EVALUATING GILL NET STANDARDIZATION AND ELECTROFISHING BOAT OPERATION TECHNIQUES IN ARIZONA RESERVOIRS

by

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ABSTRACT

I conducted a paired-gear comparison study in large standing warmwater reservoirs in Arizona during fall 2020 and spring 2021 between Arizona Game and Fish Department (AZGFD) standard gill net (Arizona net) and the American Fisheries Society (AFS) standard gill net (AFS net). The Arizona net and AFS net share the same height, hanging ratio, and twine sizes but differ in length, number of panels, and panel bar-mesh sizes. Adopting a national standard gear like the AFS gill net would allow AZGFD to use a uniform net methodology across the state, give the ability to compare data with other states that use the AFS standards, and allow for larger scale analyses. In five large lakes (Alamo, Apache, Bartlett, Pleasant, and Roosevelt) I investigated how each net was different or similar with regards to species diversity, pick and pull times, catch per unit effort (CPUE), and length structure. I also set out to create conversion factors to allow AZGFD to convert data from the Arizona net to be compared with the AFS net. I found that the AFS net caught the same species as the Arizona net, however, the Arizona net caught three additional species than the AFS net. The AFS net averaged about six and a half minutes faster to pick and pull per net than the Arizona net. For CPUE, the AFS net was higher for some species while the Arizona net was higher for others. Overall the Arizona net CPUE was greater than the AFS net. In both cases, the difference in fish caught per net was often minimal. For length frequencies, each net caught the same length ranges but had some differences in proportions of fish sizes. Lastly, I successfully developed CPUE conversion factors, although, fit of the model differed by species. Fisheries managers should recognize that each net does have biases with regards to using one net over the other for management goals. Further paired-gear testing between Arizona and AFS gill nets will add useful information to reliably help AZGFD convert to the AFS standard.

Coincidingly in the spring of 2021, I conducted a boat electrofishing study comparing three boat maneuvers and pedal operations for completing transect surveys. In the same five large reservoirs, I sampled using a continuous 600 s pedal-down transect parallel to shore (continuous parallel); an intermittent 10 s on 10 s off 600 s pedal-down transect parallel to shore (intermittent parallel); and 600 s pedal down transect with multiple arcs applying power only when incoming to shore/cover (arc intermittent) and compared their total time and distance per transect, CPUE of fish per hour and per m, and length frequencies. I found on average, continuous parallel took the least amount of time while arc intermittent took the least amount of distance to complete a 600 s pedal-down transect. For CPUE (fish/hr) there was evidence of differences for three species being higher in arc intermittent than in the other methods, which were similar, but no differences among any of the methods for five other species. For CPUE (fish/m) there was strong evidence for differences among multiple methods being higher than others for all species but two. Lastly, I found that each method caught the same size ranges of fish, however, some differences in proportions of sizes in some species were evident. Overall, each of the three electrofishing approaches tested should work well for documenting reservoir fish populations in general, but certain species and sizes may be best quantified using just one of the three approaches.

CHAPTER 1. COMPARISON OF AMERICAN FISHERIES SOCIETY AND ARIZONA GAME AND FISH DEPARTMENT STANDARD GILL NETS

INTRODUCTION

Standardization of methods and processes is common in many fields including medicine, meteorology, geology, water chemistry, and more (Bonar & Hubert 2002). From cholesterol data to computer hardware and geological maps to barometric pressure measurements, standardization has made these, and countless other processes, easier to conduct and use (Bonar & Hubert 2002). When sampling inland fisheries however, most standardization has only occurred at local, state, or provincial levels (Bonar & Hubert 2002), with continental standardization in North America not occurring. Reasons for large-scale standard sampling in inland fisheries not occurring include the monetary cost to standardize, risking the ability to compare with historical data, the inability to be creative with sampling design, and the resistance of many field biologist to top-down decrees in sampling methods (Bonar & Hubert 2002). Overall, applying different methods for collecting fisheries data without standardization limits the ability to compare fish communities and populations over space and time (Bonar et al. 2009a)

With no continental sampling standards in place, the American Fisheries Society (AFS) published the book *Standard Methods for Sampling North American Freshwater Fishes* in 2009 (Bonar et al. 2009). The book presents method and gear standards based on input from 284 biologists from 107 agencies across North America (Bonar et al. 2009b). Adoption of these methods is voluntary but steadily has been increasing. Many fisheries management agencies are interested in potentially implementing these standards, including the Arizona Game & Fish Department (AZGFD).

In 2004, prior to the publication of the AFS standard approaches, AZGFD published a standard statewide fish sampling protocol for all Arizona waters. This protocol was based on 18 state protocols already in use and recommended standardization of almost all aspects of fisheries sampling (Bonar 2019, Bryan et al. 2004). Methods listed in the AZGFD protocol either match, partially match, or do not conform with the AFS Standard Methods (Bonar 2019).

One of the important fisheries sampling methods that differs between AZGFD and AFS is the gill netting procedure. AZGFD uses general gill nets that differed in length, bar-mesh size, and number of panels from than those recommended by AFS Standard Methods. Arizona Game and Fish Department general gill nets (hereafter referred to as “Arizona net”) are 45.72-m long and have 6 randomly-ordered panels composed of 13, 25, 38, 51, 64, and 76-mm bar-mesh, compared to the AFS standard gill net (hereafter referred to as “AFS net”), which is 24.38-m long with 8 randomly ordered panels of 38, 57, 25, 44, 19, 64, 32, and 51-mm bar-mesh. Arizona and AFS nets share the same height (1.83-m), twine sizes (0.28-0.40-mm) and hanging ratio (12.7-mm). AFS standards also calls for warmwater lakes greater than 200 ha to be sampled in the late summer to winter when surface water temperatures are 20°C or less (Miranda & Boxrucker 2009). Arizona Game and Fish Department does not specify a particular season per warmwater lake size, but does suggest sampling occurs in the spring between first week of March and the last week of April, or between the first week of September and the last week of November when surface water temperatures are between 16° - 22°C (Byran et al. 2004). Lastly, AZGFD measures catch per effort as fish per hr whereas AFS standards record effort in fish per net night.

Understanding how these differences in gill net characteristics and deployment affect the catch per unit effort (CPUE) and the diversity and size structure of the catch usually requires a paired-gear comparison where two different gears are fished at the same time and location to assume they are sampling the same fish population and assemblage (Peterson & Paukert 2009). The paired gear data can then be compared using regression models and be used to develop correction factors (Peterson & Paukert 2009). Peterson & Paukert (2009) also recommend collecting at least ten paired samples when conducting a paired-gear comparison.

To help AZGFD transition to AFS standard sampling methods my objectives were to 1) compare species diversity, pick and pull times, fish CPUE, and length structure between the Arizona gill net and the AFS gill net in warmwater Arizona reservoirs; and 2) for each common species, develop conversion factors to allow AZDGF to convert historical data to the North American standard.

METHODS

Study Sites

This study was conducted at five reservoirs in central Arizona: Alamo Lake, Apache Lake, Bartlett Lake, Lake Pleasant, and Theodore Roosevelt Lake (Roosevelt Lake) during the fall of 2020 and spring of 2021 (Figure 1.1). Study reservoirs were selected based on recommendations by personnel from AZGFD and University of Arizona's School of Natural Resources and the Environment (UA SNRE).

Alamo Lake is located in western Arizona, just north of Wenden in La Paz County. It was created in 1968 after the completion of the Alamo Dam which impounds runoff from the Bill Williams River (Fullmouth & D'Amico 2019). Flood control and water storage were the main purposes for the reservoir (Fullmouth & D'Amico 2019). The lake has an approximate surface area of 1,490 ha and a surface elevation of 343 m (Fullmouth & D'Amico 2019). Alamo

Lake's fish species include Largemouth Bass *Micropterus salmoides*, Black Crappie *Promoxis nigromaculatus,* Channel Catfish *Ictalurus punctatus*, Bluegill *Lepomis macrochirus,* Redear Sunfish *L. microlophus,* Green Sunfish *L. cyanellus*, Blue Tilapia *Oreochromis aureus*, Common Carp *Cyprinus carpio*, Yellow Bullhead *Ameiurus natalis*, and Threadfin Shad *Dorosoma petenense* (Fullmouth & D'Amico 2019).

Apache Lake is located in central Arizona, northeast of Phoenix in Maricopa County. Apache Lake was formed in 1927 after the completion of the Horse Mesa Dam on the Salt River (Gill 2020). The lake has an approximate surface area of 1,080 ha, 67 km of shoreline, and a surface elevation of 580 m (Gill 2020, USFS 2020). Fish species of Apache Lake include Largemouth Bass, Smallmouth Bass *Micropterus dolomieu,* Flathead Catfish *Pylodictis olivaris,* Rainbow Trout *Oncorhynchus mykiss,* Walleye *Sander vitreus,* Yellow Bass *Morone mississippiensis,* Gizzard Shad *Dorosoma cepedianum,* Bigmouth Buffalo *Ictiobus cyprinellus,* Smallmouth Buffalo *I. bubalus,* Black Buffalo *I. niger*, Bluegill, Channel Catfish, Readear Sunfish, Green Sunfish, and Common Carp (Gill 2020, USFS 2020).

Bartlett Lake is located in central Arizona, northeast of Phoenix in Maricopa County. Bartlett Lake was formed in 1939 after the completion of Bartlett Dam, the first dam built on the Verde River (Gill 2019a). Bartlett Lake covers 1,137 ha when full, has 53 km of shoreline, and a surface elevation of 490 m (Gill 2019a). Fish species of the lake include Largemouth Bass, Smallmouth Bass, Black Crappie, Channel Catfish, Flathead Catfish, Common Carp, Threadfin Shad, Bluegill, and Green Sunfish (Gill 2019a). Since the lake is fed by the Verde River, native fish including Desert Sucker *Catostomus clarki,* Sonoran Sucker *Catostomus insignus,* Roundtail Chub *Gila robusta,* Razorback Sucker *Xyrauchen texanus*, and Colorado Pikeminnow *Ptychocheilus lucius* can be present but are rarely caught (Gill 2019a).

Lake Pleasant is located in central Arizona, northwest of Phoenix in Maricopa County. Filled in 1994 after the completion of the New Waddell Dam in 1992, Lake Pleasant is a water storage reservoir that is primarily filled from the Colorado River by Central Arizona Project (CAP) canals (Gill & Jones 2019). Lake Pleasant covers 4034 ha, has 183 km of shoreline, and an approximate surface elevation of 503 m (Gill 2019b). Fish species of the lake include Largemouth Bass, Striped Bass *Morone saxatilis*, White Bass *Morone chrysops*, Flathead Catfish, Channel Catfish, Common Carp, Threadfin Shad, Gizzard Shad, Green Sunfish, Bluegill, Redear Sunfish, Tilapia *Tilapia spp.,* White Crappie, and Black Crappie (Gill & Jones 2019).

Roosevelt lake is located in central Arizona, northeast of Phoenix in Maricopa County. Roosevelt lake was formed in 1911 after the completed construction of Theodore Roosevelt Dam and is the upper most and largest lake of the four Salt River reservoirs (Gill 2019b). At full capacity the lake covers 8880 ha, has 146 km of shoreline, and a surface elevation of 390 m (Gill 2019b). Fish species of Roosevelt Lake include Largemouth Bass, Smallmouth Bass, Black Crappie, Bluegill, Flathead Catfish, Channel Catfish, Yellow Bass, Threadfin Shad, Gizzard Shad, Bluegill, Green Sunfish, Bigmouth Buffalo, Smallmouth Buffalo, Black Buffalo, and Common Carp (Gill 2019b).

Gill Net Comparison Field Methods

Both gill nets were fished in pairs in the spring and fall. Timing of lake sampling followed the Arizona and AFS Protocols (Bryan et al. 2004) for warmwater reservoirs in the fall (first week of September - last week of November for fall 2020) and the Arizona Protocol for the spring (first week of March - the last week of April for spring 2021). However, due to equipment malfunctions, sampling had to be extended into the second week of May for spring sampling.

Ten random sites in each lake for each season were chosen using the process described in the Arizona Protocol (Bryan et al. 2004). Sampling sites chosen in the spring were different than those selected in the fall. Spring gill netting in large warmwater reservoirs is not typically conducted according to AFS Standards; however, spring gill nets were set for comparisons with the fall sampling data and for sampling information for AZGFD. A Google Earth map of each lake was used to select points and transferred to a handheld Garmin GPS (MAP 64st) unit to find sites in the field.

Lakes were sampled over 3 consecutive nights with 3 or 4 paired Arizona/AFS net sets each night for a total of 9 - 10 paired net nights per lake per season. However, due to equipment malfunctions, only 6 paired net nights were conducted on Apache Lake during spring sampling. Arizona gill nets were set perpendicular to shore at each random point. Next, AFS nets were randomly assigned left or right and ~90-m away from each Arizona net and set perpendicular to shore. Net pairs were set this way to allow the greatest opportunity for similar species of fish to pass through either net and become entangled, without the nets interfering with one another (Ryswyk 2013, Smith 2015). All nets were set midafternoon and collected the following morning to encompass two crepuscular periods.

Analysis

All sizes and species of fish captured were identified by the panel in which caught, measured (total length in mm), and weighed (g). The total number of species caught in each net was calculated and compared. Catch per unit effort (fish/net night; AFS standard) and CPUE (fish/hr; Arizona standard) was calculated for ≥ stock-length (Gabelhouse 1984) fish (hereafter referred to as “all species”). Analysis was only conducted on widespread and relatively abundant species filtered from all species (present in ≥10 net pair sets; hereafter referred to as “list species"). The amount of time it took to pull and pick nets was also recorded for each net. Times were compared using a Welch two sample t-test.

Since gill nets differed in length, analysis was done to see if CPUE (fish/net night and fish/hr) of the longer Arizona net had different CPUE than the shorter AFS net. Mean CPUEs for Arizona and AFS nets were calculated and compared for the total of all species ≥ stock-length. For list species, CPUEs of the whole net were compared using a Kruskal Wallis test.

Length frequencies for list species were compared visually between the two nets over all lakes by using an empirical cumulative distribution function (ECDF) plot (Ogle 2015). A Kolmogorov-Smirnov (KS) two-sample test was used to test differences of length frequencies between net types.

To create correction factors for list species, catch per unit effort data was log transformed (ln[X+1]). Regression analysis was used to compare log transformed CPUE data between the AFS and Arizona net to develop species-specific conversion equations. Arizona CPUE data (dependent variable) was regressed against AFS CPUE data (independent variable) with accompanying 95% confidence intervals for each list species. A goodness-of-fit (adjusted R^2 [R^2_{adj}]) value was conducted for each regression. An R^2_{adj} value closer to 1 indicated that more variation in CPUE was associated with differences between nets while an R^2_{adj} value closer to 0 indicated that variation may be caused by factors other than net differences.

Due to Arizona standards of reporting effort as fish per hr instead of fish per net night, all results are given for both measurements of CPUE. All tests assumed an α of 0.05. All analysis was done in the computer software R Studio version 1.4.1717 (RStudio 2021).

RESULTS

Total catch and pick times

A total of 4829 individual fish across 21 different species were collected (Table 1.1). 3904 individuals from 17 species ≥ stock-length (all species) were filtered from the total collected, which left 3846 individuals from 10 species (list species) remaining that were used for the analyses previously described (Table 1.1). AFS nets caught the same species as the Arizona nets and the Arizona nets only caught three additional species than the AFS net and at very low abundance (one goldfish, one koi, and five rainbow trout). Although Threadfin Shad were caught in both nets, they were almost exclusively caught in the small 13-mm bar-mesh of the Arizona net (609 total vs. 18 caught in the smallest AFS net mesh, 19-mm). The time it took to pull and pick the AFS net, which ranged from 5 to 70 minutes (SD ± 11.2) and averaged 22.7 min, was significantly (P=0.002) higher than the Arizona net, which ranged from 4 to 85 minutes (SD ± 14.7) and averaged 29.2 min.

Catch per unit effort comparison

The AFS net averaged 20.9 fish/net night (SE ± 44.2) or ~1.1 fish/hr (SE ± 2.1) while the Arizona net averaged 24.4 fish/net night (SE ± 45.8) or ~1.3 fish/hr (SE ± 2.4) for all species ≥ stock-length. For list species, there was significant difference in CPUE (fish/net night and fish/hr) between Arizona and AFS nets for Common Carp, Channel Catfish, Yellow Bass, and Flathead Catfish, each of which has higher catches in the Arizona nets (Table 1.2).

Length frequency comparison between gill nets

No significant differences between length frequencies occurred by net type for Gizzard Shad, Channel Catfish, Green Sunfish, Bluegill, and Flathead Catfish while Common Carp (P = 0.005), Largemouth Bass (P = 0.001), and White Bass (P < 0.001) did show significant differences of length frequencies (Figure 1.2). A higher proportion of Common Carp between ~400 and ~650-mm were caught in the AFS net while a greater proportion of Largemouth Bass between ~200 and 350-mm and White Bass between ~ 200 mm 350-mm were caught in the Arizona net. Black Crappie (P =0.06) and Yellow Bass (P = 0.06) were close to being significantly different for length frequencies between nets with the AFS nets exhibiting a higher proportion of smaller Yellow Bass and larger Black Crappie than Arizona nets (Figure 1.2). Both nets did catch similar length ranges for all list species (Figure 1.2).

Regression analysis

Regression equations to convert ln(X+1) transformed data between Arizona and AFS nets was conducted for 10 species (Table 1.3, 1.4). For CPUE (fish/net night) goodness of fit (R^2_{adj}) was excellent for White Bass with 91% of the CPUE variation being accounted for by differences between nets, moderate for Common Carp, Gizzard Shad, Green Sunfish, Largemouth Bass, and Black Crappie with 31 - 57% of the CPUE variation being accounted for by differences between nets, and weak for the other four with -0.49 – 14% of CPUE variation explained by differences between nets (Figure 1.3).

Goodness of fit (R^2_{adj}) for CPUE (fish/hr) was similar to that of fish/net night. R^2_{adj} was moderate for six of the ten species, with 37 – 67% of CPUE variation being accounted for by differences between nets, and weak for four species with -0.44 – 24% of CPUE variation explained by differences between nets (Figure 1.4).

DISCUSSION

Paired-gear studies have also been used to compare many aspects of gill nets, from mono vs multifilament gill nets (Henderson & Nepszy 1992, Ion & Aurel 2016), electrofishing vs gill nets (Goffaux, Grenouillet, & Kestemont 2005), benthic and whole water column gill nets (Specziar et al. 2009), and state agency vs AFS standard gill nets (Ryswyk 2006, Smith 2015). In this study the feasibility for Arizona Game & Fish Department to convert to the *AFS Standards* gill net described by Miranda & Boxrucker (2009) is shown. Differences were shown for CPUE for both fish/net night and fish/hr, and length frequencies for each species were given, as well as useful regression equations to convert Arizona and AFS CPUEs. Smith (2015) compared South Dakota Game, Fish, and Parks standard gill net CPUE, length frequency, and species diversity to the one purposed by Miranda & Boxrucker (2009) and developed reliable conversion factors between the two. Ryswyk (2006) also conducted a similar study to assist Oklahoma Department of Wildlife Conservation convert to the AFS standard gill net. Both these studies and the one conducted here give the respective agencies the information necessary to pursue sampling using the AFS Standard as well as being able to use historic data.

Total catch and pick times

Total catch of all ≥ stock-length sized fish and species diversity was similar between the two nets with the Arizona net catching about 300 more individuals than the AFS net over all samples and catching only three additional species. The longer Arizona net may have been advantageous for collecting one of the additional species (Rainbow Trout) as it was able to reach cooler deeper waters. Lastly, though not an analyzed species in this study, overall number of Threadfin Shad caught in the Arizona net was significantly higher than the AFS net due to the small 13 mm bar-mesh in the Arizona net. If Threadfin Shad need to be sampled, a 13 mm bar-mesh panel may be beneficial as an add-on panel to the AFS net as described in Miranda and Boxrucker (2009).

Pick times for AFS net were on average ~six and a half minutes faster than the Arizona net. Pick times were not twice as fast for the AFS net (with about half the length of the Arizona net) because CPUE was so similar between the two nets. With less time picking gill nets, more time can be put into setting nets for a greater sample size. Also, working with the shorter net may mean a smaller chance to get stuck on underwater debris, less time de-tangling between sets, and faster turn arounds to get nets back in the water.

Catch per unit effort comparison

Mean CPUE of all species ≥ stock-length was surprisingly similar, with the Arizona net catching only about three more fish per net night (0.2 fish/hr) than the AFS net. Fish per net night was also greater in Arizona nets than AFS nets for six out of the ten list species (four being significantly greater). However, mean CPUEs between nets ranged from fractions of fish/net night to at most ~three fish/net night. These findings show that larger surface area nets do not necessarily catch more fish, as reported by Acosta (1994) where no significant differences in CPUE per length was observed between varied lengths of nets. Differences in CPUE between nets may come from mesh sizes not shared by the two nets, order of the panels, or area where net was placed.

Length frequency comparison between gill nets

Length frequencies measured from each net were similar for list species besides Common Carp, Largemouth Bass, and White Bass ,where each net had biases toward certain size classes. In a net comparison study from South Dakota, AFS nets also selected for larger Common Carp, however, larger White Bass were also selected for in the AFS nets (Smith 2015), while in this study Arizona nets selected for larger White Bass. The Arizona net has two different panels than the shared ones with the AFS net, a smaller 13-mm mesh and larger 76 mm mesh. Since the 13-

and 76-mm mesh only account for ~5% of the catch data for list species, variation in lengths may be a result of the panels not found in the Arizona net, order of panels for each net, length of nets, or random chance of where the gill net was placed. Recognizing the length frequency biases each net has will help with defining and analyzing data associated with management goals. If the AFS net is integrated into standard sampling, comparing the new AFS net length frequency data with the ECDF charts in this study or historical data may give managers an idea of what they may have expected to catch with the Arizona net allowing them to make informed management decisions.

Regression analysis

Regression analysis for log transformed CPUE (fish/net night, and fish/hr) between Arizona and AFS nets resulted in reliable conversion factors for most species with some exceptions. Models with weak strengths of fit should be used with caution as variability was caused by factors that did not include the net differences, e.g. small sample sizes. In South Dakota, Smith (2015) found relatively high R^2_{adj} values existed for almost all studied species (29.2% to 95.7%). Ryswyk (2009) also found high R^2 values for four out of five studied species in Oklahoma (66% to 86%). Reasons for strength of fit values being higher in those studies may be in part due to their larger sample sizes. Smith (2015) had 219 paired samples and Ryswyk (2009) had 240 while our study in Arizona had only 86. Fortunately, some of the species with weak R^2_{adj} values in our study may be better sampled with other methods (such as electrofishing or fyke nets) so gill net conversions may not be needed for these species in Arizona. For example, to study Flathead Catfish population to meet or exceed Arizona Fat Cat Concept standards, boat electrofishing is more commonly used (Gill 2019a).

Deciding if one should use an equation to convert historical data comes down to seeing how well the model fits the species, identifying if the species is primarily sampled with gill nets, and knowing that the correlation equations are not an exact crossover from Arizona to AFS nets.

CONCLUSION

With the move to standardizing fisheries sampling methods to the *AFS Standards*, Arizona Game & Fish Department wanted to compare their department's current gill net to the national standards. Pick times were faster for the AFS net than the Arizona net possibly allowing more time to set greater number of nets in the water. CPUEs (fish/net night and fish/hr) were similar between the two nets except for Common Carp, Channel Catfish, Yellow Bass, and Flathead Catfish. With regards to length frequencies, each net has some biases towards a greater number of individuals of certain sizes. However, each net did catch the same range of sizes for each list species meaning one is not missing out on a certain size group if fishing a certain net. Conversion factors to compare historical data collected with the Arizona net with new data collected with the AFS net were created for 10 species. Although some of these regressions had weak strengths of fit, some of these species have other preferred sampling methods and conversion factors may not be needed. Further paired-gear testing between Arizona and other AFS standard gears across waterbodies will add useful information to reliably help Arizona Game & Fish Department convert to the North American standard.

TABLE 1.1. – Total and ≥ stock-length fish species caught from Arizona and AFS gill nets fished with equal effort in five Arizona lakes. Species used for analysis (list species) are bolded.

Species		Net			
		AFS		AZ	
Common Name	Scientific Name	Total	≥ Stock	Total	≥ Stock
Yellow Bullhead	*Ameiurus natalis*	10	10	4	4
Goldfish	*Carassius auratus*			1	
Common Carp	*Cyprinus carpio*	255	222	419	351
Koi	*Cyprinus rubrofuscus*			1	
Gizzard Shad	*Dorosoma cepedianum*	623	611	560	550
Threadfin Shad	*Dorosoma petenense*	18		609	
Smallmouth Buffalo	*Ictiobus bubalus*	1	1	5	5
Largemouth Buffalo	*Ictiobus cyprinellus*	1	1	1	1
Channel Catfish	*Ictalurus punctatus*	117	88	162	116
Green Sunfish	*Lepomis cyanellus*	22	21	19	17
Bluegill	*Lepomis macrochirus*	29	29	32	24
Smallmouth Bass	*Micropterus dolomieu*	2	2	5	4
Largemouth Bass	*Micropterus salmoides*	479	444	595	563
White Bass	*Morone chrysops*	82	81	103	102
Yellow Bass	*Morone mississippiensis*	148	146	241	236
Striped Bass	Morone saxatilis	7	4	14	14
Black Crappie	*Pomoxis nigromaculatus*	121	121	89	85
Flathead Catfish	*Pylodictis olivaris*	14	14	25	25
Walleye	*Sander vitreus*	6	6	1	1
Rainbow Trout	*Oncorhynchus mykiss*			5	5
Tilapia	*Oreochromis spp.*	2		1	

TABLE 1.2. – Results from Kruskal Wallis test comparing total CPUE (fish/net night and fish/hr) and mean catch between Arizona and AFS gill net. Significant *P*-values are bolded.

	CPUE (fish/net night)			CPUE (fish/hr)		
Species	*P-values*	Mean CPUE AFS	Mean CPUE AZ	*P-values*	Mean CPUE AFS	Mean CPUE AZ
Common Carp	***P*<0.001**	2.58	4.08	***P*<0.001**	0.13	0.21
Gizzard Shad	*P*=0.70	12.73	11.46	*P*=0.86	0.63	0.59
Channel Catfish	***P*<0.001**	1.02	1.34	***P*<0.001**	0.05	0.07
Green Sunfish	*P*=0.54	0.24	0.20	*P*=0.54	0.01	0.01
Bluegill	*P*=0.92	0.34	0.28	*P*=0.91	0.02	0.01
Largemouth Bass	*P*=0.28	5.16	6.52	*P*=0.24	0.26	0.34
White Bass	*P*=0.63	5.06	6.38	*P*=0.60	0.26	0.33
Yellow Bass	***P*=0.04**	4.56	7.38	***P*=0.02**	0.23	0.39
Black Crappie	*P*=0.81	1.40	0.99	*P*=0.83	0.07	0.05
Flathead Catfish	***P*=0.003**	0.16	0.29	***P*=0.003**	0.01	0.02

TABLE 1.3 – Species-specific regression equations used for lake-wide conversion factors for ln(X+1) transformed CPUE (fish/net night; AFS standard) data between Arizona and AFS gill nets.

Common Name	Scientific Name	Arizona to AFS	AFS to Arizona
Common Carp	*Cyprinus carpio*	Arizona = 0.48*(AFS) + 0.4	AFS = (Arizona – 0.4)/0.48
Gizzard Shad	*Dorosoma cepedianum*	Arizona = 0.44*(AFS) + 1.3	AFS = (Arizona – 1.3)/0.44
Channel Catfish	*Ictalurus punctatus*	Arizona = 0.39*(AFS) + 0.26	AFS = (Arizona – 0.26)/0.39
Green Sunfish	*Lepomis cyanellus*	Arizona = 0.82*(AFS) + 0.036	AFS = (Arizona – 0.036)/0.82
Bluegill	*Lepomis macrochirus*	Arizona = 0.34*(AFS) + 0.13	AFS = (Arizona – 0.13)/0.34
Largemouth Bass	*Micropterus salmoides*	Arizona =0.69*(AFS) + 0.34	AFS = (Arizona – 0.34)/0.69
White Bass	*Morone chrysops*	Arizona = 0.89*(AFS) + 0.058	AFS = (Arizona – 0.058)/0.89
Yellow Bass	*Morone mississippiensis*	Arizona = 0.26*(AFS) + 0.83	AFS = (Arizona – 0.83)/0.26
Black Crappie	*Pomoxis nigromaculatus*	Arizona = 0.79*(AFS) + 0.18	AFS = (Arizona – 0.18)/0.79
Flathead Catfish	*Pylodictis olivaris*	Arizona = -0.06*(AFS) + 0.12	AFS = (Arizona – 0.12)/-0.06

TABLE 1.4 – Species-specific regression equations used for lake-wide conversion factors for ln(X+1) transformed CPUE (fish/hr; Arizona standard) data between Arizona and AFS gill nets.

Common Name	Scientific Name	Arizona to AFS	AFS to Arizona
Common Carp	*Cyprinus carpio*	Arizona = 0.34*(AFS) + 0.057	AFS = (Arizona – 0.057)/0.34
Gizzard Shad	*Dorosoma cepedianum*	Arizona = 0.56*(AFS) + 0.22	AFS = (Arizona – 0.22)/0.37
Channel Catfish	*Ictalurus punctatus*	Arizona = 0.36*(AFS) + 0.026	AFS = (Arizona – 0.026)/0.36
Green Sunfish	*Lepomis cyanellus*	Arizona = 1.0*(AFS) + 0.0019	AFS = (Arizona – 0.0019)/1.0
Bluegill	*Lepomis macrochirus*	Arizona = 0.5*(AFS) + 0.0096	AFS = (Arizona – 0.0096)/0.5
Largemouth Bass	*Micropterus salmoides*	Arizona =0.59*(AFS) + 0.062	AFS = (Arizona – 0.062)/0.59
White Bass	*Morone chrysops*	Arizona = 0.65*(AFS) + 0.045	AFS = (Arizona – 0.045)/0.65
Yellow Bass	*Morone mississippiensis*	Arizona = 0.36*(AFS) + 0.079	AFS = (Arizona – 0.079)/0.36
Black Crappie	*Pomoxis nigromaculatus*	Arizona = 0.79*(AFS) + 0.025	AFS = (Arizona – 0.025)/0.79
Flathead Catfish	*Pylodictis olivaris*	Arizona = -0.054*(AFS) + 0.0088	AFS = (Arizona – 0.0088)/-0.054

FIGURE 1.1. – Gill net study sites on five large reservoirs in Arizona; Alamo Lake, Apache Lake, Bartlett Lake, Lake Pleasant, and Roosevelt Lake with fall 2020 sites (circle) and spring 2021 (square) indicated. Points are located in the middle of the paired sets.

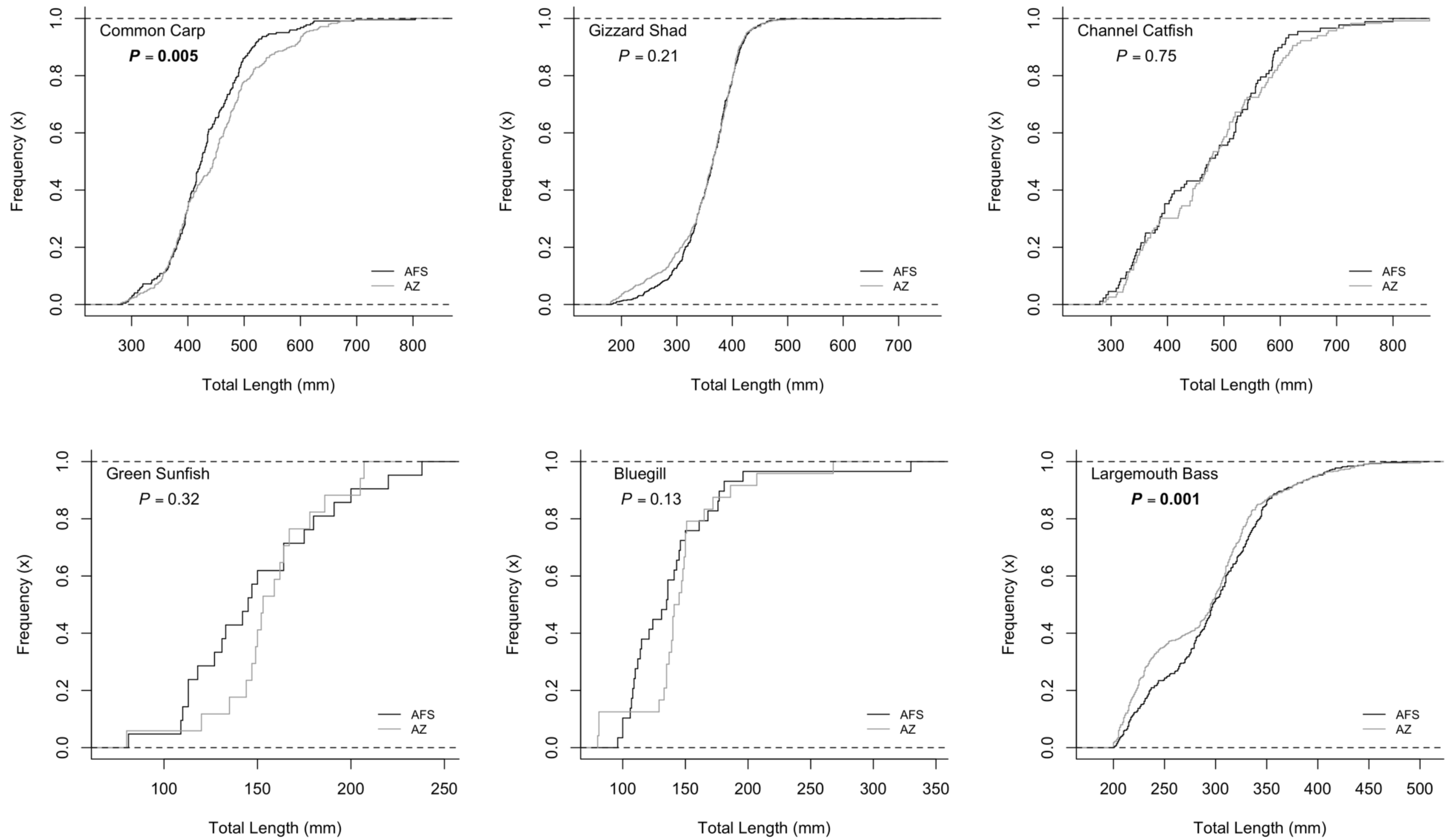

FIGURE 1.2. – Length frequencies of Arizona and AFS gill net for 10 species sampled across 5 Arizona lakes. Significant *P*-values are bolded.

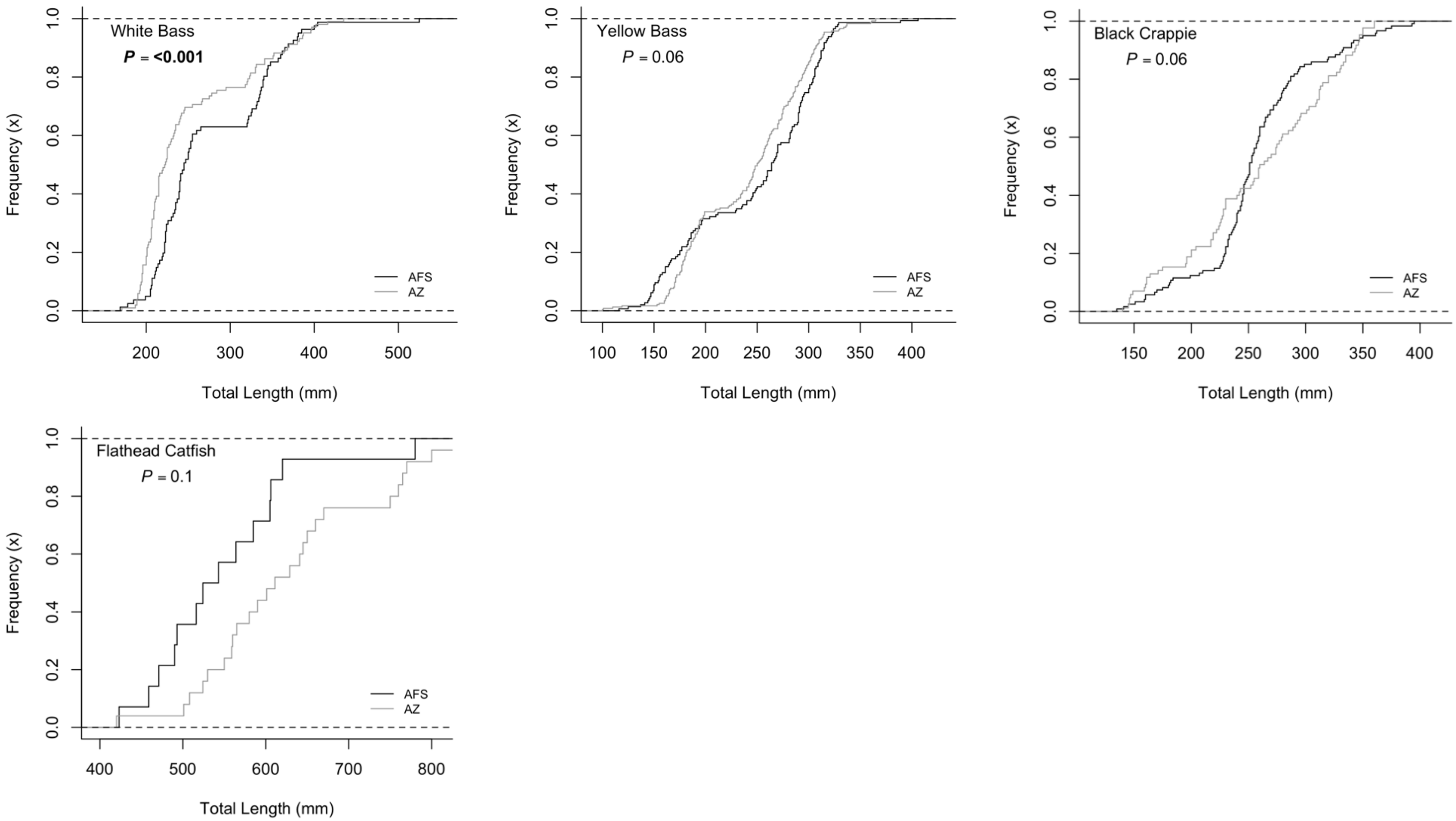

FIGURE 1.2. – Cont.

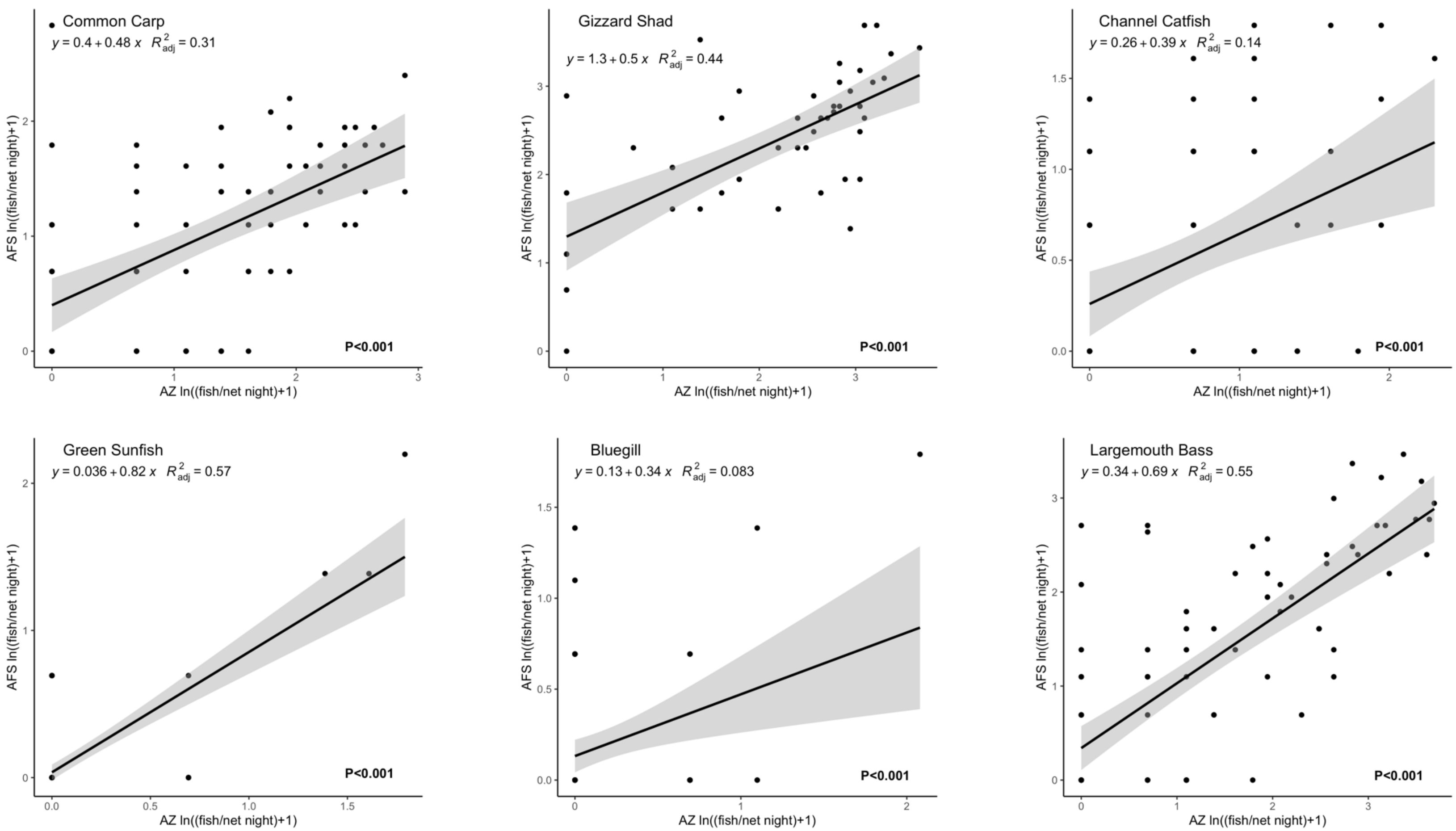

FIGURE 1.3. – CPUE (fish/net night) regression analysis between Arizona and AFS gill nets with accompanying 95% confidence intervals, regression equation, R^2_{adj} values, and *P*-values for 10 species. Significant P-values are bolded.

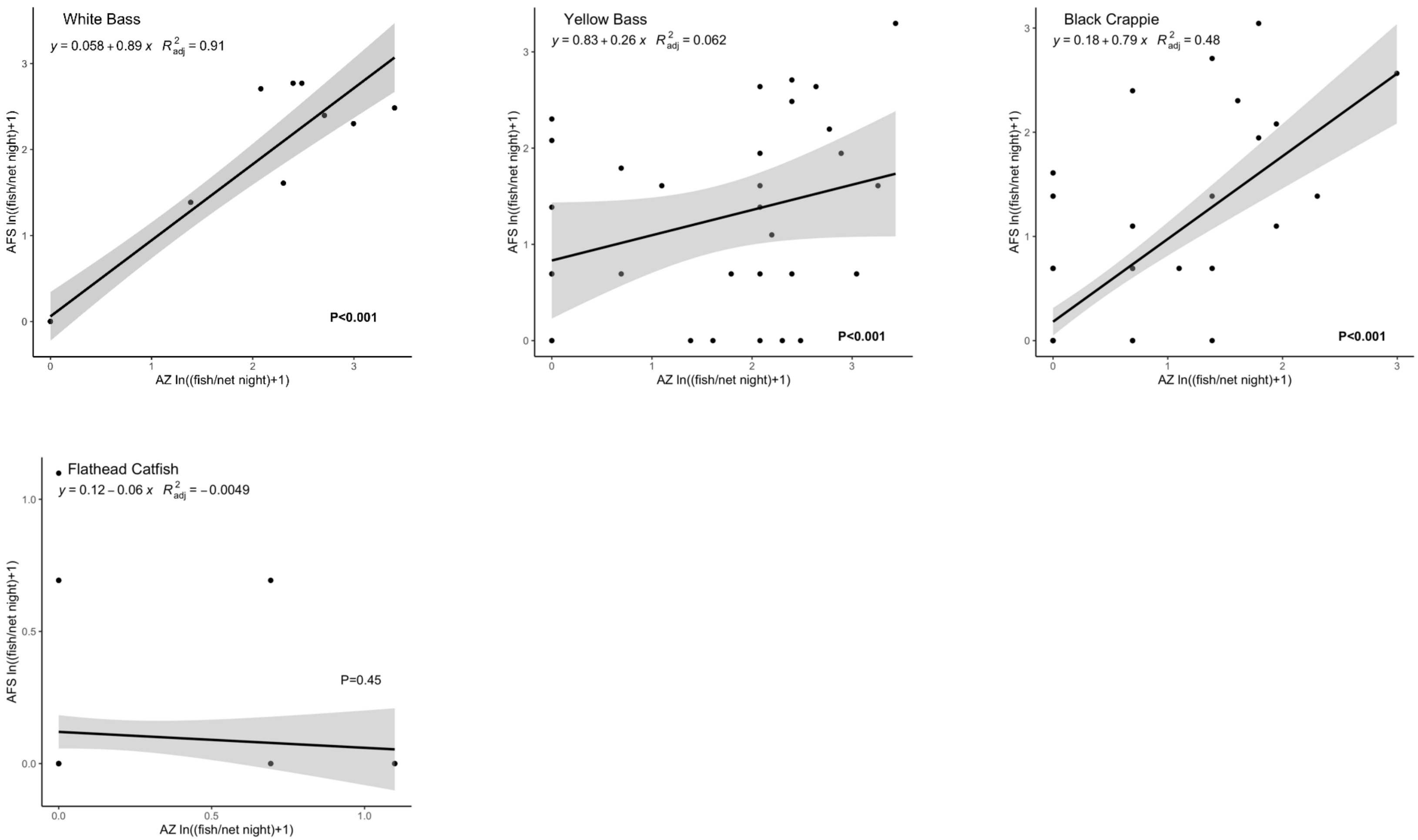

FIGURE 1.3. – Cont.

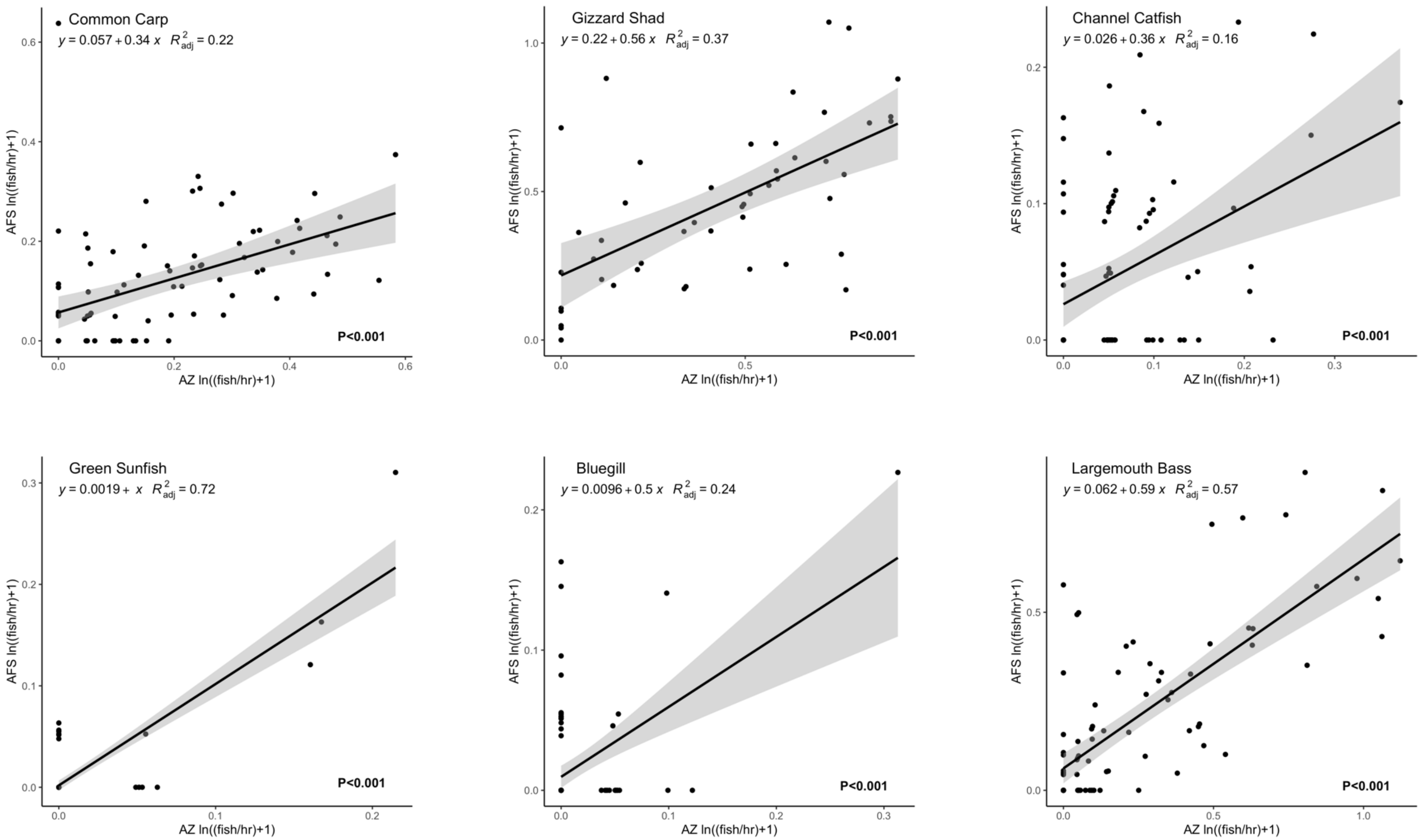

FIGURE 1.4. – CPUE (fish/hr) regression analysis between Arizona and AFS gill nets with accompanying 95% confidence intervals, regression equation, R^2_{adj} values, and *P*-values for 10 species. Significant P-values are bolded.

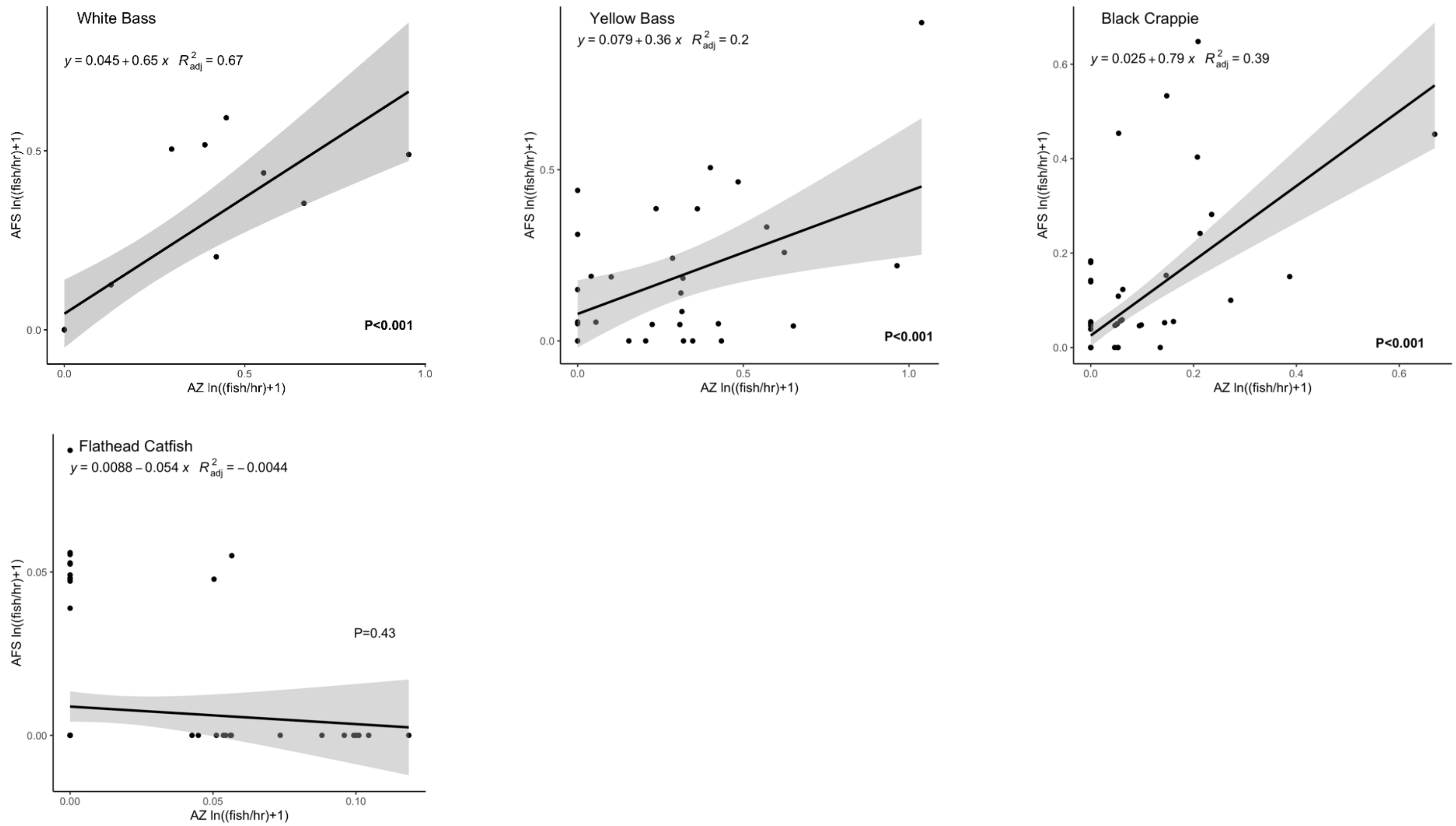

FIGURE 1.4. – Cont.

CHAPTER 2. COMPARISON OF THREE BOAT ELECTROFISHING MANEUVERS AND PEDAL OPERATION

INTRODUCTION

Standardization of techniques and methods has been essential to world progress (Bonar et al. 2009). From medicine to computer technology and data analysis, standardization has allowed for huge advancements in these processes that make them easier to compare across boundaries as well as make our lives easier day to day (Bonar & Hubert 2002, Bonar et al. 2009). Although common in many fields, standardization had been uncommon in inland fisheries sampling with most only occurring at local, state, or provincial levels (Bonar & Hubert 2002). Before 2009, there were no North American standards recommended for inland fisheries biologists and managers to use. Because of this, fisheries biologists had used inconsistent sampling methods and recorded data in ways that were challenging to interpret later (Bonar et al. 2009) making comparisons about fish populations difficult.

Because standard sampling procedures are important to fisheries managers to evaluate populations over time among systems (Nobel 2002), comparison of fisheries data is problematic when different methods are used or when similar methods are used with varying procedures (Bonar et al. 2009). To address the need of standardizing North American inland fisheries, the American Fisheries Society published the book *Standard Methods for Sampling North American Freshwater Fish* in 2009. The book recommends method and gear standards based on input from 284 biologists from 107 agencies across North America (Bonar et al. 2009).

One of the standard methods for sampling warmwater fish in large standing waters is electrofishing. This technique is commonly used by fisheries biologists to sample fish in bodies of freshwater by sending an electrical current through the water stunning fish within the electrical field allowing biologists to easily net them. In large warmwater lakes and reservoirs, electrofishing is appealing due to its ability to collect multiple fish species and sizes across a range of littoral habitats and environmental conditions, minimal crew size needed, lack of physically demanding activity, and durable equipment that is easily transported (Miranda & Boxrucker 2009). However, because of its popularity and widespread use across myriad groups and agencies, there is little uniformity in how biologists best employ this method in the field (P. Cooney, Smith-Root, personal communication).

How electrofishing boat operation affects fish catches in large standing bodies of warmwater is little known. AFS *Standard Methods* calls for a continuous, typically 600 s, transect for sampling (Bonar 2019, Miranda & Boxrucker 2009). In *Standard Methods*, Miranda & Boxrucker (2009) recommend a parallel to shore approach with meandering around obstacles and sporadic backing up to catch fish and avoid pockets. While *Standard Methods* calls for continuous electrical output, many biologists have adopted an intermittent output, either parallel to shore or shocking into shore/cover, where power is administered at certain intervals, usually dependent on the biologist's judgement. This method has been adopted from the idea and observations that a continuous power output may "herd" fish, where fish can feel the electricity coming and swim away. For example, U.S. Fish and Wildlife Service biologists use bursts of approximately 3 seconds on then 3 seconds off to sample river herring to prevent pushing fish (Sprankle 2016), while a protocol in Florida for canal monitoring consists of 5-7 seconds on then off for 2-3 seconds (Rehage, Gandy, & Trujillo 2013) This method is also common when there is lot of cover, however in areas of open shoreline, continuous shocking is often used (P. Cooney, personal communication). Cooney (personal communication) also noted that no two people electrofish the same stretch of river or the same stretch of shoreline in the same manner. Because of these differences within the same method, it is important to see how electrofishing boat maneuvers and pedal operation effect catch rate.

To help understand the effects of different boat maneuvers and pedal operation in large Arizona warmwater reservoirs, the objectives of this study were to 1) test CPUE (catch per unit effort) of different species among three different combinations of boat maneuvers and pedal operation, and 2) test for length frequency differences among fish caught using the three electrofishing methods.

METHODS

Study Sites

This study was conducted at five reservoirs in central Arizona: Alamo Lake, Apache Lake, Bartlett Lake, Lake Pleasant, and Theodore Roosevelt Lake (Roosevelt Lake) during the fall of 2020 and spring of 2021 (Figure 2.1). Study reservoirs were selected based on recommendations by personnel from AZGFD and University of Arizona's School of Natural Resources and the Environment (UA SNRE).

Alamo Lake is located in western Arizona, just north of Wenden in La Paz County. It was created in 1968 after the completion of the Alamo Dam which impounds runoff from the Bill Williams River (Fullmouth & D'Amico 2019). Flood control and water storage were the main purposes for the reservoir (Fullmouth & D'Amico 2019). The lake has an approximate surface area of 1,490 ha and a surface elevation of 343 m (Fullmouth & D'Amico 2019). Alamo Lake's fish species include Largemouth Bass *Micropterus salmoides*, Black Crappie *Promoxis nigromaculatus,* Channel Catfish *Ictalurus punctatus*, Bluegill *Lepomis macrochirus,* Redear Sunfish *L. microlophus,* Green Sunfish *L. cyanellus*, Blue Tilapia *Oreochromis aureus*, Common

Carp *Cyprinus carpio*, Yellow Bullhead *Ameiurus natalis*, and Threadfin Shad *Dorosoma petenense* (Fullmouth & D'Amico 2019).

Apache Lake is located in central Arizona, northeast of Phoenix in Maricopa County. Apache Lake was formed in 1927 after the completion of the Horse Mesa Dam on the Salt River (Gill 2020). The lake has an approximate surface area of 1,080 ha, 67 km of shoreline, and a surface elevation of 580 m (Gill 2020, USFS 2020). Fish species of Apache Lake include Largemouth Bass, Smallmouth Bass *Micropterus dolomieu,* Flathead Catfish *Pylodictis olivaris,* Rainbow Trout *Oncorhynchus mykiss,* Walleye *Sander vitreus,* Yellow Bass *Morone mississippiensis,* Gizzard Shad *Dorosoma cepedianum,* Bigmouth Buffalo *Ictiobus cyprinellus,* Smallmouth Buffalo *I. bubalus,* Black Buffalo *I. niger*, Bluegill, Channel Catfish, Readear Sunfish, Green Sunfish, and Common Carp (Gill 2020, USFS 2020).

Bartlett Lake is located in central Arizona, northeast of Phoenix in Maricopa County. Bartlett Lake was formed in 1939 after the completion of Bartlett Dam, the first dam built on the Verde River (Gill 2019a). Bartlett Lake covers 1,137 ha when full, has 53 km of shoreline, and a surface elevation of 490 m (Gill 2019a). Fish species of the lake include Largemouth Bass, Smallmouth Bass, Black Crappie, Channel Catfish, Flathead Catfish, Common Carp, Threadfin Shad, Bluegill, and Green Sunfish (Gill 2019a). Since the lake is fed by the Verde River, native fish including Desert Sucker *Catostomus clarki,* Sonoran Sucker *Catostomus insignus,* Roundtail Chub *Gila robusta,* Razorback Sucker *Xyrauchen texanus*, and Colorado Pikeminnow *Ptychocheilus lucius* can be present but are rarely caught (Gill 2019a).

Lake Pleasant is located in central Arizona, northwest of Phoenix in Maricopa County. Filled in 1994 after the completion of the New Waddell Dam in 1992, Lake Pleasant is a water storage reservoir that is primarily filled from the Colorado River by Central Arizona Project

(CAP) canals (Gill & Jones 2019). Lake Pleasant covers 4034 ha, has 183 km of shoreline, and an approximate surface elevation of 503 m (Gill 2019b). Fish species of the lake include Largemouth Bass, Striped Bass *Morone saxatilis*, White Bass *Morone chrysops*, Flathead Catfish, Channel Catfish, Common Carp, Threadfin Shad, Gizzard Shad, Green Sunfish, Bluegill, Redear Sunfish, Tilapia *Tilapia spp.,* White Crappie, and Black Crappie (Gill & Jones 2019).

Roosevelt Lake is located in central Arizona, northeast of Phoenix in Maricopa County. Roosevelt Lake was formed in 1911 after the completed construction of Theodore Roosevelt Dam and is the upper most and largest lake of the four Salt River reservoirs (Gill 2019b). At full capacity the lake covers 8880 ha, has 146 km of shoreline, and a surface elevation of 390 m (Gill 2019b). Fish species of Roosevelt Lake include Largemouth Bass, Smallmouth Bass, Black Crappie, Bluegill, Flathead Catfish, Channel Catfish, Yellow Bass, Threadfin Shad, Gizzard Shad, Bluegill, Green Sunfish, Bigmouth Buffalo*,* Smallmouth Buffalo*,* Black Buffalo, and Common Carp (Gill 2019b).

Electrofishing Comparison Field Methods

Differences among catch per unit effort (CPUE) of different species among three different types of boat operations were tested: a continuous 600 s pedal-down transect parallel to shore (hereafter referred to as “continuous parallel”); an intermittent 10 s on 10 s off 600 s pedal-down transect parallel to shore (hereafter referred to as “intermittent parallel”); and 600 s pedal down transect with multiple arcs (apex 6-12m from shore) applying power only when incoming to shore/cover (hereafter referred to as “arc intermittent”; Figure 2.2).

Timing of lake sampling followed the AFS *Standard Methods* (Miranda & Boxrucker 2009) and Arizona Protocol (Bryan et al. 2004) for warmwater reservoirs (first week of March through the last week of April 2021). However, due to equipment malfunctions, sampling had to be extended into the second week of May. Six stations, each containing three transects using different methods (parallel continuous, parallel intermittent, or arc intermittent) were randomly selected in each reservoir. Only two stations were sampled in Bartlett and five stations in Alamo due to boat mechanical issues. At each station, the three transects were sampled consecutively, the order being chosen randomly. Two stations were sampled each night over three successive nights. This design was chosen to test each method in a similar habitat. Electrofishing transects were sampled in consistent direction (counterclockwise or clockwise) for each lake.

Gear for electrofishing included an Coffelt aluminum-hulled electofishing boat, Honda BF50a outboard motor, Smith-Root Apex Control Box, two Smith-Root booms and AUA-6 electrode anode array on each boom. Conductivity of the water was measured at the start of each station. Settings for electrofishing started off at 60 HZ frequency, 200 volts, and a 25% duty cycle pulse DC and were adjusted accordingly to water conductivity to reach the corresponding peak amp goal value according to L. Miranda et al. (unpublished data). Transects started at least 30 min after sunset. Boat speeds were between 1-3 km/h. After each 600 s transect was completed and fish of all sizes and species were processed before being released halfway in the completed transect to better ensure sure fish were not sampled twice.

Analysis

All sizes and species of fish captured were identified, measured (total length in mm), and weighed (g). Total time (pedal-down plus driving time in min) and distance (m) traveled of each transect were also recorded. Analysis was only conducted on widespread and relatively abundant species caught with all three methods (≥15 total fish sampled across all three methods) and for ≥

stock-length fish (Gabelhouse 1984). CPUE data was then multiplied by six to transform CPUE (fish/600 s) to CPUE (fish/h).

Total time (min) per transect and total distance (m of shoreline) per transect for each method was plotted for visual examination and compared. CPUE (fish/h) data vs. method for each species were also plotted to visually examine distributions.

To test for differences among CPUE (fish/h) data for each method a Friedman test was conducted with each station set as blocking factor. A pairwise Wilcoxon signed-rank test was then used to identify methods that differed from each other (Datanovia 2018). *P*-values were adjusted using a Bonferroni multiple testing correction method (*P*-values multiplied by number of comparisons, in this case three).

Catch data for each transect was divided by the distance traveled (m) to get CPUE (fish/m). CPUE (fish/m) data was plotted for visual comparison among the three methods. To test for differences among CPUE (fish/m) for each method a Friedman test (transect group as blocking factor) was also conducted. A pairwise Wilcoxon signed-rank test was then used to identify methods that differed from each other (Datanovia 2018). *P*-values were adjusted using a Bonferroni multiple testing correction method.

To visually compare length frequencies among the three methods an empirical cumulative distribution function (ECDF) was plotted (Ogle 2015). A Kolomogorov-Smirnov (KS) two-sample test was used to test differences of length frequencies among methods. *P*-values were adjusted using a Bonferroni multiple testing correction method.

The process above was repeated for each of the tested species. All tests assumed an α of 0.05. All analysis was done in the computer software R Studio version 1.4.1717 (RStudio 2021).

RESULTS

Time and distance among methods

Time and distance per transect varied by method. It took an average of 11 min per transect to sample a total 600 s pedal-down time for parallel continuous, 21.2 min per transect for arc intermittent, and 23.6 min per transect for parallel intermittent (Figure 2.3). For distance, transects averaged 531.6-m for parallel continuous, 486.4-m for arc intermittent, and 1179.6-m for parallel intermittent (Figure 2.3).

Catch per unit effort (time) per electrofishing method

A total of 3541 fish of 15 species were caught among each of electrofishing methods (arc intermittent, parallel continuous, and parallel intermittent) with 3173 individuals of 8 species (Common Carp, Gizzard Shad, Green Sunfish, Bluegill, Largemouth Bass, Yellow Bass, Channel Catfish, and White Bass) used for analysis using the criteria above (Table 2.1).

There were no significant differences in mean CPUE (fish/hr) among the three methods for Common Carp, Gizzard Shad, Channel Catfish, and White Bass (Table 2.2; Figure 2.4). A post hoc Wilcoxon test showed arc intermittent having a significantly higher CPUE (fish/hr) than parallel continuous methods for Bluegill (P = 0.023) and Yellow Bass (P = 0.017; Table 2.2; Figure 2.4). The post hoc test did not show which methods differed for Green Sunfish (Friedman test P = 0.015). Largemouth Bass showed some evidence of differences between methods (Friedman test P = 0.057) with arc intermittent possibly having higher CPUE (fish/hr) than parallel continuous (P = 0.071).

Catch per unit effort (distance) per method

When comparing CPUE (fish/m) among methods only Channel Catfish and White Bass showed no significant differences (Table 2.3). Gizzard Shad showed some evidence of significant differences between methods (*P* = 0.056) with arc intermittent possibly having higher CPUE (fish/m) than parallel intermittent (*P* = 0.067). Arc intermittent produced a higher CPUE (fish/m) than parallel intermittent for Common Carp (*P* = 0.004), Green Sunfish (*P* = 0.016), Bluegill (*P* = 0.013), Largemouth Bass (*P* >0.001), and Yellow Bass (*P* = 0.026; Table 3; Figure 2.5). Parallel continuous had a higher CPUE (fish/m) than parallel intermittent only for Largemouth Bass (*P* = 0.011; Table 2.3; Figure 2.5). Lastly, arc intermittent produced a higher CPUE (fish/m) than parallel continuous for Bluegill (*P*-value = 0.012) and Yellow Bass (*P*-value = 0.015; Table 2.3; Figure 2.5).

Length frequency comparison among methods

There were no significant differences among length frequencies and method for Common Carp, Green Sunfish, Yellow Bass, Channel Catfish, and White Bass (Table 2.4: Figure 2.6). Gizzard Shad showed significant differences between parallel continuous and parallel intermittent (*P* >0.001) and arc intermittent and parallel intermittent (*P* >0.001). Differences occurred in Bluegill between arc intermittent and parallel intermittent (*P* >0.001), and Largemouth Bass between arc intermittent and parallel continuous (*P* = 0.034; Table 2.4; Figure 2.6). A higher proportion of Gizzard shad between ~ 225 and 400 mm were caught using arc intermittent and parallel continuous than parallel intermittent. More Largemouth Bass between ~ 200 and 400 mm were caught using arc intermittent than parallel continuous. Lastly, a higher percentage of Bluegill between ~ 80 and 200 mm were caught in arc intermittent vs parallel intermittent.

DISCUSSION

This is the first study we know of that attempts to compare and standardize boat electrofishing maneuvers in large, standing, warmwater bodies. Furthermore, it is one of few studies that investigates differences among CPUE and/or length frequencies among different types of electrofishing pedal use/boat operation methods. In the Illinois River, a “scalloped” boat maneuver (similar to arc intermittent method in this study) had a significantly higher CPUE for Silver Carp *Hypophthalmichthys molitri* and Flathead Catfish than their standard sampling protocol while there was no significant difference for 39 other species (Bouska et al. 2017). In small lakes in South Dakota, CPUE between day and night electrofishing for Smallmouth Bass was similar enough that day electrofishing can take place of night electrofishing if visibility is under a certain threshold (Blackwell et al. 2017). Lastly, comparing CPUE between a continuous vs. point electrofishing method in a river floodway system found that CPUE was significantly lower in the continuous vs. the point method and length frequencies of the studied Largemouth Bass were not different between the two (Trumbo et al. 2016). In this study, three common electrofishing methods were compared; a parallel to shore intermittent shocking, a parallel to shore continuous shocking, and an arcing into shore where shocking was administered incoming to shore. These methods were compared by time and distance for each transect as well as CPUE and length frequencies for species caught.

Time and distance among methods

The time and distance it took to complete a transect unsurprisingly depended on the way each method was conducted. If only looking at time and distance constraints for electrofish sampling, parallel continuous, as already recommended in AFS standard methods, may be the best option as it took a short amount of time and distance. If there are no constraints for time but there is for distance, arc intermittent may be advantageous as it took the least amount of distance to complete 600 s of “pedal-down” shock time but did take about double the time to complete a transect compared to parallel continuous. Lastly, if there are no constraints for time and distance, parallel intermittent would be acceptable as it took the most amount of time and distance to complete a transect. Differences between time and distance required among methods should be considered if constraints for sampling time and/or distance exist.

Catch per unit effort (time) per electrofishing method

For four out of the eight species (Common Carp, Gizzard Shad, Channel Catfish, and White Bass) no strong evidence existed that for a given boat operation method, CPUE (fish/hr) differed. These same species also showed no significant differences in CPUE between two different boat electrofishing methods in a large river (Bouska et al. 2017). This suggests that any of the three electrofishing methods in this study give comparable results suitable for sampling these fishes. Green Sunfish did show significant differences among methods, however, which two methods is unknown. Three species (Bluegill, Yellow Bass, and possibly Largemouth Bass) showed differences between two methods – arc intermittent and parallel continuous. The significantly lower CPUE mean for Bluegill and Yellow Bass collected with parallel continuous vs arc intermittent suggest that arc intermittent or parallel intermittent may be better for collecting these two species.

Higher catch rates from arc intermittent may be a result of fish herding and being able to chase these species into land. Also, arc intermittent potentially allows netters three chances to catch the same fish, on the way into shore, at shore, and backing out where parallel continuous and intermittent only allows one chance before the fish is out of reach behind the boat. Lastly, because arc intermittent brings the boat almost perpendicular to shore you can shock all the way into land while the other two methods must stay a certain distance away from shore due to the outboard. These reasons may allow for more fish of certain species e.g. Bluegill, Yellow Bass, and possibly Largemouth Bass to be sampled by arc intermittent.

Catch per unit effort (distance) per method

Catch per unit effort by distance showed six of the eight species (Common Carp, Gizzard Shad, Bluegill, Green Sunfish, Largemouth Bass, and Yellow Bass) differed or almost differed among methods. These six species all had significantly (or almost significantly) higher CPUE (fish/m) for arc intermittent vs parallel intermittent. Channel Catfish and White Bass had small sample sizes (18 and 15) which may be the reason for not showing significances among these methods. Even though parallel intermittent was on average more than double the distance of arc intermittent, it did not catch more fish of these species. This can be attributed to the fact that distance does not equate to the amount of time shocking and change in boat path can bias CPUE (Tyszko et al. 2017). Largemouth Bass also showed significant differences between parallel continuous and parallel intermittent, further solidifying that traveling without sampling does not help catch more fish. Lastly, Bluegill and Yellow Bass again had higher mean CPUE (fish/m) between arc intermittent and parallel continuous and may be attributed to the reasons given above for CPUE (fish/hr) and completing 600 s of shocking in less distance.

McInerny and Cross (2000) and Tyszko et al. (2017) found similarities between CPUE for time and distance due to a consistent boat operation so if a standard sampling protocol calls for electrofishing transects a set distance instead of shocking time, it is important to note in metadata what method is being used. For example, using a parallel continuous method over 500 m results in that whole distance being shocked while using a parallel intermittent only fishes a fraction of that distance. Also, arc intermittent is advantageous in this scenario since you can shock more area in a shorter amount of shoreline distance because of the perpendicular travel (Figure 1).

Length frequency comparison among methods

Length frequencies were similar for each species and method except for Gizzard Shad, Largemouth Bass, and Bluegill. A possible explanation for greater numbers of larger fish caught in arc intermittent is pushing bigger fish from deeper water to shore. Larger Gizzard Shad, Largemouth Bass, and Bluegill are probably not as close to shore as smaller ones. Bouska et al. (2017) had a similar finding collecting more Silver Carp between ~ 450 and 725 mm using their "scalloped" method vs. their standard (similar to parallel continuous in this study). Fisheries managers should recognize the differences in length frequencies among methods with regards to management goals.

CONCLUSION

The ease of electrofishing makes it an appealing sampling method by fisheries biologist and managers. Due to it being a common method, varying operating procedures, in addition to electrofishing settings, are often used while employing it in the field. This study tested three of these possible operating procedures and compared their CPUE (fish/hr and fish/m) and length frequencies. This study suggests that any boat maneuver/pedal combination can be used in large warmwater bodies to electrofish for Common Carp, Gizzard Shad, Green Sunfish, Channel Catfish, and White Bass if using a time-based transect sampling. However, an arc intermittent method may be advantageous for sampling Bluegill, Yellow Bass, and possibly Largemouth Bass in warm standing waters using a time-based transect sampling. When using a distance-based transect sample this study finds that using a parallel intermittent procedure is not recommended due to the low CPUE/hr for almost all the species. Also, using a transect time-based standard may be a better choice than a transect distance-based standard. This is because one can almost use any method when sampling with specific pedal-down time limit, however, one is limited to methods that spend more time pedal-down shocking than traveling with specific distance limit. Lastly, a greater proportion of larger Gizzard Shad, Largemouth Bass, and Bluegill were caught using arc intermittent. These findings show if one is targeting larger fish for these species, the arc intermittent procedure may be best as it may push bigger fish from deeper water or beds (centrarchids) in the spring. However, arc intermittent can put more wear on a boat’s outboard engine from the constant speeding forward then reversing from shore. Overall, using whatever electrofishing method one sees fit for time-based transects should work well and be comparable for general fish surveys of large standing, water containing warmwater species unless targeting certain species and sizes.

TABLE 2.1 – Total and ≥ stock-length fish species caught among three methods of electrofishing over five lakes in Arizona. Species used for analysis are bolded.

Species		Method						Total	
		Arc Intermittent		Parallel Continuous		Parallel Intermittent			
Common Name	Scientific Name	Total	**≥ Stock**	Total	**≥ Stock**	Total	**≥ Stock**	Total	**≥ Stock**
Yellow Bullhead	*Ameiurus natalis*	1	1	1	1			2	2
Common Carp	*Cyprinus carpio*	138	116	70	65	95	87	303	268
Gizzard Shad	*Dorosoma cepedianum*	373	373	248	248	379	379	1000	1000
Threadfin Shad	*Dorosoma petenense*	71		31		40		142	
Smallmouth Buffalo	*Ictiobus bubalus*	1	1					1	1
Largemouth Buffalo	*Ictiobus cyprinellus*			1	1			1	1
Channel Catfish	*Ictalurus punctatus*	17	10	2	2	7	6	26	18
Green Sunfish	*Lepomis cyanellus*	82	82	22	21	21	21	125	124
Bluegill	*Lepomis macrochirus*	298	266	163	148	252	233	713	647
Smallmouth Bass	*Micropterus dolomieu*	2	2					2	2
Largemouth Bass	*Micropterus salmoides*	395	349	288	274	390	352	1073	975
White Bass	*Morone chrysops*	3	3	5	5	7	7	15	15
Yellow Bass	*Morone mississippiensis*	71	71	21	21	35	34	127	126
Black Crappie	*Pomoxis nigromaculatus*	4	4			3	3	7	7
Flathead Catfish	*Pylodictis olivaris*			3	3	1	1	4	4

TABLE 2.2. – Results from Friedman test (transect groups as blocking factor) and Wilcoxon signed-rank test conducted on CPUE (fish/hr) data among three electrofishing methods for eight species. Significant results ($P < 0.05$) are bolded.

Species			Bonferroni Adjusted *P*-values		
Common Name	Scientific Name	Friedman Test *P*-values	Arc Intermittent Vs. Parallel Continuous	Parallel Continuous Vs. Parallel Intermittent	Arc Intermittent Vs. Parallel Intermittent
Common Carp	*Cyprinus carpio*	0.338	0.145	1	0.825
Gizzard Shad	*Dorosoma cepedianum*	0.076	0.239	0.309	1
Channel Catfish	*Ictalurus punctatus*	0.097	0.169	1	0.957
Green Sunfish	*Lepomis cyanellus*	**0.015**	0.116	1	0.089
Bluegill	*Lepomis macrochirus*	**0.034**	**0.023**	0.768	0.774
Largemouth Bass	*Micropterus salmoides*	0.057	0.071	1	1
White Bass	*Morone chrysops*	0.670	1	1	1
Yellow Bass	*Morone mississippiensis*	**0.018**	**0.017**	0.861	0.134

TABLE 2.3. – Results from Friedman test (transect groups as blocking factor) and Wilcoxon signed-rank test conducted on CPUE (fish/m) data among three electrofishing methods for eight species. Significant results ($P < 0.05$) are bolded.

Species			Bonferroni Adjusted *P*-values		
Common Name	Scientific Name	Friedman Test *P*-values	Arc Intermittent Vs. Parallel Continuous	Parallel Continuous Vs. Parallel Intermittent	Arc Intermittent Vs. Parallel Intermittent
Common Carp	*Cyprinus carpio*	**0.005**	0.15	0.202	**0.004**
Gizzard Shad	*Dorosoma cepedianum*	0.055	0.399	1	0.067
Channel Catfish	*Ictalurus punctatus*	0.060	0.126	1	0.321
Green Sunfish	*Lepomis cyanellus*	**0.007**	0.122	0.945	**0.016**
Bluegill	*Lepomis macrochirus*	**0.002**	**0.012**	1	**0.013**
Largemouth Bass	*Micropterus salmoides*	**<0.001**	0.3	**0.011**	**<0.001**
White Bass	*Morone chrysops*	0.670	1	1	1
Yellow Bass	*Morone mississippiensis*	**0.007**	**0.015**	1	**0.026**

TABLE 2.4. – Results from Kolmogorov-Smirnov (KS) test conducted on length frequency data among three electrofishing methods for eight species. Significant results ($P < 0.05$) are bolded.

Species		Bonferroni Adjusted *P*-values		
Common Name	Scientific Name	Arc Intermittent Vs. Parallel Continuous	Parallel Continuous Vs. Parallel Intermittent	Arc Intermittent Vs, Parallel Intermittent
Common Carp	*Cyprinus carpio*	1	1	0.631
Gizzard Shad	*Dorosoma cepedianum*	0.723	**<0.001**	**<0.001**
Channel Catfish	*Ictalurus punctatus*	1	1	1
Green Sunfish	*Lepomis cyanellus*	1	1	1
Bluegill	*Lepomis macrochirus*	1	0.102	**0.007**
Largemouth Bass	*Micropterus salmoides*	**0.035**	1	0.091
White Bass	*Morone chrysops*	1	1	0.143
Yellow Bass	*Morone mississippiensis*	0.499	1	1

FIGURE 2.1. – Electrofishing study sites on five large reservoirs in Arizona; Alamo Lake, Apache Lake, Bartlett Lake, Lake Pleasant, and Roosevelt Lake. Points indicate start and end of each station. White lines indicate course of travel.

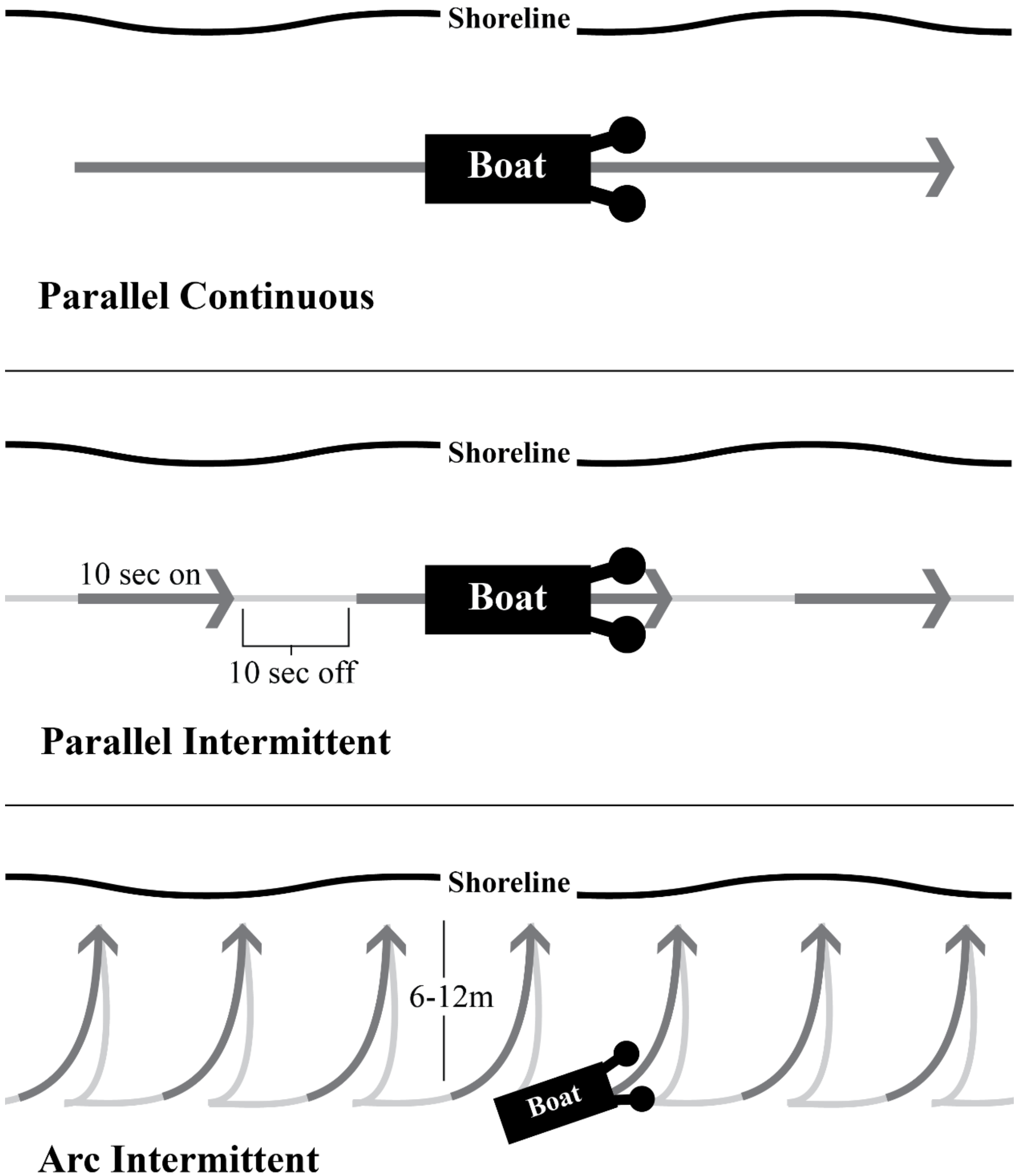

FIGURE 2.2. – Schematic of electrofishing boat procedures for each method type. Dark gray arrows indicate shocking (pedal down) and light gray lines indicate boat maneuver (not shocking).

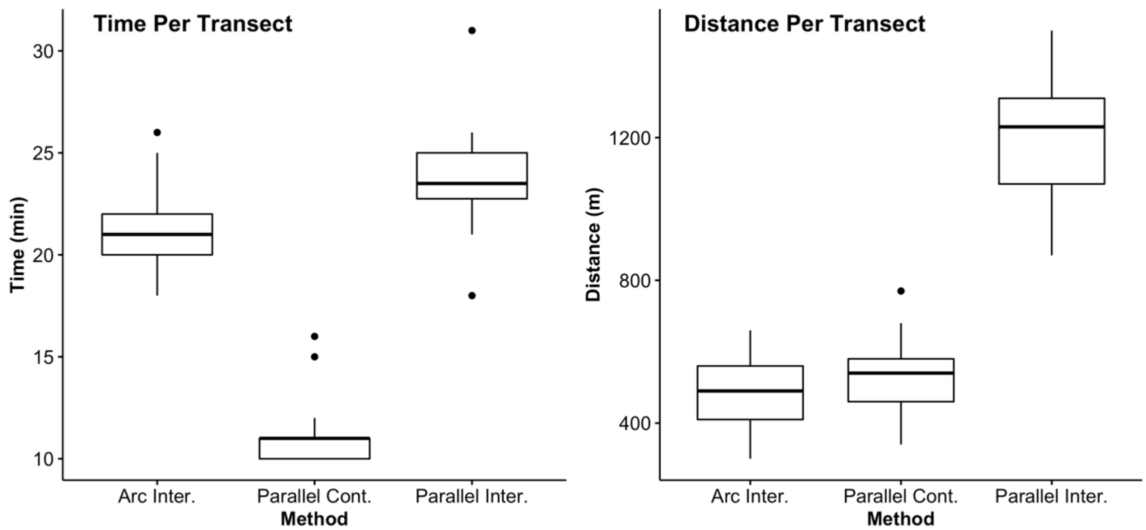

FIGURE 2.3. – Total time used (all boat driving including pedal-down operation) and distance traveled per 600 s pedal-down transect among three electrofishing boat methods.

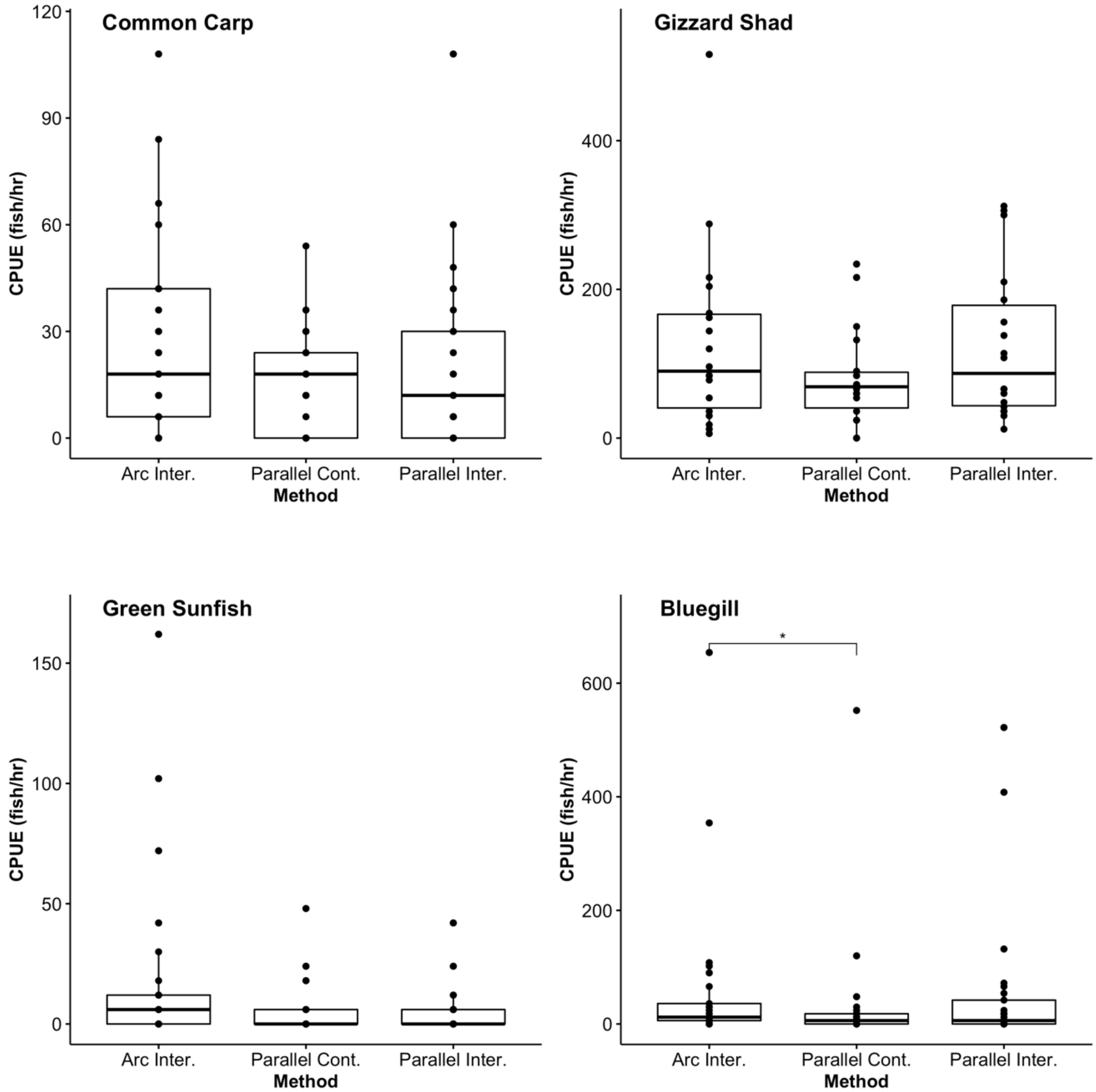

FIGURE 2.4. – Boxplot comparison of CPUE (fish/hr) among fish species and electrofishing method. Asterisks (*) indicate significant differences between methods that are bracketed.

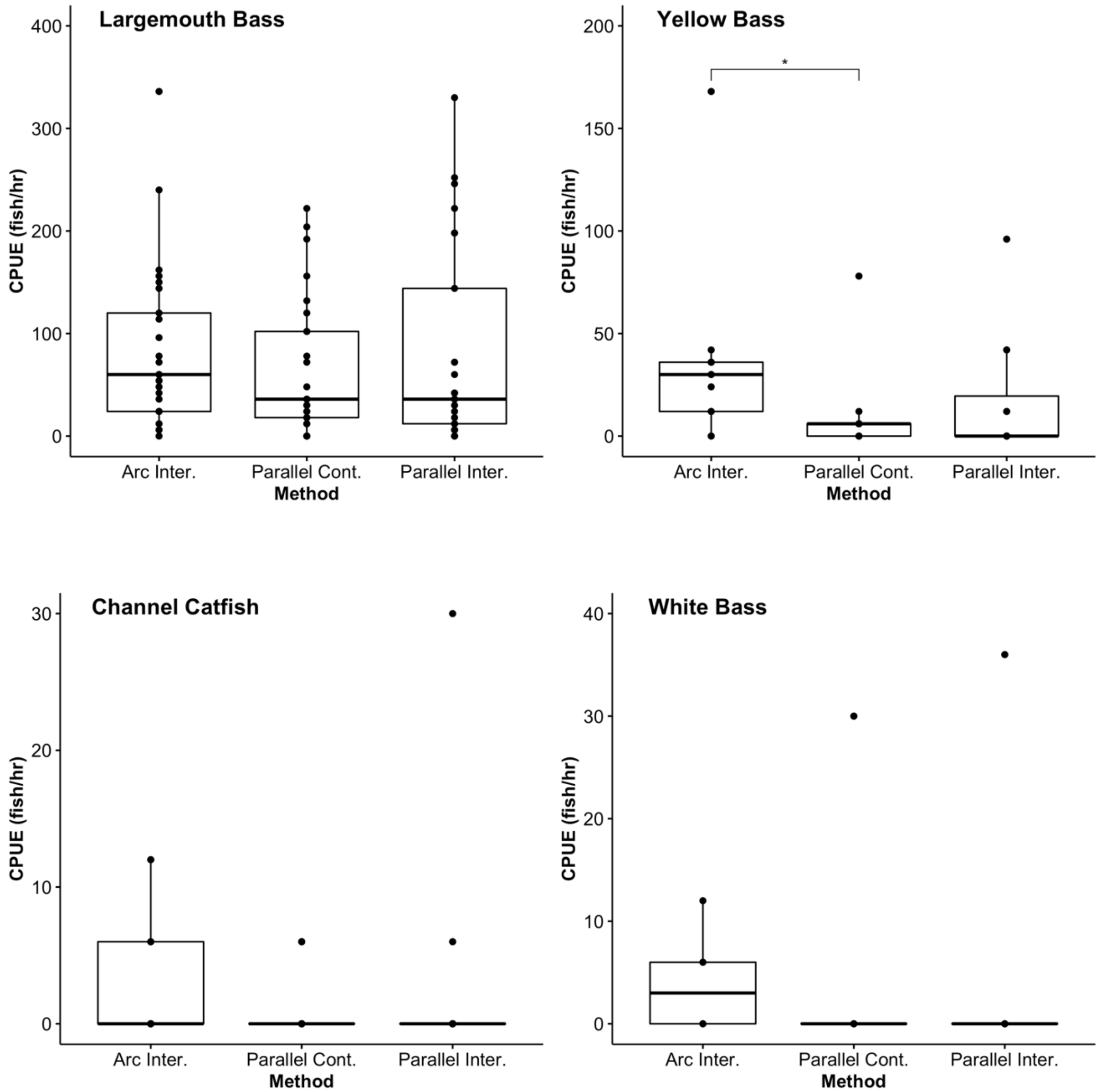

FIGURE 2.4. – Continued.

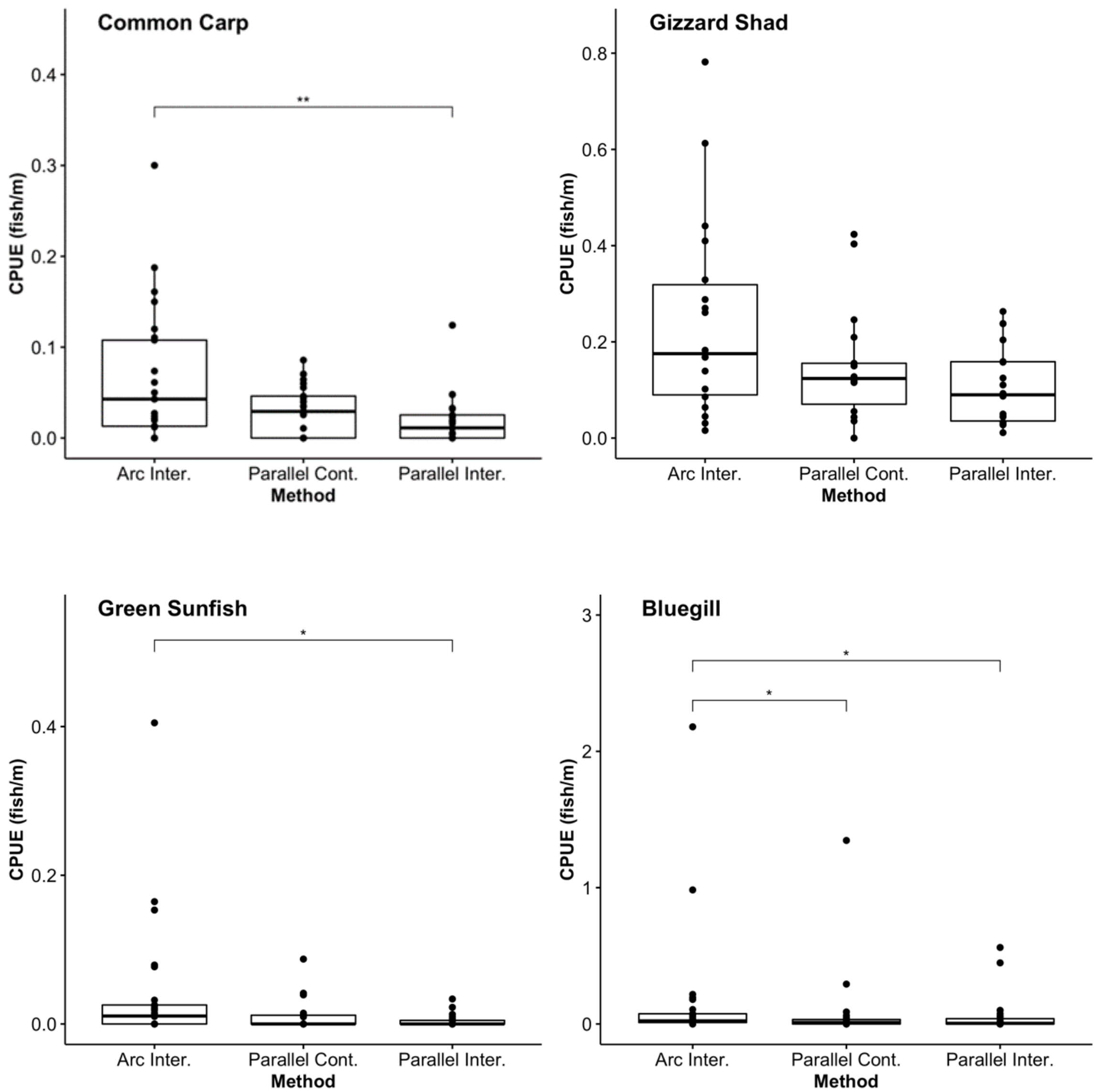

FIGURE 2.5. – Boxplot comparison of CPUE (fish/m) among fish species and electrofishing method. Asterisks (*) indicate significant differences between methods that are bracketed.

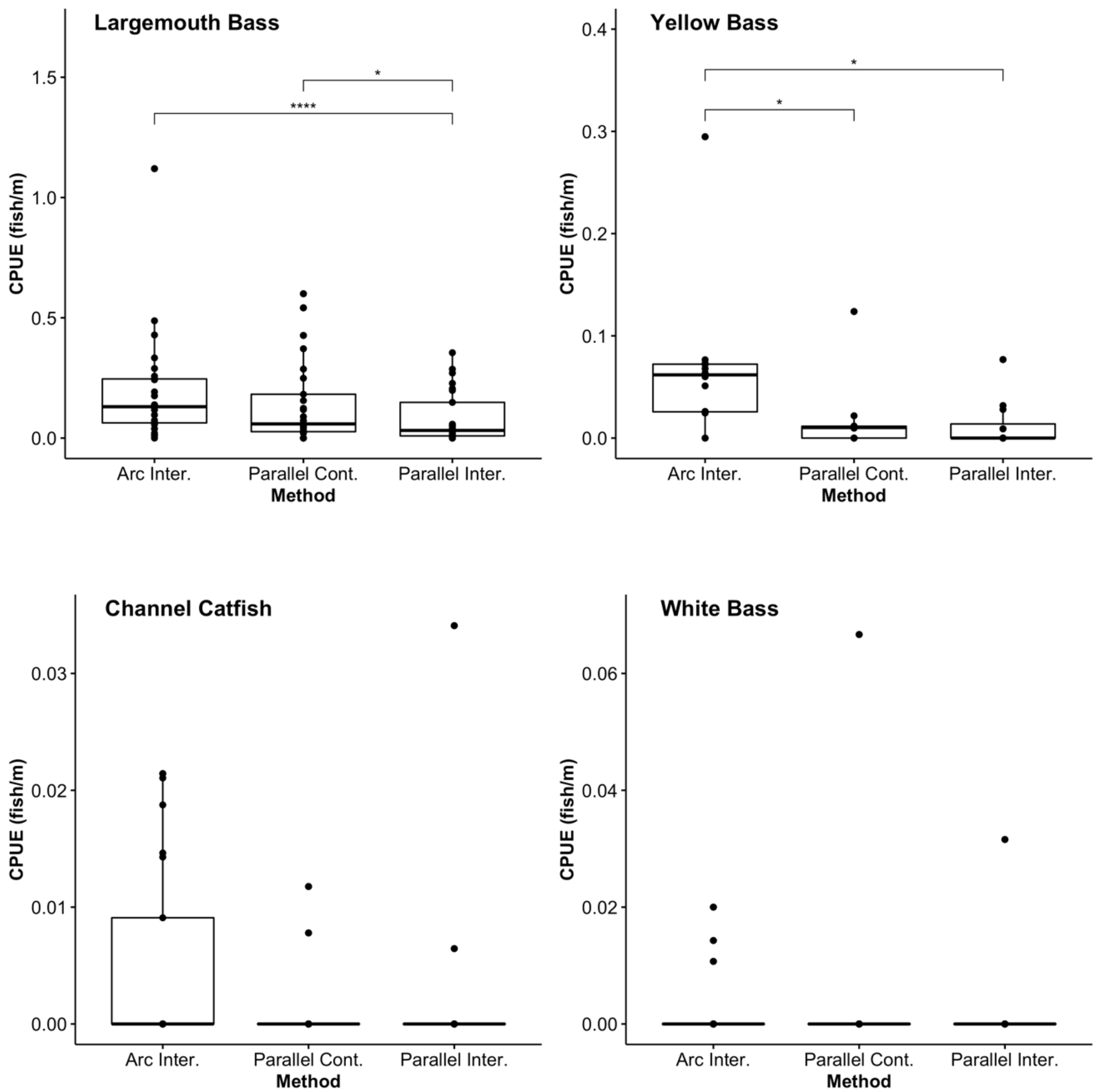

FIGURE 2.5. – Continued.

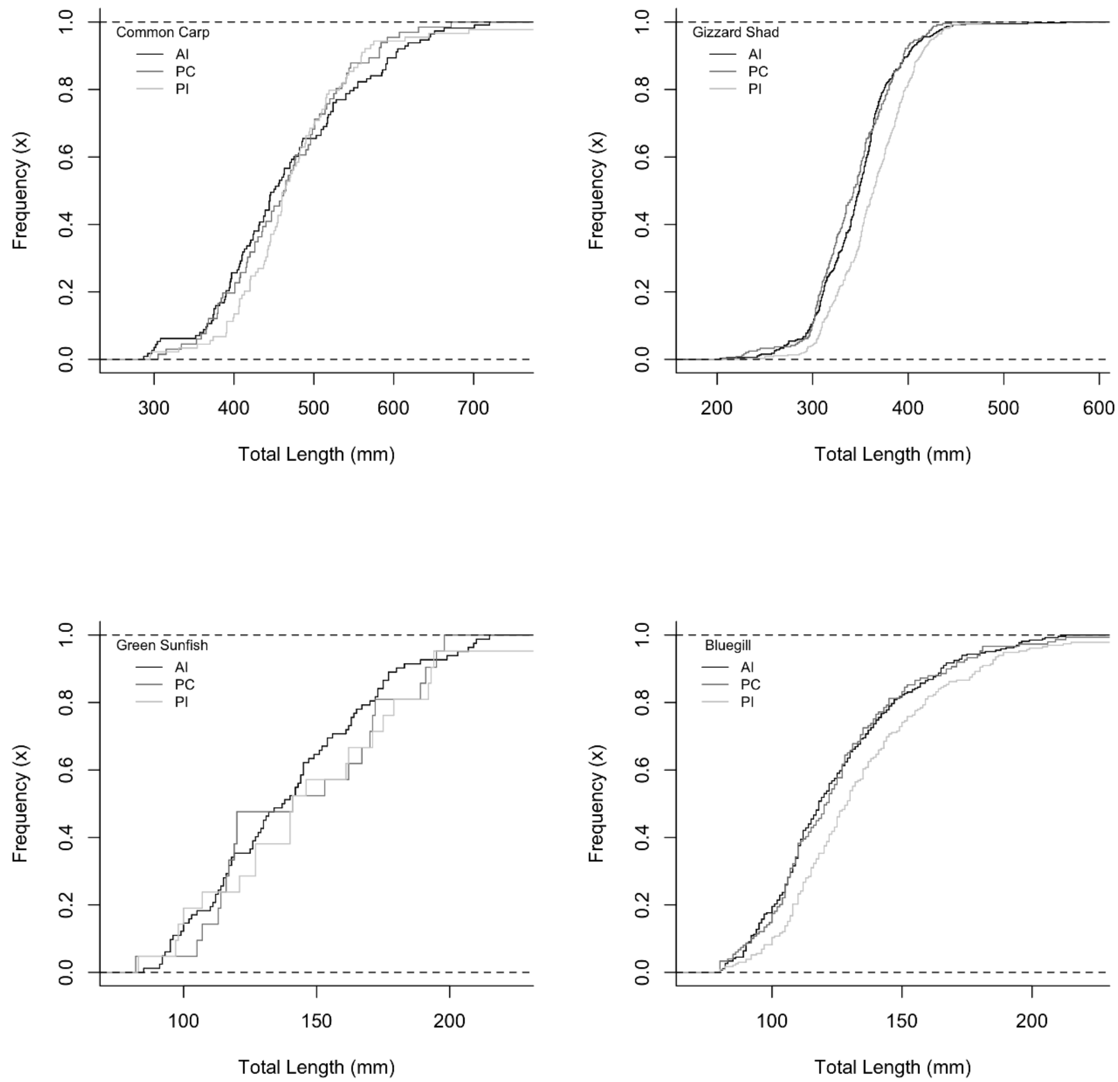

FIGURE 2.6. – Length frequency distribution of species caught among three methods of electrofishing. Black line = arc intermittent, dark grey = parallel continuous, light grey = parallel intermittent.

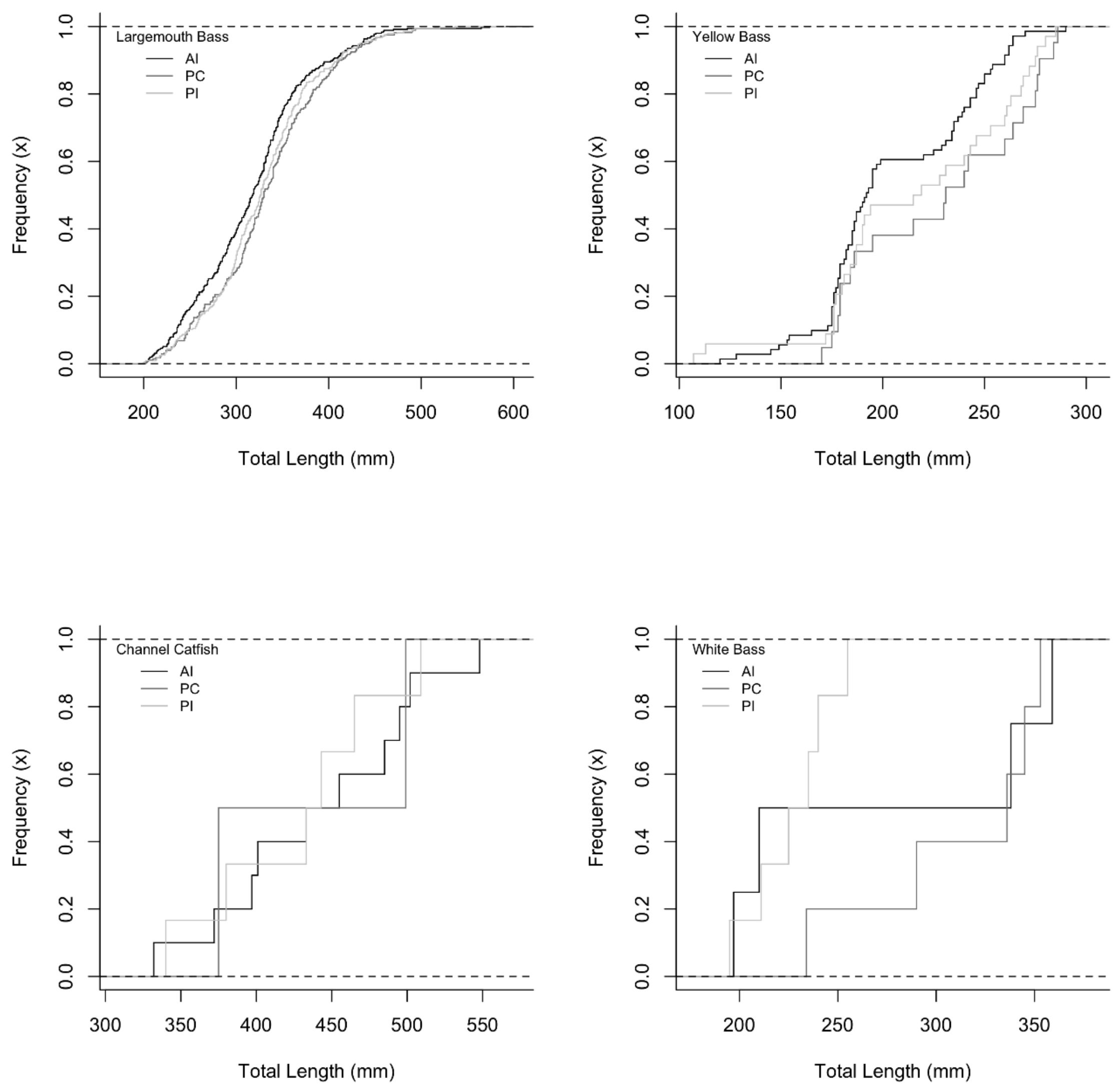

FIGURE 2.6. – Continued.

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