomer lake was biased against smaller fish whereas the other two lakes were biased against larger fish). However, the bias against large fish was quite consistent across months within lakes, suggesting sampling season did not really matter with respect to size bias. Therefore, to obtain the most accurate and consistent samples, I recommend sampling in July, and possibly August, when the water temperature is above 26°C. Sampling outside this window lead to meaningfully lower catch rates that could be erroneously interpreted as the lake having a smaller population size when it is in fact just seasonal variation in capture probability.

In my wetlab trials, fish were more likely to surface at the lower power levels than higher power levels. This challenges conventional wisdom that more power is better for higher catch rates. However, I was unable to identify the minimum power threshold required to elicit the surfacing response. While I did not see surfacing behavior in the lowest power levels, this is likely because I only had 4 shocking trials at the lowest power level (1-1.9 uW/cm^3) for trial type 1 (constant voltage for 2 minutes). For trial type 2 (increasing 50-volts every 30 seconds for 2 minutes), no fish surfaced at the lowest power level, presumably because fish needed $\geq$38 seconds to surface and the 50-volt power setting was only applied for 30 seconds before the next setting (100 volts) was applied.

Additional replications at lower D_m levels (i.e., <2 uW/cm3) are needed to find a power threshold to successfully illicit a surfacing response in Flathead Catfish. However, it is clear that excess power levels were less likely to elicit capture-prone responses from Flathead Catfish.

Some Flathead Catfish appear to be more susceptible exhibiting a surfacing response during LFE than others. Only 9.8% of fish surfaced in the laboratory trials, indicating a high degree of variation among individuals in response to electrical fields. Further, all fish in trials were initially captured using electrofishing, so it is clear they were vulnerable to the gear, yet they often did not respond when tested. As such, the lack of response suggests fish can respond to LFE sometimes and not others. Finding such low response rates appears consistent with field sampling results in that I recaptured only 6% of the marked population in the higher capture-rate summer months (June-August) even though I sampled the entire shoreline of the reservoir every month. These results are consistent with Morris (2018), who also saw only a small proportion (5.6%) of fish surface in experimental tanks. Overall, this suggests that only a small proportion of Flathead Catfish population exposed to LFE exhibit the surfacing response. Additionally, 6 individual fish surfaced multiple times throughout the wetlab trials, but 12 individuals only surfaced once, suggesting these 6 fish were more capture prone than other fish in the trials. I also saw variability in recapture rates among the 719 fish recaptured in the field where 400 were recaptured more than once (one fish was recaptured 5 times in Lake

McMurtry). Due to the variation I saw between individuals, additional research is needed to determine if all fish have equal vulnerability to electrofishing or if this gear may be sampling a subset of the entire population. This may be a mechanism explaining the variation in capture efficiency I found among lakes.

All sampling gears have biases (Zale et al. 2012). Although LFE produces size-biased measurements, the gear also produces the most efficient and precise estimates for sampling Flathead Catfish populations (Bodine et al. 2013) and could still be of use for detecting relative changes given the consistent nature of the size bias. For example, the actual PSD of a sample may be lower than the true PSD of the population (if that lake has lower capture efficiency of large fish), but an increase in the sampled PSD could still accurately indicate the true population's PSD increased. This assumes that the bias is constant so relative changes will reflect changes in the population rather than changes in the gear's performance. I found size bias was relatively constant but overall capture probabilities changed considerably throughout the year (i.e., based on season and water temperature) so it will be important to standardize sampling to a time when these changes are small enough length of time that they do not noticeably effect catch data. Therefore, I recommend 1) conducting 5 minute samples and 2) sampling in the months of July and August when the water temperature is $\geq$26°C as this sampling design will maximize catch rates, have high precision (Chapter 1) and keep size bias relatively constant during the sampling season. Biologists should still recognize that catch rates may vary considerably between systems, though this pattern was minimized in July and August samples in our study. Further research is needed to determine the extent of among-lake variation in capture probability of LFE for Flathead Catfish.

Acknowledgements

Support for this manuscript was provided by the Natural Resource Ecology and Management Department at Oklahoma State University and USDA National Institute of Food and Agriculture, Hatch project number 1023034 and the Division of Agricultural Sciences and Natural Resources at Oklahoma State University. I also thank the numerous Oklahoma State University volunteers and graduate students for helping in field sampling. I am grateful to Anna Moeller for numerous suggestions related to the Cormack Jolly Seber model analysis I completed in RMARK. I am grateful to Jan Dean for numerous suggestions related to design and analysis of the wetlab trials.

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Table 1. Lake size and the number of fish marked, captured, and recaptured from Lake Carl Blackwell, Lake McMurtry, and Boomer Lake as part of an experiment quantifying the accuracy of size-specific catch rates of Flathead Catfish using low-frequency electrofishing (15 pps).

Reservoir	Size (Ha)	Marked	Captured	Recaptured
Lake Carl Blackwell	1,356	1,061	1,376	315
Lake McMurtry	467	835	1,186	351
Boomer Lake	102	167	220	53

Table 2. Top models from Cormack Jolly Seber modeling and their corresponding AICc scores from mark-recapture studies in Lake Carl Blackwell, Lake McMurtry, and Boomer Lake sampling Flathead Catfish populations with low-frequency electrofishing (15 pps). Phi is the estimate of apparent survival (which includes actual mortality, tag loss, and emigration) and *p* is the capture probability. Bolded models are within 2 AICc units from of the model with the lowest AICc. The ~ indicates Phi or p were a function of the variables that follow. A ~1 indicates the parameter was a fixed constant. ctemp is water temperature (centered and scaled for analysis) at the time of sampling, length is fish length (mm, TL; centered and scaled for analysis), and time is the sampling occasion (i.e., one monthly sample of the entire lake).

model	npar	AICc	ΔAICc	weight
Lake Carl Blackwell				
Phi(~1)p(~ctemp + length + time)	24	2123.49	0.00	0.59
Phi(~1)p(~length + time)	23	2124.18	0.69	0.41
Phi(~1)p(~ctemp + time)	23	2142.70	19.22	0.00
Phi(~1)p(~time)	22	2144.85	21.37	0.00
Phi(~1)p(~ctemp + length)	4	2513.00	389.51	0.00
Phi(~1)p(~length)	3	2516.67	393.18	0.00
Phi(~1)p(~ctemp)	3	2527.92	404.44	0.00
Phi(~1)p(~1)	2	2532.66	409.18	0.00
Lake McMurtry				
Phi(~1)p(~ctemp + length + time)	23	2249.09	0.00	0.50
Phi(~1)p(~ctemp + time)	22	2249.81	0.72	0.35
Phi(~1)p(~length + time)	22	2252.22	3.13	0.10
Phi(~1)p(~time)	21	2253.96	4.86	0.04
Phi(~1)p(~length)	3	2810.65	561.56	0.00
Phi(~1)p(~1)	2	2810.68	561.58	0.00
Phi(~1)p(~ctemp)	3	2811.89	562.80	0.00
Phi(~1)p(~ctemp + length)	4	2812.16	563.07	0.00
Boomer Lake				
Phi(~1)p(~time)	14	344.07	0.00	0.53
Phi(~1)p(~length + time)	15	345.93	1.86	0.21
Phi(~1)p(~ctemp + time)	15	346.12	2.06	0.19
Phi(~1)p(~ctemp + length + time)	16	348.09	4.03	0.07
Phi(~1)p(~ctemp)	3	386.67	42.60	0.00
Phi(~1)p(~ctemp + length)	4	387.81	43.75	0.00
Phi(~1)p(~1)	2	389.02	44.95	0.00
Phi(~1)p(~length)	3	389.69	45.63	0.00

Table 3. Beta estimates from top Cormack Jolly Seber models from capture-recapture sampling with low-frequency electrofishing (15 pps) for Flathead Catfish in Lake Carl Blackwell. Phi represents apparent survival and *p* represents the capture probability. The ~ indicates Phi or p were a function of the variables that follow. A ~1 indicates the parameter was a fixed constant, ctemp is water temperature (which was centered and scaled) at the time of sampling, length is fish length (mm, TL, which was centered and scaled), and time is the sampling occasion (i.e., one monthly sample of the entire lake). SE is the standard error of the estimate LCL is the lower 95% confidence interval, and UCL is the upper 95% confidence interval.

Beta	Estimate	SE	LCL	UCL
Top model:	Phi(~1)p(~ctemp + length + time)			
Phi:(Intercept)	2.75	0.18	2.41	3.10
p:(Intercept)	-13.97	0.00	-13.97	-13.97
p:ctemp	0.53	0.32	-0.10	1.15
p:length	-0.35	0.08	-0.50	-0.19
p:time3	10.28	0.00	10.28	10.28
p:time4	-0.10	623.88	-1222.90	1222.70
p:time5	10.96	0.00	10.96	10.96
p:time6	10.65	0.00	10.65	10.65
p:time7	-9.48	1264.50	-2487.90	2468.94
p:time8	-0.10	266.44	-522.31	522.12
p:time9	-0.10	687.57	-1347.74	1347.55
p:time10	-0.10	616.10	-1207.66	1207.46
p:time11	-14.42	0.00	-14.42	-14.42
p:time12	7.67	0.00	7.67	7.67
p:time13	10.49	0.00	10.49	10.49
p:time14	11.01	0.00	11.01	11.01
p:time15	11.57	0.00	11.57	11.57
p:time16	11.52	0.00	11.52	11.52
p:time17	11.19	0.00	11.19	11.19
p:time18	9.63	0.00	9.63	9.63
p:time19	-9.17	947.07	-1865.43	1847.09
p:time20	-20.33	13318.07	-26123.75	26083.09
p:time21	-35.04	23512.15	-46118.85	46048.78
p:time22	-28.83	19468.24	-38186.57	38128.92

Table 4. Capture probabilities of stock size (280 mm TL) Flathead Catfish as a function water temperature and month based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Lake Carl Blackwell. The gray shaded capture probabilities indicate water temperatures when sampling occurred in each month.

Stock Size (280 mm)							
Temperature °C	April	May	June	July	August	September	October
14	0.000	0.005	0.009	0.015	0.015	0.010	0.002
15	0.000	0.006	0.010	0.018	0.017	0.012	0.003
16	0.000	0.007	0.012	0.021	0.020	0.014	0.003
17	0.001	0.008	0.014	0.025	0.023	0.017	0.004
18	0.001	0.010	0.017	0.029	0.027	0.020	0.004
19	0.001	0.012	0.019	0.034	0.032	0.023	0.005
20	0.001	0.014	0.023	0.039	0.038	0.027	0.006
21	0.001	0.016	0.027	0.046	0.044	0.032	0.007
22	0.001	0.019	0.031	0.054	0.051	0.037	0.008
23	0.001	0.022	0.036	0.062	0.060	0.043	0.009
24	0.002	0.026	0.043	0.073	0.069	0.051	0.011
25	0.002	0.030	0.050	0.084	0.081	0.059	0.013
26	0.002	0.035	0.058	0.098	0.093	0.069	0.015
27	0.003	0.041	0.067	0.113	0.108	0.080	0.018
28	0.003	0.048	0.078	0.130	0.125	0.092	0.021
29	0.004	0.056	0.091	0.150	0.143	0.107	0.025
30	0.004	0.066	0.105	0.171	0.165	0.123	0.029
31	0.005	0.076	0.121	0.196	0.188	0.142	0.034
32	0.006	0.089	0.140	0.222	0.214	0.163	0.039

Table 5. Capture probabilities of preferred size (610 mm TL) Flathead Catfish as a function water temperature and month based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Lake Carl Blackwell. The gray shaded capture probabilities indicate water temperatures when sampling occurred in each month.

Preferred Size (610 mm)							
Temperature °C	April	May	June	July	August	September	October
14	0.000	0.003	0.005	0.008	0.008	0.006	0.001
15	0.000	0.003	0.006	0.010	0.009	0.007	0.001
16	0.000	0.004	0.007	0.012	0.011	0.008	0.002
17	0.000	0.005	0.008	0.014	0.013	0.009	0.002
18	0.000	0.005	0.009	0.016	0.015	0.011	0.002
19	0.000	0.006	0.011	0.019	0.018	0.013	0.003
20	0.000	0.008	0.013	0.022	0.021	0.015	0.003
21	0.001	0.009	0.015	0.026	0.024	0.018	0.004
22	0.001	0.010	0.017	0.030	0.029	0.021	0.004
23	0.001	0.012	0.020	0.035	0.034	0.024	0.005
24	0.001	0.014	0.024	0.041	0.039	0.028	0.006
25	0.001	0.017	0.028	0.048	0.046	0.033	0.007
26	0.001	0.020	0.032	0.056	0.053	0.039	0.008
27	0.001	0.023	0.038	0.065	0.062	0.045	0.010
28	0.002	0.027	0.044	0.076	0.072	0.053	0.012
29	0.002	0.032	0.052	0.088	0.084	0.061	0.014
30	0.002	0.037	0.060	0.102	0.097	0.071	0.016
31	0.003	0.043	0.070	0.117	0.112	0.083	0.019
32	0.003	0.050	0.081	0.135	0.130	0.096	0.022

Table 6. Capture probabilities of trophy size (910 mm TL) Flathead Catfish as a function water temperature and month based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Lake Carl Blackwell. The gray shaded capture probabilities indicate water temperatures when sampling occurred in each month.

Trophy Size (910 mm)							
Temperature °C	April	May	June	July	August	September	October
14	0.000	0.002	0.003	0.005	0.005	0.003	0.001
15	0.000	0.002	0.003	0.006	0.005	0.004	0.001
16	0.000	0.002	0.004	0.007	0.006	0.005	0.001
17	0.000	0.003	0.004	0.008	0.008	0.005	0.001
18	0.000	0.003	0.005	0.009	0.009	0.006	0.001
19	0.000	0.004	0.006	0.011	0.010	0.007	0.002
20	0.000	0.004	0.007	0.013	0.012	0.009	0.002
21	0.000	0.005	0.009	0.015	0.014	0.010	0.002
22	0.000	0.006	0.010	0.018	0.017	0.012	0.003
23	0.000	0.007	0.012	0.021	0.020	0.014	0.003
24	0.000	0.008	0.014	0.024	0.023	0.017	0.004
25	0.001	0.010	0.016	0.028	0.027	0.019	0.004
26	0.001	0.011	0.019	0.033	0.032	0.023	0.005
27	0.001	0.013	0.022	0.039	0.037	0.027	0.006
28	0.001	0.016	0.026	0.045	0.043	0.031	0.007
29	0.001	0.019	0.031	0.053	0.050	0.036	0.008
30	0.001	0.022	0.036	0.061	0.059	0.042	0.009
31	0.002	0.025	0.042	0.071	0.068	0.050	0.011
32	0.002	0.030	0.049	0.083	0.079	0.058	0.013

Table 7. Beta estimates from top Cormack Jolly Seber models from capture-recapture sampling with low-frequency electrofishing (15 pps) for Flathead Catfish in Lake McMurtry. Phi represents apparent survival and *p* represents the capture probability. The ~ indicates Phi or p were a function of the variables that follow. A ~1 indicates the parameter was a fixed constant, ctemp is water temperature (which was centered and scaled) at the time of sampling, length is fish length (mm, TL, which was centered and scaled), and time is the sampling occasion (i.e., one monthly sample of the entire lake). SE is the standard error of the estimate LCL is the lower 95% confidence interval, and UCL is the upper 95% confidence interval.

Beta	Estimate	SE	LCL	UCL
Top model:	Phi(~1)p(~ctemp + length + time)			
Phi:(Intercept)	2.86	0.19	2.48	3.23
p:(Intercept)	-2.49	0.30	-3.09	-1.90
p:ctemp	0.57	0.26	0.07	1.07
p:length	-0.12	0.07	-0.26	0.02
p:time3	-21.64	3588.40	-7054.89	7011.62
p:time4	0.25	0.28	-0.30	0.79
p:time5	-1.29	0.34	-1.96	-0.61
p:time6	-30.42	0.00	-30.42	-30.42
p:time7	-24.84	3566.68	-7015.53	6965.85
p:time8	-45.11	0.00	-45.11	-45.11
p:time9	-26.05	3649.87	-7179.79	7127.68
p:time10	-23.79	2928.69	-5764.02	5716.44
p:time11	-2.35	0.55	-3.43	-1.26
p:time12	-0.09	0.30	-0.68	0.50
p:time13	-0.41	0.31	-1.01	0.19
p:time14	0.02	0.29	-0.54	0.58
p:time15	0.31	0.27	-0.21	0.83
p:time16	-0.47	0.28	-1.03	0.09
p:time17	-2.28	0.44	-3.16	-1.41
p:time18	-20.79	2256.72	-4443.96	4402.38
p:time19	-90.55	0.00	-90.55	-90.55
p:time20	-49.95	0.00	-49.95	-49.95
p:time21	-17.95	979.45	-1937.66	1901.77

Table 8. Capture probabilities of stock size (280 mm TL) Flathead Catfish as a function water temperature and month based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Lake McMurtry. The gray shaded capture probabilities indicate water temperatures when sampling occurred in each month.

Stock Size (280 mm)							
Temperature °C	April	May	June	July	August	September	October
14	0.005	0.045	0.033	0.050	0.066	0.031	0.005
15	0.005	0.048	0.035	0.054	0.071	0.033	0.006
16	0.006	0.052	0.038	0.057	0.075	0.036	0.006
17	0.006	0.055	0.041	0.061	0.080	0.038	0.006
18	0.007	0.059	0.044	0.065	0.086	0.041	0.007
19	0.007	0.063	0.047	0.070	0.091	0.044	0.007
20	0.008	0.068	0.050	0.075	0.097	0.047	0.008
21	0.008	0.072	0.053	0.080	0.104	0.050	0.009
22	0.009	0.077	0.057	0.085	0.111	0.054	0.009
23	0.009	0.082	0.061	0.091	0.118	0.057	0.010
24	0.010	0.088	0.065	0.097	0.125	0.061	0.011
25	0.011	0.094	0.069	0.103	0.133	0.066	0.011
26	0.011	0.100	0.074	0.110	0.142	0.070	0.012
27	0.012	0.106	0.079	0.117	0.150	0.075	0.013
28	0.013	0.113	0.084	0.124	0.160	0.080	0.014
29	0.014	0.120	0.090	0.132	0.169	0.085	0.015
30	0.015	0.128	0.096	0.140	0.180	0.091	0.016
31	0.016	0.136	0.102	0.149	0.190	0.097	0.017
32	0.017	0.145	0.109	0.158	0.201	0.103	0.018

Table 9. Capture probabilities of preferred size (610 mm TL) Flathead Catfish as a function water temperature and month based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Lake McMurtry. The gray shaded capture probabilities indicate water temperatures when sampling occurred in each month.

Preferred Size (610 mm)							
Temperature °C	April	May	June	July	August	September	October
14	0.004	0.036	0.026	0.040	0.052	0.025	0.004
15	0.004	0.038	0.028	0.042	0.056	0.026	0.004
16	0.004	0.041	0.030	0.045	0.060	0.028	0.005
17	0.005	0.044	0.032	0.048	0.064	0.030	0.005
18	0.005	0.047	0.034	0.052	0.068	0.032	0.005
19	0.005	0.050	0.037	0.055	0.073	0.035	0.006
20	0.006	0.054	0.039	0.059	0.078	0.037	0.006
21	0.006	0.057	0.042	0.063	0.083	0.040	0.007
22	0.007	0.061	0.045	0.068	0.089	0.043	0.007
23	0.007	0.065	0.048	0.072	0.094	0.045	0.008
24	0.008	0.070	0.052	0.077	0.101	0.049	0.008
25	0.008	0.075	0.055	0.082	0.107	0.052	0.009
26	0.009	0.080	0.059	0.088	0.114	0.056	0.010
27	0.010	0.085	0.063	0.094	0.122	0.059	0.010
28	0.010	0.091	0.067	0.100	0.129	0.064	0.011
29	0.011	0.097	0.072	0.106	0.137	0.068	0.012
30	0.012	0.103	0.077	0.113	0.146	0.072	0.013
31	0.013	0.110	0.082	0.120	0.155	0.077	0.014
32	0.014	0.117	0.087	0.128	0.165	0.083	0.014

Table 10. Capture probabilities of trophy size (910 mm TL) Flathead Catfish as a function water temperature and month based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Lake McMurtry. The gray shaded capture probabilities indicate water temperatures when sampling occurred in each month.

Trophy Size (910 mm)							
Temperature °C	April	May	June	July	August	September	October
14	0.003	0.029	0.021	0.032	0.042	0.020	0.003
15	0.003	0.031	0.022	0.034	0.045	0.021	0.004
16	0.004	0.033	0.024	0.037	0.048	0.023	0.004
17	0.004	0.035	0.026	0.039	0.052	0.024	0.004
18	0.004	0.038	0.028	0.042	0.055	0.026	0.004
19	0.004	0.040	0.030	0.045	0.059	0.028	0.005
20	0.005	0.043	0.032	0.048	0.063	0.030	0.005
21	0.005	0.046	0.034	0.051	0.067	0.032	0.005
22	0.005	0.050	0.036	0.055	0.072	0.034	0.006
23	0.006	0.053	0.039	0.059	0.077	0.037	0.006
24	0.006	0.057	0.042	0.063	0.082	0.039	0.007
25	0.007	0.061	0.045	0.067	0.088	0.042	0.007
26	0.007	0.065	0.048	0.071	0.093	0.045	0.008
27	0.008	0.069	0.051	0.076	0.100	0.048	0.008
28	0.008	0.074	0.054	0.081	0.106	0.051	0.009
29	0.009	0.079	0.058	0.087	0.113	0.055	0.009
30	0.009	0.084	0.062	0.092	0.120	0.059	0.010
31	0.010	0.090	0.066	0.099	0.128	0.063	0.011
32	0.011	0.096	0.071	0.105	0.136	0.067	0.012

Table 11. Beta estimates from top Cormack Jolly Seber models from capture-recapture sampling with low-frequency electrofishing (15 pps) for Flathead Catfish in Boomer Lake. Phi represents apparent survival and *p* represents the capture probability. The ~ indicates Phi or p were a function of the variables that follow. A ~1 indicates the parameter was a fixed constant, length is fish length (mm, TL, which was centered and scaled), and time is the sampling occasion (i.e., one monthly sample of the entire lake). SE is the standard error of the estimate LCL is the lower 95% confidence interval, and UCL is the upper 95% confidence interval.

Beta	Estimate	SE	LCL	UCL
Second Top model:	Phi(~1)p(~length + time)			
Phi:(Intercept)	22.72	8588.80	-16811.32	16856.76
p:(Intercept)	-1.77	0.54	-2.84	-0.71
p:length	0.12	0.17	-0.21	0.45
p:time3	-0.12	0.66	-1.42	1.17
p:time4	-1.39	0.74	-2.85	0.07
p:time5	-1.79	0.80	-3.35	-0.22
p:time6	-2.25	0.90	-4.01	-0.49
p:time7	-53.13	0.00	-53.13	-53.13
p:time8	-60.28	0.00	-60.28	-60.28
p:time9	-67.92	0.00	-67.92	-67.92
p:time10	-71.27	0.00	-71.27	-71.27
p:time11	-73.36	0.00	-73.36	-73.36
p:time12	-1.87	0.80	-3.43	-0.30
p:time13	-0.41	0.61	-1.61	0.79
p:time14	-1.67	0.71	-3.06	-0.29

Table 12. Capture probabilities of Flathead Catfish as a function of length of fish (280, 610, and 910 mm, TL) and time (month of sampling) based on Cormack Jolly Seber models from a capture-recapture study with low-frequency electrofishing (15 pps) at Boomer Lake.

Size Class (mm)	April	May	June	July	August	September	October
280	0.021	0.151	0.048	0.192	0.063	0.043	0.027
610	0.025	0.159	0.051	0.203	0.067	0.046	0.029
910	0.029	0.167	0.054	0.213	0.071	0.048	0.031

Table 13. Results of wet laboratory electrofishing trials to determine the power density required to elicit surfacing and non-capture prone response in Flathead Catfish exposed to low-pulse frequency (15 pps) DC electrofishing in a uniform power density within a rectangular tank. Two trial types were conducted: an increasing power trial that was conducted by increasing 50 volts every 30 seconds for 2 minutes (trial type 1); and a constant power treatment that applied the same randomly selected voltage for 2 minutes (trial type 2). D_m is the power (uW/cm^3) applied to the fish. Surfacing was defined as a fish swimming at the surface of the water for >2 seconds. Non-capture prone responses were defined as muscle twitching, forced swimming, and any other movement that did result in the fish showing a surfacing behavior. Counts are listed in the power density that was being applied at the time the fish responded. Fish that did not respond are all listed in the highest power tested by the end of the trial for surfacing response data and the lowest power tested for non-capture prone responses.

	Surfacing Response				Non- Capture Prone Response			
	Trial Type 1		Trial Type 2		Trial Type 1		Trial Type 2	
D_m	Yes	No	Yes	No	Yes	No	Yes	No
1-1.9				4	61	3	2	2
2-2.9			4	13			10	7
3-3.9	11		1	25			17	9
4-4.9			1	19			16	4
5-5.9			1	17			15	3
6-6.9				11			10	1
7-7.9	4		2	28			29	1
8-8.9			1	11			12	
9-9.9				13			13	
10-10.9				18			18	
11-11.9				11			11	
12-12.9				8			8	
13-13.9		49		4			4	
Total	15	49	10	182	61	3	165	27

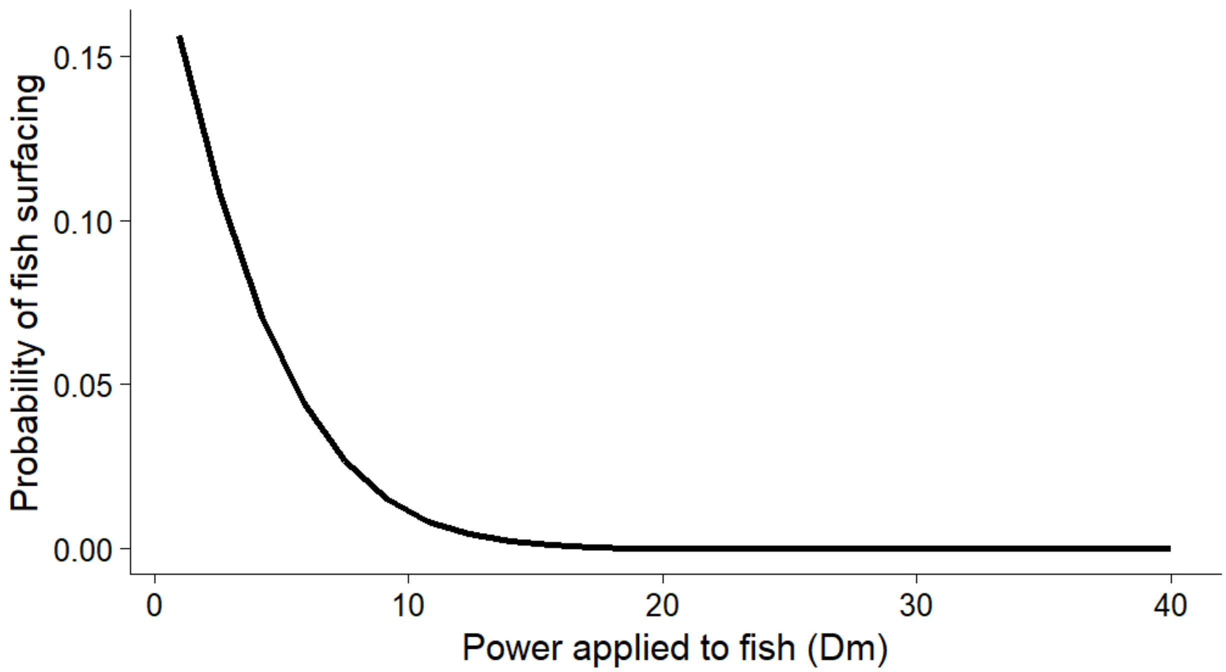

Figure 1. The probability of a Flathead Catfish exhibiting a capture-prone surfacing response (swimming on the water surface for ≥ 2 minutes) as a function of the power applied to the fish (Dm) in low-frequency (15 pps) pulsed DC electrofishing trials conducted with a uniform power density in a rectangular tank.

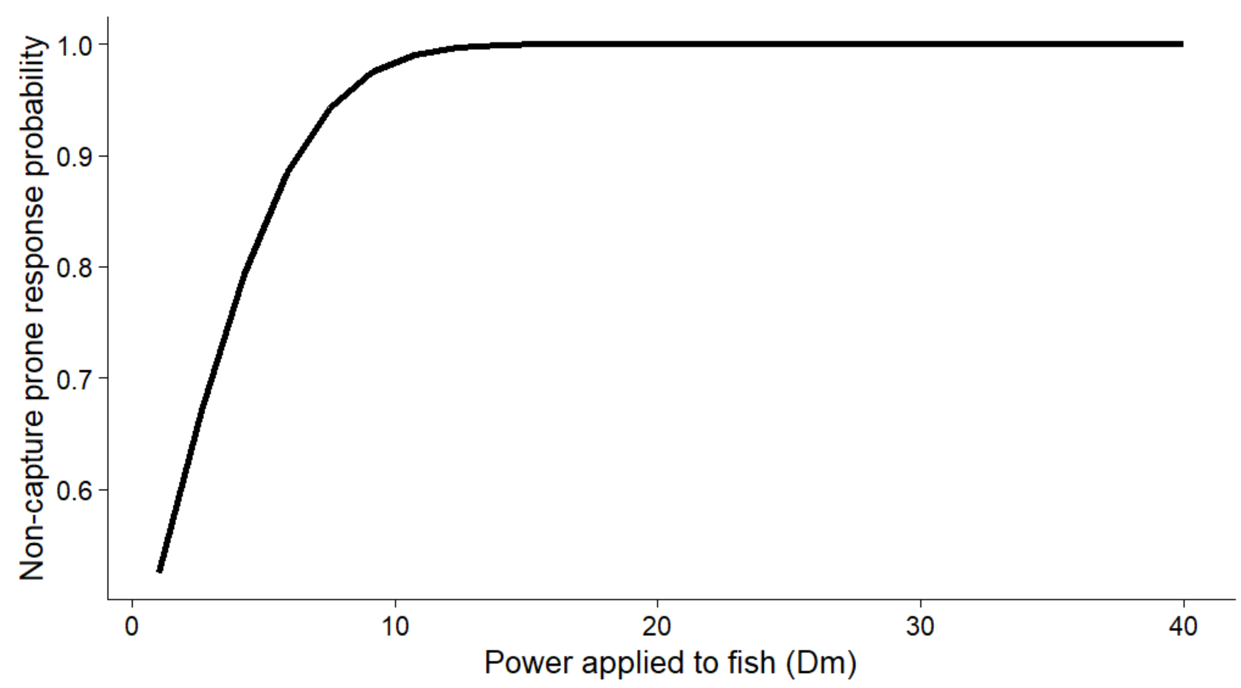

Figure 2. The probability of a Flathead Catfish exhibiting a non-capture-prone response (muscle twitching, forced swimming, and any other movement that did result in the fish showing a surfacing behavior) as a function of the power applied to the fish (Dm) in low-frequency (15 pps) pulsed DC electrofishing trials conducted with a uniform power density in a rectangular tank.

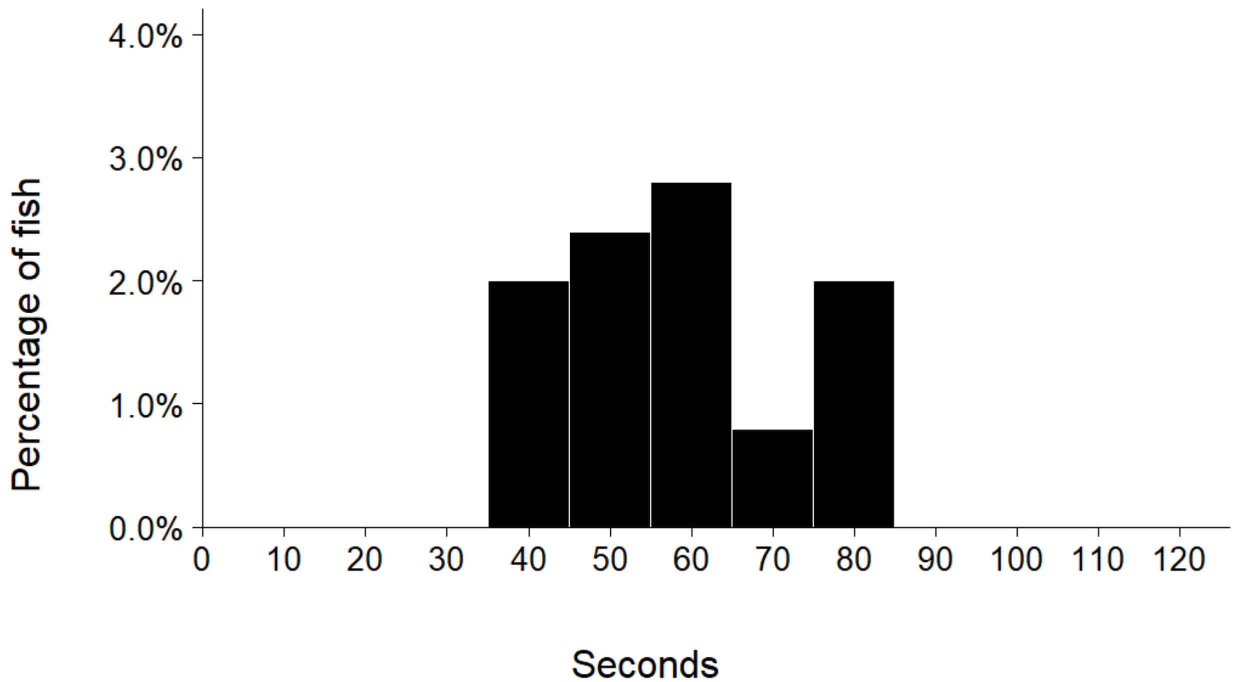

Figure 3. Frequency of Flathead Catfish exhibiting a capture-prone surfacing response at different times during 2-minute low-frequency (15pps) pulsed DC electrofishing trials conducted in a rectangular tank. Results presented combine all tested power levels from two trial types: an increasing power trial that was conducted by increasing 50 volts every 30 seconds for 2 minutes; and a constant power trial that applied the same randomly selected voltage for 2 minutes. A total of 256 fish was tested.

VITA

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Candidate for the Degree of

Master of Science

Thesis: PRECISION AND ACCURACY OF LOW-FREQUENCY ELECTROFISHING FOR SAMPLING RESERVOIR FLATHEAD CATFISH PYLODICTIS OLIVARIS POPULATIONS

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