WESTERN ILLINOIS UNIVERSITY

Bigheaded Carp Monitoring and Removal
2018 Report

Geographic Location

Pools 16-20 of the Mississippi River

Participating Agencies

Western Illinois University and Illinois Department of Natural Resources

Statement of Need

Silver carp, bighead carp, and grass carp (bigheaded carp) have spread throughout the Mississippi River basin since their introduction in the 1970's and can be detrimental to native fishes and ecosystems. To limit their impact and further expansion, fishermen have been contracted through state and federal agencies to remove bigheaded carp using predominantly gillnets. Mesh size of entanglement gears, such as gillnets, determines the size structure of fishes able to be captured. To increase efficiency and effectiveness of bigheaded carp harvest and minimize the capture of bycatch, it is important to understand the relationship of gillnet mesh size with the size structure of persistent populations. Bigheaded carp can drive density dependent reductions in their body condition and that of other native species. Detection of a deviation from body condition baselines in bigheaded carp and native species over time can be used as a surrogate to evaluate tools used to reduce bigheaded carp populations.

Project Objectives

1) Remove 100,000-200,000 lbs of bigheaded carp species in the UMR Pools 14-20 using commercial fishermen and intensive netting protocols.
2) Tag and recapture jaw-tagged fish to determine bigheaded carp population abundance through intensive sampling in the UMR Pools 14-20.
3) Acoustically tag and monitor bigheaded carp to assess frequency and timing of fish passage at LD19.
4) Track body condition of bighead carp, silver carp, bigmouth buffalo, smallmouth buffalo, common carp, freshwater drum, and paddlefish over time in Pools 16-19 in the UMR (low-density management zone).
5) To determine the relationship between the size of bigheaded carp and commonly encountered bycatch and the bar mesh size of gillnets that they are captured in.

Project Highlights

- Commercial removal efforts have resulted in 202,556.5 lbs of bigheaded carp removed from 01/01/2018 – 12/31/2018.
- A total of 470 bigheaded carp were jaw-tagged in 2018 (36 bighead carp, 7 hybrid silver x bighead carp, and 427 silver carp in Pools 16-19).
- A total of 37 bigheaded carp with acoustic transmitters were captured in 2018 (8 removed and 29 released).

- Baseline relative weights (Wr) of Silver Carp and Bighead Carp has been established and is much higher than other locations with higher densities
- The size structure of silver carp, black buffalo, bigmouth buffalo, common carp, grass carp, and smallmouth buffalo caught in different sized gillnets is relatively predictable and follows a logical trend

Methods:

Study site

Data were collected in from September 2015 to December 2018 on Pools 16, 17, 18, 19, and 20 of the Upper Mississippi River (UMR). The UMR is classified as the portion of the river above Cairo, Illinois to St. Anthony Falls near Minneapolis, Minnesota. The UMR consists of 29 lock and dams that vary in size and passage capability. The UMR has a drainage basin of 490,000 km^2 and at the mouth has a discharge of 5,796 m^3/s. Pools 16, 17, 18, and 19 of the Mississippi are the border waters between Iowa and Illinois. Pool 16 extends for 41.4 km and occupies an area of 11,630 acres. It extends from lock and dam 15 in Rock Island, IL to lock and dam 16 in Muscatine, IA. Pool 17 extends for 32.3 km and covers 8,137 acres between lock and dams 16 in Muscatine, IA and 17 near New Boston, IL. Pool 18 is 42.8 km long and 11,746 acres. Pool 18 is located between lock and dams 17 near New Boston, IL to lock and dam 18 in Gladstone, IL. Pool 19 extends 74.5 km from lock and dam 18 in Gladstone, IL to lock and dam 19 in Keokuk, IA and covers 30,466 acres.

Sample Collection

Fish were collected using monofilament gillnets provided by Western Illinois University (WIU) biologists and contracted removal effort. Net mesh sizes used were 3, 3.5, 4, 4.25, 4.5, and 5-inch bar gillnets. Gillnets were set in a range of habitats (backwater, side channel, main channel border, and tributaries) areas to target bigheaded carp. Bigheaded carp were located by utilizing side scan sonar, visual cues, and by fishing areas that have had historically high catch rates. The time nets were set and removed were recorded, along with, mesh size, net height, length, color, and twine size. Dissolved oxygen, specific conductivity, and temperature was measured at net locations using a YSI Pro 2030 meter (Yellow Springs, Ohio, USA), and GPS coordinates were taken using a Vemco VR-100 receiver (Bedford, Nova Scotia, Canada). Once set, the nets were either left overnight to fish or a method of driving fish towards the nets to scare them into the nets called “pounding” was employed. Nets were then removed from the area, and fish were removed from the net. Fish collected from nets were identified to species and the number of each species was recorded, weighed to the nearest 10 g, measured to the nearest mm, and the size of mesh they were caught in was recorded. Silver carp, bighead carp, and grass carp (bigheaded carp) were removed from the system and bycatch were released back into the water at capture location.

Statistical analysis

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Population estimates from jaw and acoustic tagged fish were determined using Chapman's population estimates. All tables were created using Microsoft Excel. Catch per unit of effort data of bigheaded carps in 2018 from Pools 14-19 (excluding Pool 15) was performed using Microsoft Excel. Mean, minimum total length (TL), maximum TL, and modal length bins were calculated using Microsoft Excel.

R (version 3.5.1) paired with R studio was used for statistical analysis and data visualization. Data was explored to remove outliers, data entry errors, and determine the shape of the data. Data was only used from September 15-March to minimize variability associated with feeding and spawning behaviors for relative weight (Wr) only. All other analyses used data from January to December with the exception of various weeks due to conditions unacceptable for sampling.

Wr was then calculated based on the standard weight equation for each species that was available. Grass carp and black buffalo could not be included in this analysis because a standard weight equation does not exist for these species.

Wr for a species were compared between years, then between Pools and years. Box plots were then constructed to display the Wr for each species between years, then between Pools. An Analysis of Variance (ANOVA) was then run between years to determine if there was a statistically significant difference (α=.05). A Tukey's Post Hoc test (α=.05) was then ran to determine where the difference between the years within each Pool lied.

Results and Discussion

Population Estimates Using Jaw Tagging

A total of 1,455 bigheaded carp have been jaw tagged from 2015-2018. There were 470 bigheaded carp (36 bighead, 7 hybrids, and 427 silver carp) jaw tagged in March 2018 with a combined 53 recaptures in Pools 17-19 on the UMR (Table 1). There have been a combined 223 recaptured from all bigheaded carp species from 2015-2018 in Pools 17-20. Using 2017 recapture data, Pool 19 bighead and silver carp populations are estimated to be 38,832 ± 20,056. Pool 18 has a much lower estimation of 3,876 ± 1,989 and Pool 17 population was estimated at 18,384 ± 11,928 silver and bighead carp.

Recapture data from jaw tags has been limited in estimating populations due to low recapture success. Grass carp have been unsuccessful in recapturing and capture success of hybrid silver x bighead carp is relatively low above LD19. 2018 boasted higher capture and tagging numbers than previous years (2015-2017) for silver carp. We did not tag any grass carp in 2016-2018 and focused mostly on silver and bighead carp. In 2017, we had more bighead carp tagged and captured than the other sampling years. Fidelity to areas where fish are tagged has the potential to bias estimates. The value of jaw tags [JND1]

Table 1: Total number of jaw tags placed in four species of bigheaded carp from 2015-2018 in Pools 17-20 of the UMR. Data is presented as captured/recaptured.

	2015				**2016**				**2017**	**2018**		
Species/Pool	**17**	**18**	**19**	**20**	**17**	**18**	**19**	**20**	18	17	18	19

Silver Carp	24/6	17/5	299/66	1,781/14	51/3	10/3	82/11	308/1	6/1	37/16	51/18	339/12
Bighead Carp	8/4	2/0	19/6	96/3	20/6	40/13	46/8	99/1	2/1	3/1	0	33/4
HYBRID	0	1/0	5/2	56/0	3/0	6/2	13/2	20/1	0	3/2	0	4/0
Grass Carp	22/0	22/4	292/16	52/1	0	0	0	0	0	0	0	0

Contracted Commercial Removal

During the 2018 sampling season, efforts were higher in Pool 19 and decreased as sampling moved upstream. Silver carp were the most abundant of the bigheaded carp species that were captured and removed. A total of 5,591 silver carp were removed from Pools 16-19 for a combined weight of 98,185.1 pounds. Grass carp were the next highest catch rates with 2,294 individuals harvested equaling 64,704.4 pounds from Pools 16-19. Bighead carp from Pool 14 and 16-19 totaled 840 fish captured with a combined removal weight of 26,227.5 pounds. There were 39 F_1 silver x bighead carp hybrid individuals removed weighing 512.4 pounds. There were 12,927.3 lbs of undiscerned bighead, silver, and grass carp. The total 2018 commercial removal efforts were 202,556.5 pounds from Pools 14 and 16-19 on the UMR (Table 2, 3).

Pool 18 contained the largest average weights of bighead carp at 38 pounds, while silver carp were on average larger in Pool 16 at 26.6 pounds. Grass carp had an average weight of 24.6 pounds from Pool 17. Overall bigheaded carp on average weigh the most in Pool 16 followed by Pools 18, 19, and 17. Pool 14 was calculated, but does not have any conclusive information because there was a sample size of 2 bighead carp captured throughout the 2018 field season (Table 2).

Increased contracted commercial efforts have been successful in removing large quantities of biomass annually from the ecosystem in this more recently invaded management zone. As contracted fishing moves upstream from Pool 19, the total CPUE decreases during 2018, signifying that Pool 19 is a key focal point for removing pressure from upstream movement and contains the highest densities (Figure 1). 2018 had substantially more numbers of total bigheaded carp removed (8,764) than previous years with 2017 being the next highest year (4,533). The total removed weight follows the same trend of 2018 being the highest (202,556.2 lb) and 2017 having nearly half the weight at 105,553.6 lb. Signifying that 2018 has been the most successful year to date for commercial efforts on the UMR and showcases the benefit of adding additional fishermen to increase harvest efforts. This effort is further supported by better prediction tools aided by our FWS and USGS partners and using telemetry data to help guide our efforts.

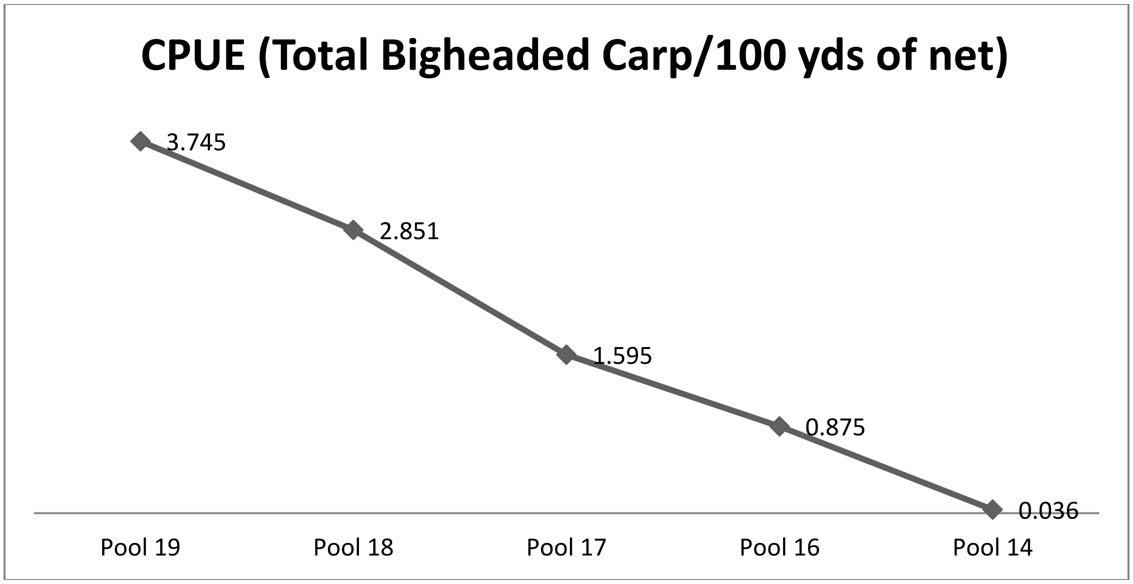

Figure 1: Catch per unit effort for bigheaded carp contracted commercial removal using gill nets by reach in 2018.

Table 2: Total bigheaded carp gill netting effort in Pools 16-19 of the Mississippi River in 2018.

2018	Pool 19	Pool 18	Pool 17	Pool 16	Pool 14	Total
Netting Effort						
Total Yards of Net	141000	69800	59800	61500	5600	337700
Catch Effort						
Total AC (N)	5280	1990	954	538	2	8764
Total AC Weight (lb)	97155.4	42526	13083.1	17753.2	63.4	170581.1
Average AC Weight (lb)	18.4	21.4	13,7	33	31.7	104.5
Total BHCP (N)	346	270	150	72	2	840
Total BHCP Weight (lb)	8680.7	10268.1	5147.3	2068	63.4	26227.5
Average BHCP Weight (lb)	25.1	38	34.3	28.7	31.7	157.8
Total SVCP (N)	3569	1044	640	338	0	5591
Total SVCP Weight (lb)	56965.3	19150.3	13083.1	8986.4	0	98185.1
Average SVCP Weight (lb)	16	18.3	20.4	26.6	0	81.3
Total HYBRID (N)	26	2	8	3	0	39
Total HYBRID Weight (lb)	332	65.6	56.2	58.4	0	512.2
Average HYBRID Weight (lb)	12.8	32.8	7	19.5	0	72.1
Total GSCP (N)	1339	674	156	125	0	2294
Total GSCP Weight (lb)	31177.5	13042	3844.6	1640.4	0	49704.5
Average GSCP Weight (lb)	23.3	19.4	24.6	13.1	0	80.4
Catch per unit of effort						

CPUE (BHCP/100 yds of net)	0.245	0.387	0.251	0.117	0.036	1.036
CPUE (SVCP/100 yds of net)	2.531	1.496	1.07	0.55	0	5.647
CPUE (HYBRID/100 yds of net)	0.018	0.003	0.013	0.005	0	0.039
CPUE (GSCP/100 yds of net)	0.95	0.966	0.261	0.203	0	2.38
CPUE (Total AC/100 yds of net)	3.745	2.851	1.595	0.875	0.036	9.102

Table 2: Total number of bigheaded carp captured using gill nets in in 2015-2018 in Pools 14-20 of the Upper Mississippi River.

Year	Pool	Bighead Carp	Silver Carp	Hybrid Carp	Grass Carp	Total
2015	17	8	24	0	22	54
	18	2	17	1	22	42
	19	19	299	5	292	615
	20	92	1689	56	45	1882
2016	16	8	0	0	0	8
	17	42	121	4	58	225
	18	135	44	9	82	270
	19	174	1547	31	373	2125
	20	110	436	2	8	556
2017	16	84	137	6	170	397
	17	100	568	4	113	785
	18	178	552	4	134	868
	19	140	1164	11	604	1919
	20	104	446	4	10	564
2018	14	2	0	0	0	2
	16	72	338	3	125	538
	17	150	640	8	156	954
	18	270	1044	2	674	1990
	19	346	3569	26	1339	5280
Total		2036	12635	176	4227	19074

Table 3: Total weight of bigheaded carp removed from Pools 14 and 16-20 on the UMR.

	Total Weights (LBS)				
Species	**2015**	**2016**	**2017**	**2018**	**Total**
Bighead Carp	242.3	21505.5	17835.2	26227.5	65810.2
Silver Carp	1168	43415	38863.8	98185.1	181631.8
Hybrid Carp	0	1683	415.4	512.4	2610.7
Grass Carp	192.3	13547.9	19972	64704.4	98416.4
Mixed Bulk Weights	0	0	28467.4	12927.3	41394.7
Total	1602.6	80151	105553.6	202556.5	389863.8

Table 4: Total bycatch species captured using gill nets from Pools 14-20 of the Mississppi River in 2015-2018.

	2015		**2016**					**2017**						**2018**					
Pool	**17**	**19**	**16**	**17**	**18**	**19**	**20**	**14**	**15**	**16**	**17**	**18**	**19**	**14**	**15**	**16**	**17**	**18**	**19**
Family/Species																			
Acipenseridae																			
Lake Sturgeon								1		1				1					
Amiidae																			
Bowfin					2	2	3						3			1	1	6	8
Catostomidae																			
Bigmouth Buffalo	15	64	20	152	282	420	3	2		213	973	846	759	2		471	627	625	646
Black Buffalo			12	36	36	174	5	3		210	127	61	639	3		202	168	142	380
Golden Redhorse																	1		
Highfin Carpsucker												2							
Quillback					15	8				2		235							
River Carpsucker	2	14		17	8	76				12	2	95	48			28	12	19	83
Shorthead Redhorse						2						2							
Smallmouth Buffalo	5	14		62	11	240	8	1		1,800	761	304	411		1	379	183	149	432
White Sucker												1							
Centrarchidae																			
Black Crappie												3							
Largemouth Bass		1				3	2				1	1						4	3
White Crappie							1					7	6			1	1		2
Clupeidae																			

Gizzard Shad		4			75	7				5		2,592	5			2	4	5	1
Cyprinidae																			
Common Carp	40	43	42	67	301	1,106	16	3	2	138	362	493	1,261	3	2	297	360	1,190	1,869
Hiodontidae																			
Mooneye													3			2	1	2	8
Ictaluridae																			
Channel Catfish	1			5	3	55				7	1	5	24			7	9	23	57
Flathead Catfish					1	3				7	14	7	23			29	36	36	13
Lepisosteidae																13	64		
Longnose Gar		21	3	16		14				5	6	2	16				48	3	42
Shortnose Gar		37	1	3	3	28					8	3	21			5	14	7	83
Moronidae																			
Striped x White Bass	1										2	31					5	9	9
White Bass	1				1	4					2	451					1	4	
Yellow Bass					1							2							
Sciaenidae																			
Freshwater Drum	49	19	5	145	90	143	1	3		60	292	291	365	3		117	473	476	725
Esocidae																			
Northern Pike			1	2	5	11				5	2	3	19			14	13	9	27
Polyodontidae																			
Paddlefish	5		18	574	65	435		66		249	1,238	176	437	66		360	1,073	536	853
Percidae																			
Sauger										1						1		2	
Walleye	3				1											13	2	5	1
Total	122	217	102	1,079	898	2,729	36	79	2	2,715	3,791	5,613	4,040	78	3	1,942	3,096	3,252	5,242

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Acoustic Monitoring

Using a VR-100 receiver with an omni-directional hydrophone, 45 detections of acoustically tagged bigheaded carp were detected at least once during 2018. There were 3 additional bigheaded carp that were detected twice with hydrophones. A total of 8 acoustically tagged bigheaded carp were removed from 29 fish that were captured from Pools 16-19 in 2018 (Table 16).

During an intensive harvest effort on April 11, 2018 in Big Timber backwater refuge in Pool 17, we recaptured 12 acoustically tagged bigheaded carp. Stationary and portable hydrophones detected 23 total carp within the backwater that day. Using 4 contracted commercial fishing crews, there were 332 (54% reduction) carp captured. There was an estimated population lower limit of 196 (30% reduction) bigheaded carp and an upper limit of 599 (91% reduction) carp within Big Timber.

The combination of extended efforts of commercial removal crews along with acoustic telemetry data can provide great opportunities at removing congregated schools of bigheaded carp and help determine population estimates based on tag captures. Increasing acoustically transmitted bigheaded carp and stationary real-time receivers could benefit during increased removal events and help establish better population estimates in the UMR.

Table 5: Top: number of acoustic tags that were detected in 2017 and 2018 in Pools 16-19 of the Upper Mississippi River. Some tags were detected twice within that reach in the same year Bottom: number of acoustic tags captured in 2017 and 2018 in Pools 16-19 of the Upper Mississippi River. The number of fishes that were released or kept are listed below the catch number.

VR100 acoustic tag detections								
	2017				**2018**			
Number of detections	**16**	**17**	**18**	**19**	**16**	**17**	**18**	**19**
1:	2	15	3	2	19	9	5	12
2:		4	1	1	1			2

Acoustic tags captured				
2017	**2018**			
16	**16**	**17**	**18**	**19**
4	2	18	13	7
3 release 1 kept	1 release 1 kept	15 release 3 kept	10 release 3 kept	3 release 1 kept

Relative Weight of 7 Common Species Caught During Commercial Efforts

Bighead Carp

Bighead carp show an increase in Wr from 2015 to 2016 then a slight decrease in Wr in the following years (figure 2). A statistically significant difference was detected with the

ANOVA ($p=0.002$) and the Tukey's test determined that the significant difference occurred between 2015 and 2016 ($p=0.003$), 2015 and 2017 ($p\leq0.001$), and 2015 and 2018 ($p=0.024$).

In Pool 16 there is only one year of data that fits this time frame (figure 3). Pool 17 does not have data available for 2016. Wr seems to have dropped significantly from 2015 to 2017, then Wr increases again in 2018 (figure 3). A statistically significant difference was detected with the ANOVA ($p=0.002$) and the Tukey's test determined that the significant difference occurred between 2015 and 2017 ($p=0.003$), and 2017 and 2018 ($p=0.034$). In Pool 18 there is limited data for 2015. Wr seems to be steady in Pool 18 through the years as seen in figure 3. The ANOVA indicated that there was no significant difference between years ($p=0.734$). In Pool 19 it can be seen in figure 3 that there seems to be a decrease in 2015 and 2017, but there is an increase in 2018. However, the ANOVA indicates that there is no significant difference between the years ($p=0.725$).

There is a low amount of data associated with bighead carp, this is because there are far fewer of this species than other bigheaded carp that are captured using gill nets. More data is needed to analyze the effects of bigheaded carp in the UMR.

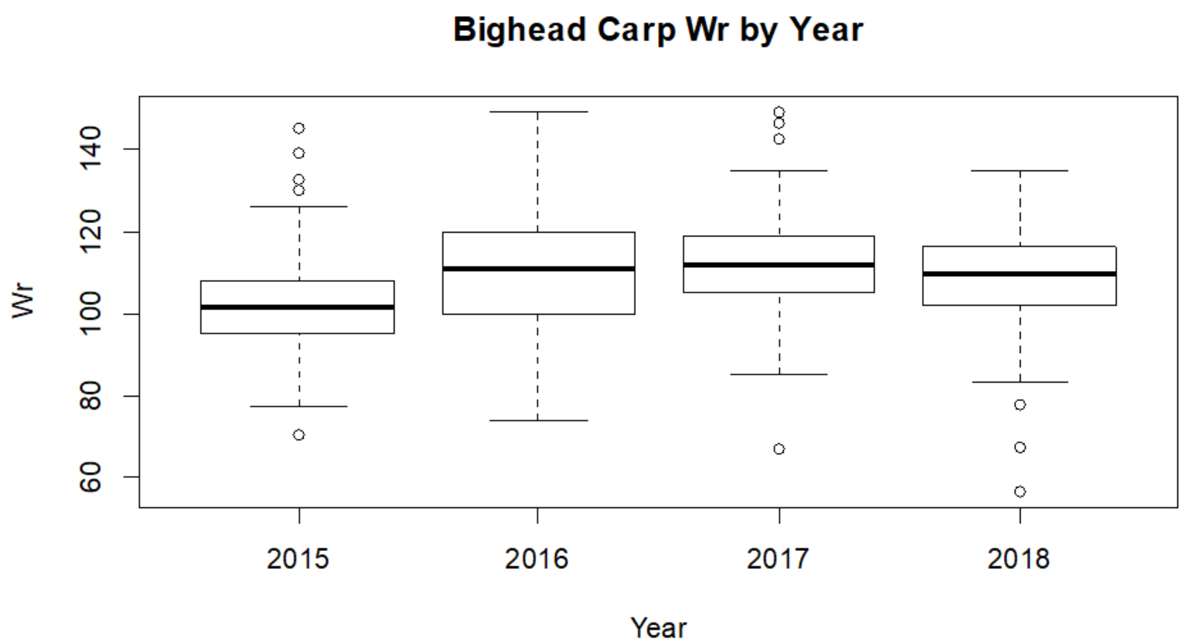


Figure 2: Bighead carp Wr by year in Pools 16-20 of the Mississippi River

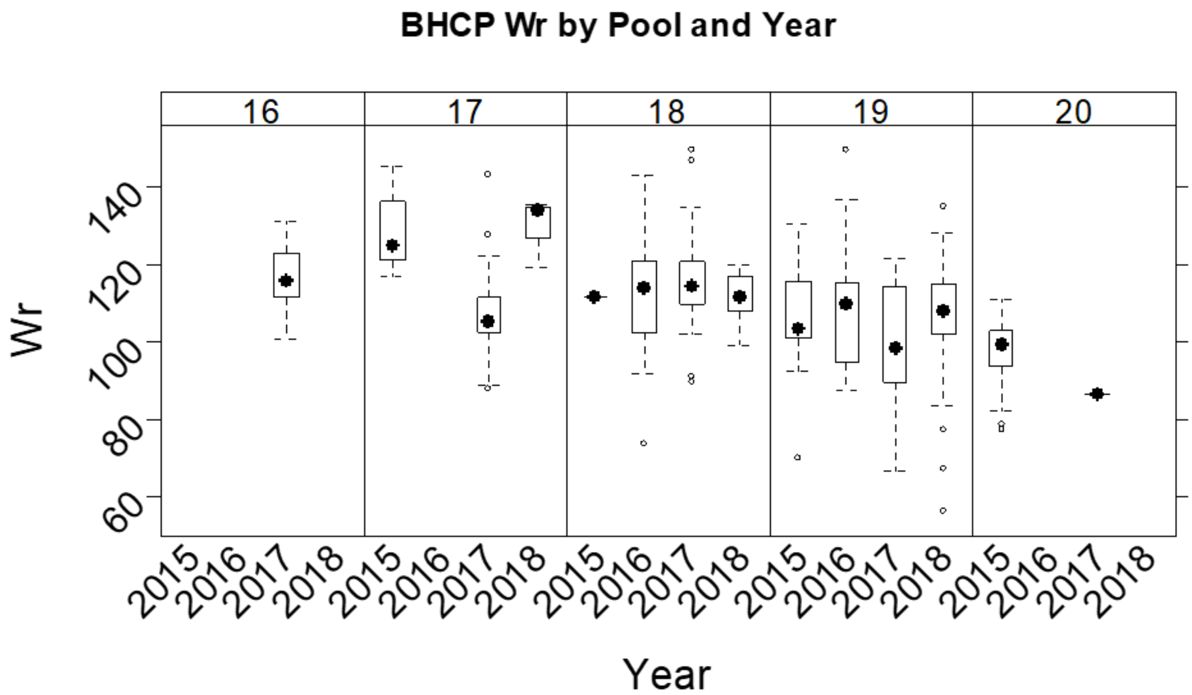


Figure 3: Bighead carp Wr in by Pool and year

Silver Carp

When data is combined by Pool then separated by year, silver carp showed a decrease in Wr from 2015 to 2016 then an increase since 2016 (figure 4). Apart from 2015 and 2017 (p=0.069) all years had significantly different Wr. All p values except the one mentioned above were lower than 0.05.

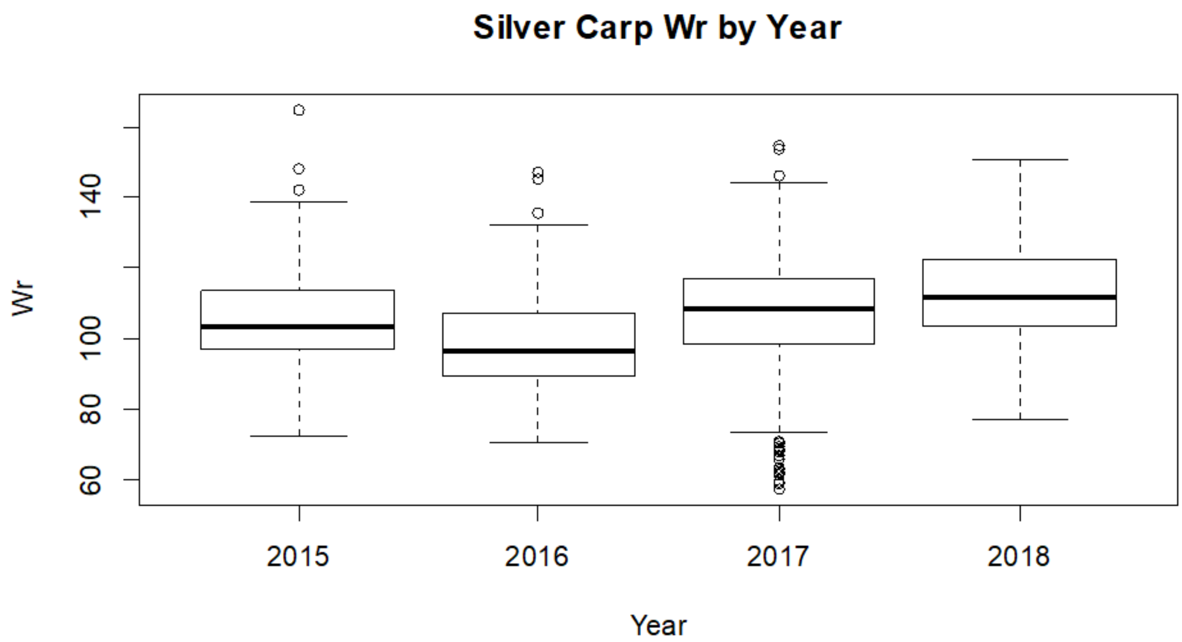
In Pool 16 between years there is only data for 2017 and 2018 available. As seen in figure 5 there seems to be a decreasing trend in terms of silver carp Wr. The ANOVA (p=0.004) and the Post Hoc Tukey's (p=0.004) confirmed this difference is significant.

In Pool 17 there is no data for the selected time period in 2016. In figure 5 it can be observed that there is an increasing trend between years. This trend was only statistically significant in between 2017 and 2018 where the ANOVA showed significance (p=0.008) and the Post Hoc Tukey's test yielded a p value of 0.006. The other differences seen in the data were not statistically significant.

In Pool 18 there seems to be a decreasing trend between 2015 and 2017, but then an increasing trend in Wr in 2018 (figure 5). This trend was only significant in two places, the first being between 2015 and 2017 (p=0.01) showing a statistically significant drop in Wr. The next is between 2017 and 2018 (p≤0.001) where there is a statistically significant increase in Wr.

Pool 19 showed a drop in Wr from 2015 to 2016 but then an increasing trend in Wr since 2016. The difference between 2015 and 2016, 2016 and 2017, 2016 and 2018, and 2017 and 2018 are all significant (p≤0.001). This shows that there has been a significant increase in Wr every year since 2016.

Data is lacking in several areas of this data set. To continue to monitor Wr data must be taken diligently and at appropriate times. Continued collections are needed to continue to monitor bigheaded carp Wr and the effects they have on other species.



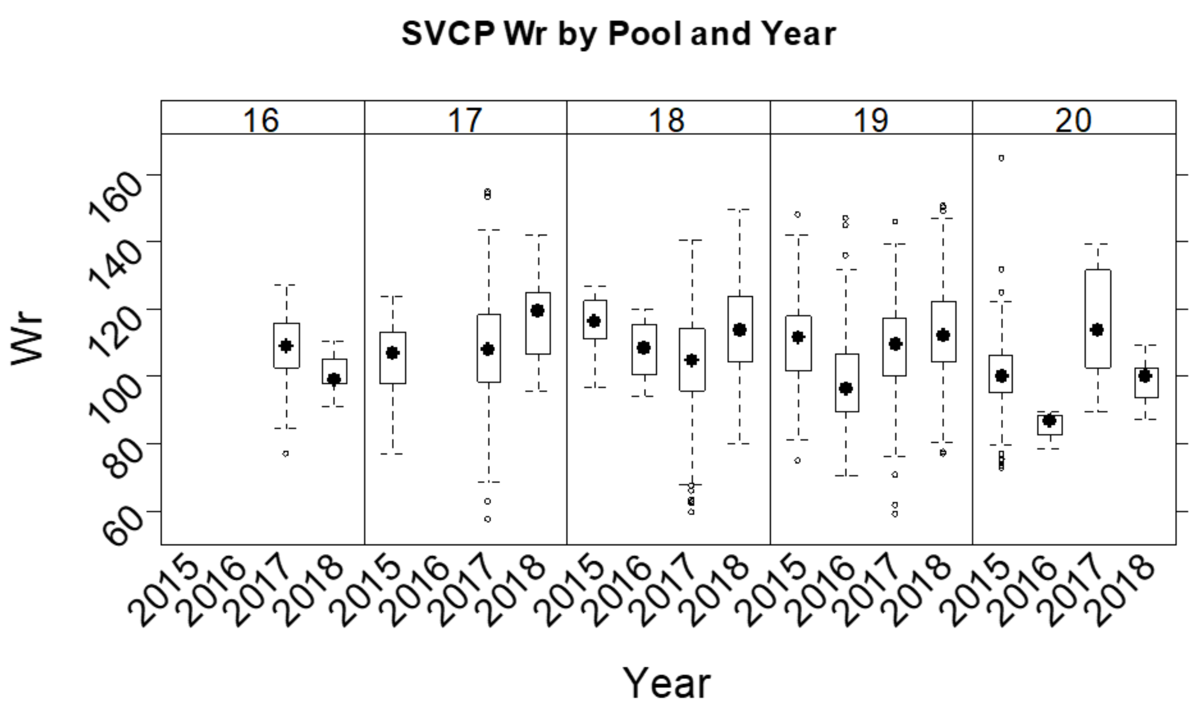


Figure 5: Silver carp Wr in by Pool and year

Bigmouth Buffalo

When all data is combined bigmouth buffalo have showed relatively stable Wr throughout all years of sampling (figure 6). There was only a significant difference between 2017 and 2018 ($p=0.033$) and it was an overall increase in Wr.

In Pool 16 there is only data available for 2017 and 2018, there does appear to be an increase in the Wr of fish from 2017 to 2018 (figure 7), but 2018 is higher than 2017. There was a significant difference shown in the ANOVA ($p=0.005$) and the Post Hoc Tukey's test ($p=0.005$) meaning that Wr in 2018 is significantly higher than the Wr in 2017.

In Pool 17 the Wr of bigmouth buffalo starts low in 2015 then increases to its highest point in 2016 and appears to have a downward trend since 2016 (figure 7). The ANOVA indicated that there was a significant difference in the data ($p\leq0.001$), and the Post Hoc Tukey's test showed that there was a significant difference between 2015 and 2016, and 2015 and 2017 ($p\leq0.001$).

In Pool 18 there is no data available for 2015. Throughout 2016, 2017, and 2018 Wr appears to be stable (figure 7). The ANOVA showed that here was no significant difference between any of the years in Pool 18 ($p=0.208$).

In Pool 19 Wr is stable for 2015-2017 with an increase in Wr in 2018 (figure 7). The ANOVA ($p=0.01$) and Post Hoc Tukey's test ($p=0.006$) indicated a difference between 2017 and 2018 ($p=0.006$) where 2018 is significantly higher.

To continue to monitor Wr data must be taken diligently and at appropriate times. Continued collections are needed to continue to monitor bigheaded carp Wr and the effects they have on other species.

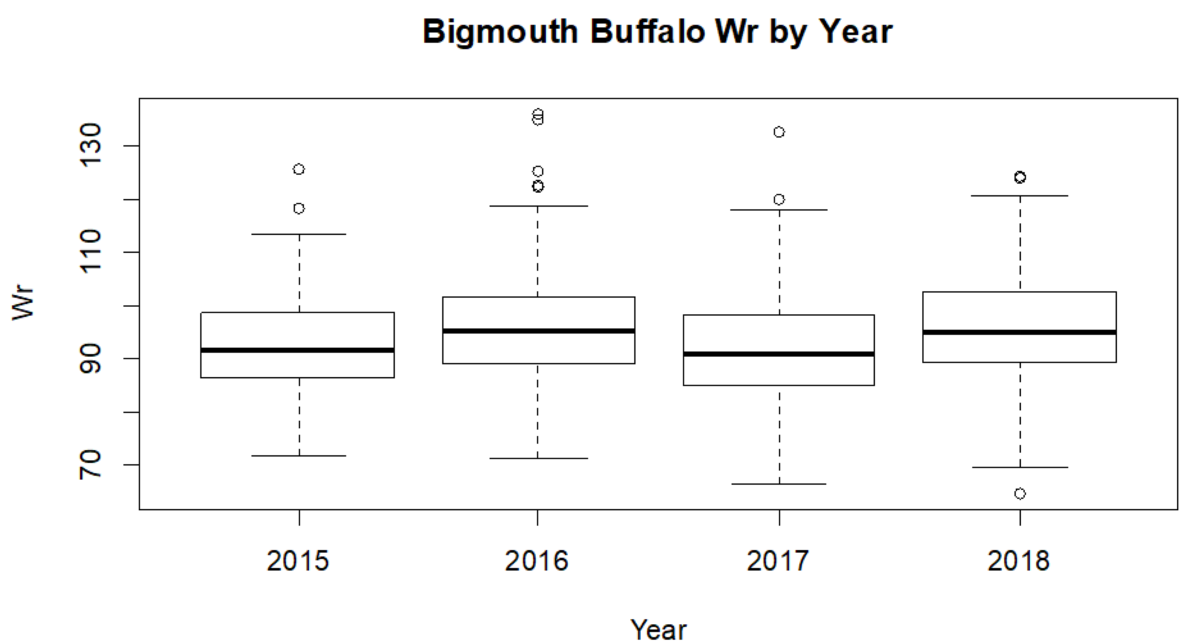


Figure 6: Bigmouth Buffalo Wr combined Pools by year

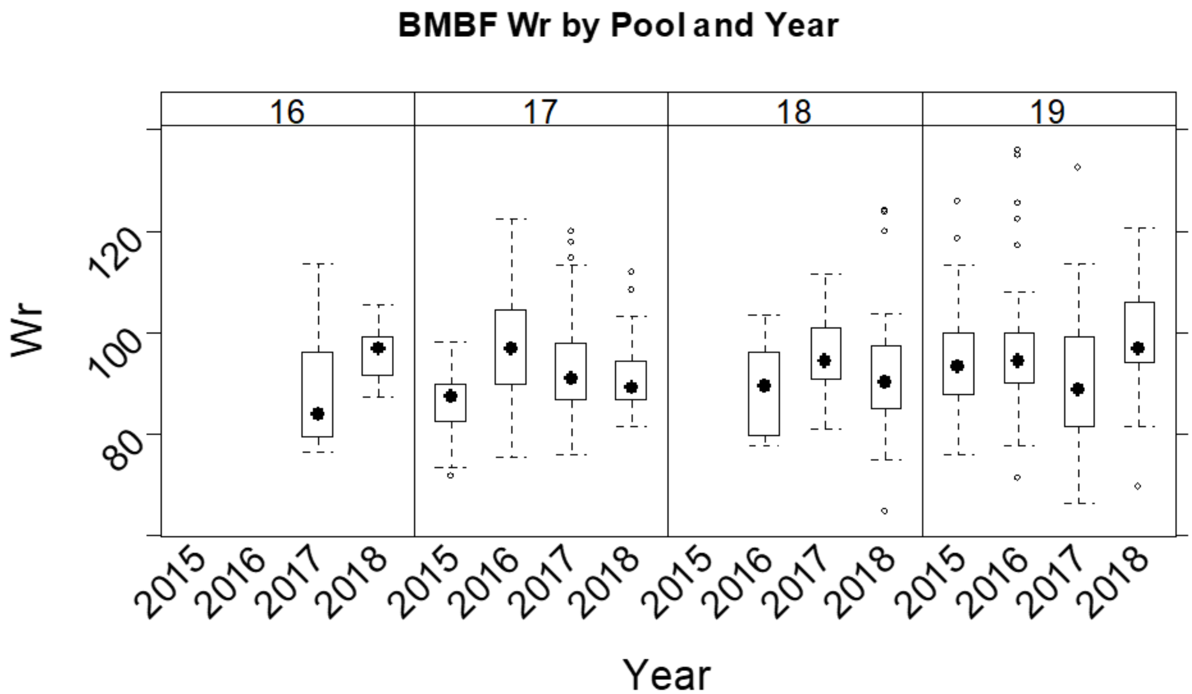


Figure 7: Bigmouth Buffalo Wr by Pool and year

Smallmouth Buffalo

When all Pool data is combined and split between years it appears that smallmouth buffalo Wr is stable throughout the years (figure 8) the ANOVA test confirmed that there are no statistically significant differences between years (p=0.095).

In Pool 16 there is no data for 2015 or 2016. In 2017 and 2018 the Wr of smallmouth buffalo is stable as seen in figure 8 and confirmed by the ANOVA (p=0.565). The Wr in Pool 16 for each year is below Wr 100 which means they are below the 75th percentile for the species.

In Pool 17 there is no data in this time period for 2018. The Wr is low in 2015 and increases in 2016 but then drops in 2017 (figure 9), however, there is no statistical significance to these differences as shown by the ANOVA (p=0.082).

In Pool 18 there is no data for 2015 in this time period. The Wr in Pool 18 appears to be stable (figure 9), however, Wr is low in all years with an average around 85. There are no statistically significant differences in between years for Pool 18 shown by the ANOVA (p=0.285).

In Pool 19, 2015, 2016, and 2018 appear to have similar Wr values, however, 2017 appears to be much lower than all 3 years (figure 9). The ANOVA test indicated that there was a difference (p=0.006) somewhere in the data. The Post Hoc Tukey’s test showed that 2017 was significantly different from 2016 (p=0.04) and 2018 (p=0.003).

To continue to monitor Wr data has to be taken diligently and at appropriate times. Continued collections are needed to continue to monitor bigheaded carp Wr and the effects they have on other species.

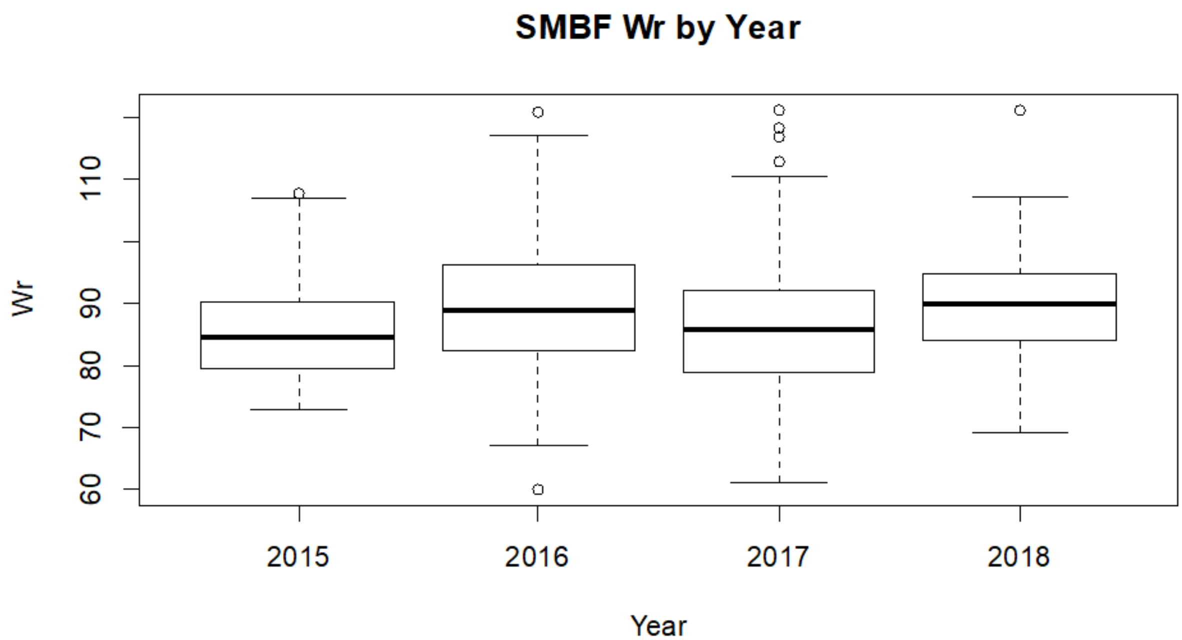


Figure 8: Smallmouth Buffalo Wr combined Pools by year

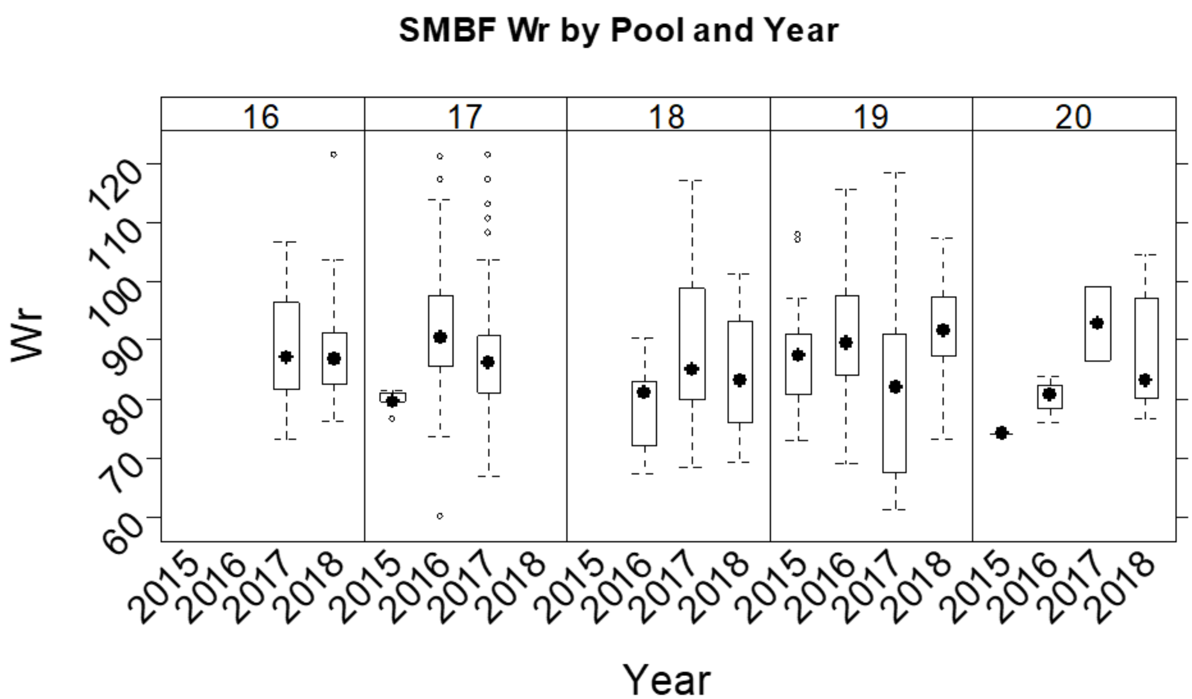


Figure 9: Smallmouth Buffalo Wr by Pool and year

Common Carp

When all Pool data is combined and separated by year Wr appears to be stable across years (figure 10), however, the ANOVA indicated a significant difference ($p \leq 0.001$) between the years. The Post Hoc Tukey's test indicates that there is a significant difference between 2015 and 2016 ($p=0.018$), 2015 and 2017 ($p=0.041$), 2016 and 2017 ($p \leq 0.001$), and 2017 and 2018 ($p \leq 0.001$).

For common carp in Pool 16 there are only 2 years of data 2017, and 2018. When plotted Wr in 2018 appears to be higher than Wr in 2017 (figure 11). The ANOVA ($p=0.018$) and the Post Hoc Tukey's test ($p=0.018$) indicated that these two years are significantly different from each other.

In Pool 17 Wr for common carp is stable throughout the years, this is shown in figure 11 as well as in the ANOVA where no statistically significant differences were detected ($p=0.523$).

There is no data for common carp in Pool 18 during 2015. Wr for common carp in Pool 18 between 2016 and 2018 is stable, this is shown by figure 11 and the ANOVA test which showed no significant differences between years ($p=0.083$).

In Pool 19 Wr appears to increase for 2015 to 2016, then decrease in 2017, then increase in 2018 again (figure 11). The ANOVA showed that there was a significant difference in this data ($p \leq 0.001$). The Post Hoc Tukey's test showed three spots were the differences within years was significant. The differences were significant between 2015 and 2017 ($p=0.008$) where Wr decreases, 2016 and 2017 ($p \leq 0.001$) where Wr decreased, and 2017 and 2018 ($p \leq 0.001$) where Wr increased.

To continue to monitor Wr data has to be taken diligently and at appropriate times. Continued collections are needed to continue to monitor bigheaded carp Wr and the effects they have on other species

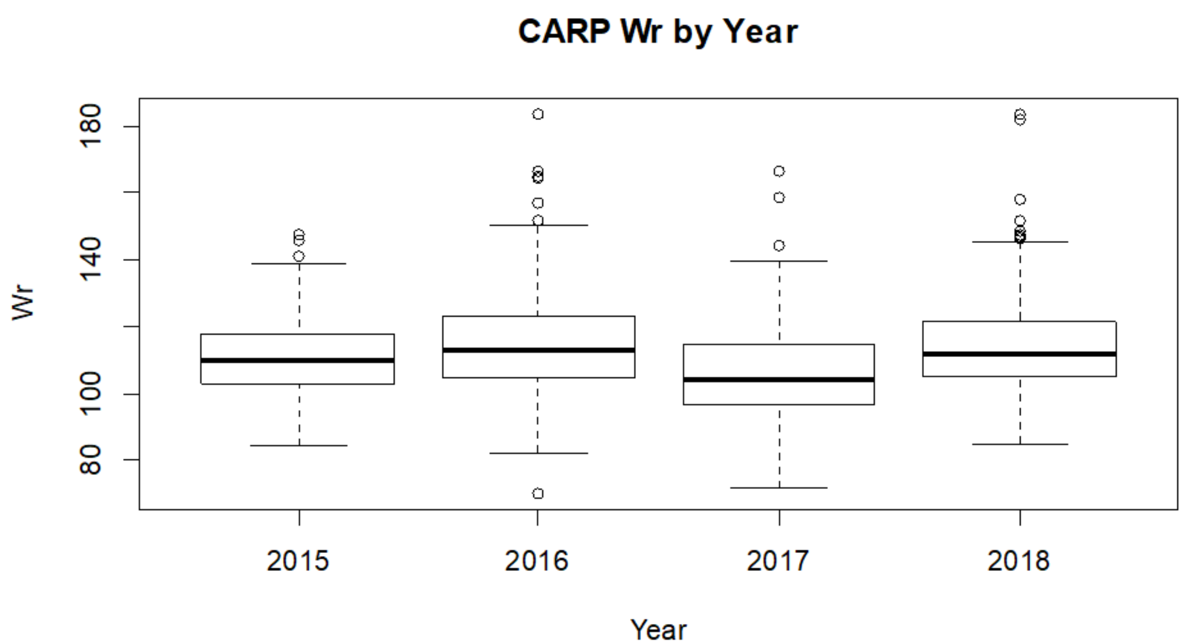


Figure 10: Common Carp Wr combined Pools by year

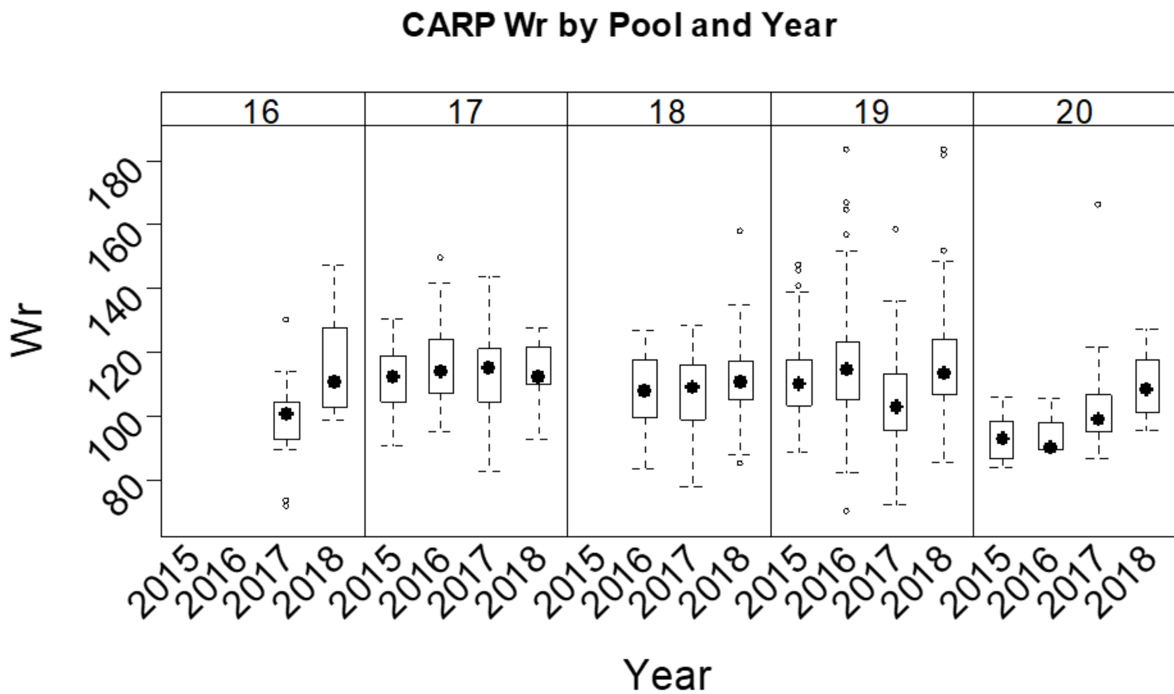


Figure 11: Common Carp Wr Pool and year

Freshwater Drum

When all Pool data is combined and split between years it appears that freshwater drum Wr is stable in 2015 and 2016, there is then a slight drop in 2017 but Wr goes up in 2018 (figure 12). The ANOVA indicates there is a significant difference in the data ($p \leq 0.001$). The Post Hoc Tukey's test indicates a significant difference between 2016 and 2018 ($p=0.011$), and 2017 and 2018 ($p \leq 0.001$).

In Pool 16 there is only data for 2017 and 2018. Between 2017 and 2018 Wr seems to be very similar to one another (figure 13) and the ANOVA confirms there is no significant difference ($p=0.994$).

Figure 13 shows Wr for 2015-2018 in Pool 17, Wr increases slightly from 2015 to 2016 then drops in 2017 and 2018. The ANOVA indicates significance ($p=0.008$), the only significant difference between years detected in the Post Hoc Tukey's test is between 2015 and 2018 ($p=0.040$), and 2016 and 2018 ($p=0.021$).

In Pool 18 there is no data available from 2015. From 2016 to 2017 there is a drop in Wr, and from 2017 to 2018 there is an increase in Wr (figure 13). The ANOVA indicates there is a significant difference in the data ($p \leq 0.001$). The Post Hoc Tukey's test shows there is a significant difference between 2016 and 2017 ($p \leq 0.001$), and 2017 and 2018 ($p \leq 0.001$).

Freshwater drum Wr in Pool 19 from 2015 to 2018 appears to be steady (figure 13). The ANOVA showed no significant differences in the data, meaning that Wr's for freshwater drum have remained steady in Pool 19 through the years.

To continue to monitor Wr data has to be taken diligently and at appropriate times. Continued collections are needed to continue to monitor bigheaded carp Wr and the effects they have on other species.

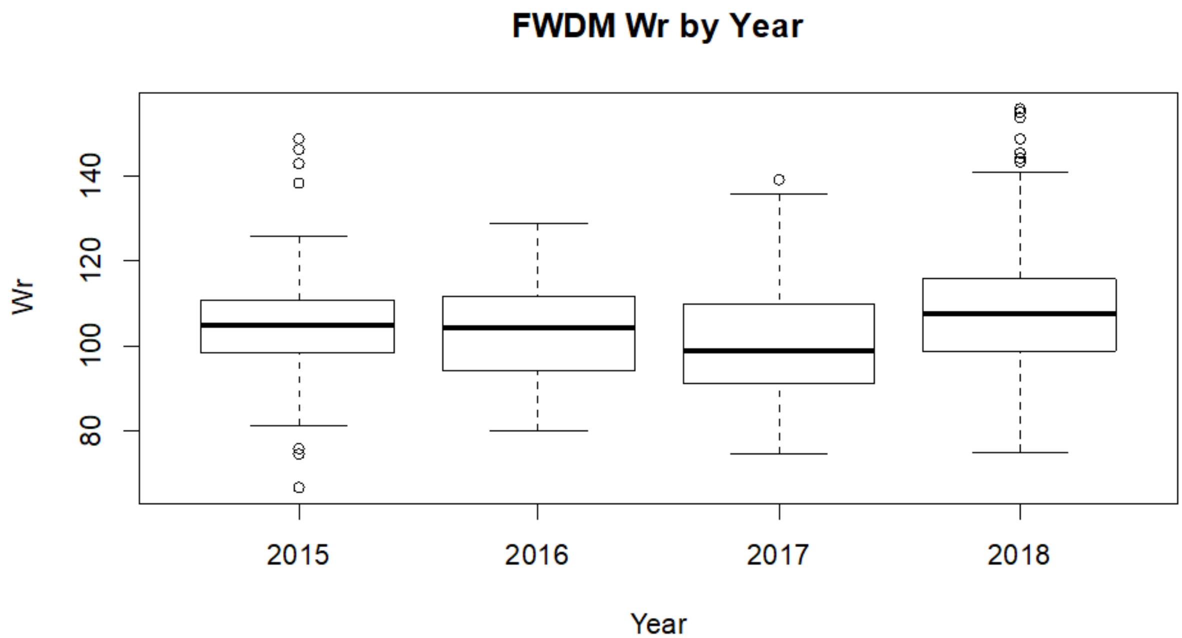


Figure 12: Freshwater Drum Wr combined Pools by year

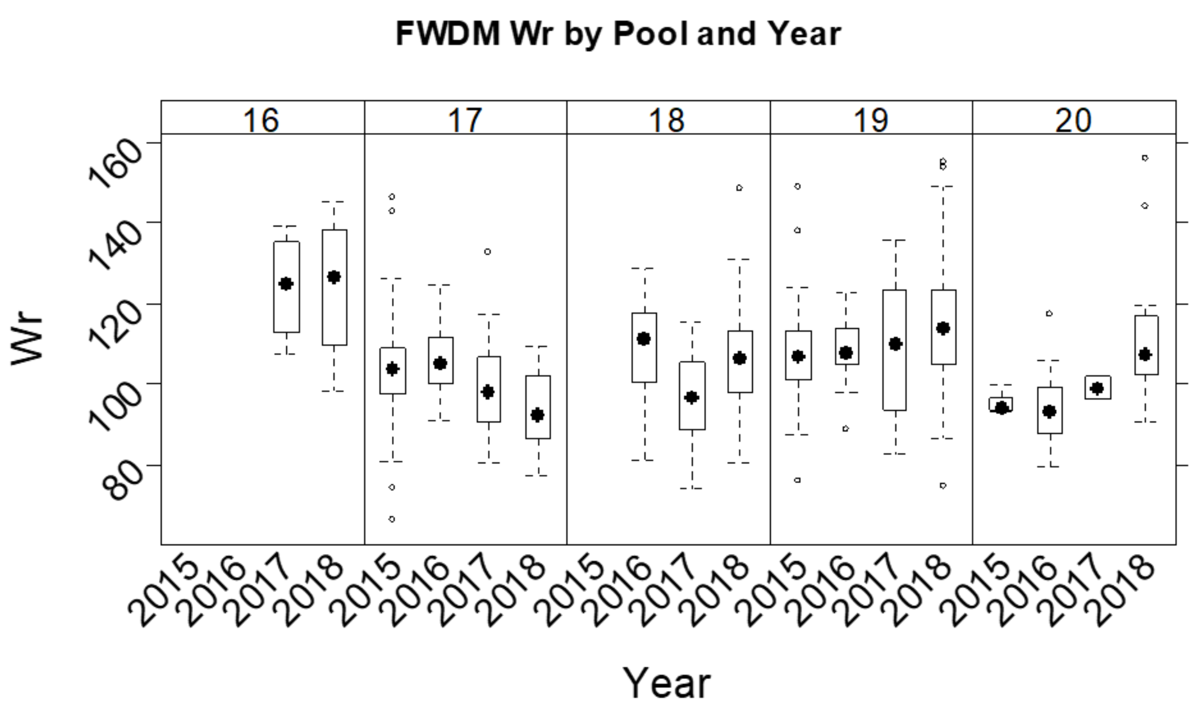


Figure 13: Freshwater Drum Wr by Pool and year

Paddlefish

For Paddlefish there is no data for Pools 16 or 20 for 2015-2018. There is also very little data on Paddlefish in Pools 18 and 19 for this time period. Due to the lack of data, an analysis on all of the data from the Pools will be combined, then separated by year, and an analysis of Pool 17 will be conducted.

Paddlefish have shown a steady trend in Wr since 2015 when all of the Pools are combined (figure 14), although low, averaging a Wr of 75, the Wr has remained steady with no significant differences between the years of data showing in the ANOVA ($p=0.084$).

Paddlefish in Pool 17 show a very similar trend to when all data for Pools is combined and separated by year (figure 15). The main difference is significance is shown in the ANOVA ($p \leq 0.001$) and the Post Hoc Tukey's shows a significant difference between 2016 and 2017 ($p \leq 0.001$) meaning there was a statistically significant drop in Wr from 2016 to 2017.

To continue to monitor Wr data has to be taken diligently and at appropriate times. Continued collections are needed to continue to monitor bigheaded carp Wr and the effects they have on other species.

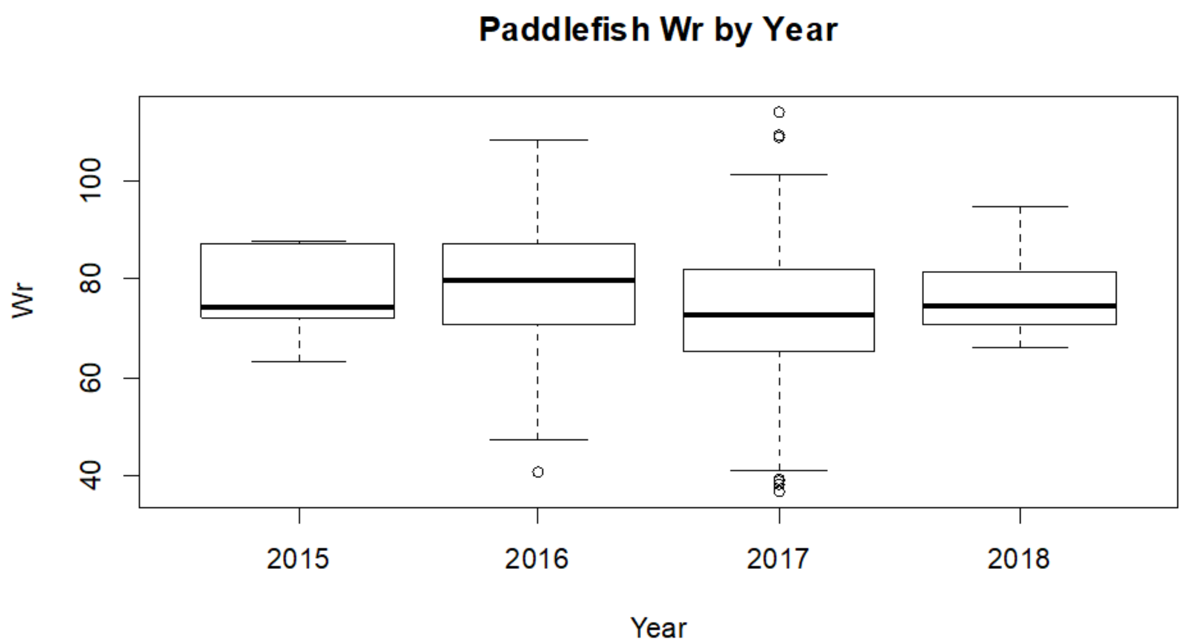


Figure 14: Paddlefish Wr combined Pools by year

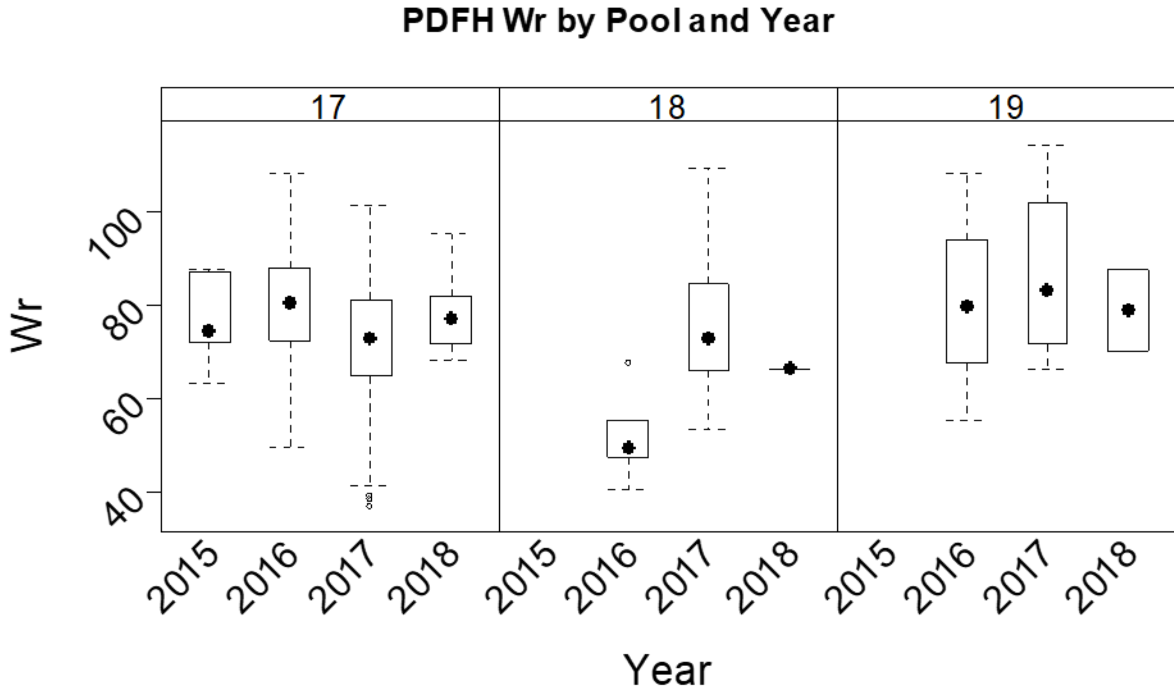


Figure 15: Paddlefish Wr by Pool and year

Size Selectivity of Gill Nets Used to Capture 9 Common Species Caught During Commercial Efforts

Silver Carp

Silver carp size selection is relatively determinant and predictable based on mesh size of gillnets. The K-S test determine that all mesh sizes capture sizes were significantly different in silver carp except for 4 and the 4.25-inch bar gillnets which showed similar spread and were not significantly different from each other. This means that 4 inch and 4.25 inch can used interchangeably if needed. The average size, modal length bin, mean total length, minimum total length of fish caught, and the maximum total length of fish caught in the gillnets can be found in table 6. The retention curve which had the lowest deviance was common spread retention curve (figure 16) this curve fits with how silver carp become trapped in gillnets. Silver carp generally wedge themselves in nets by their heads or the thickest part of their body. Tangling is uncommon because they have very few body features that can get tangled in the nets. More mesh sizes and fish need to be added to this model to increase the validity.

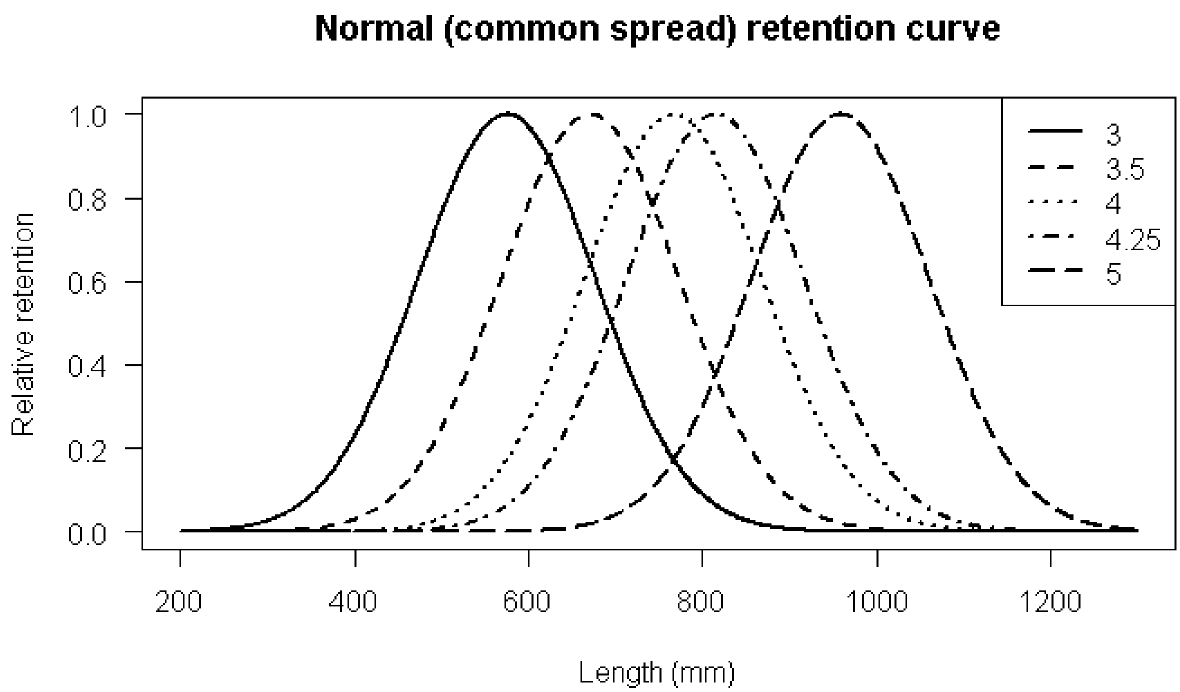


Figure 16: Relative retention of 3, 3.5, 4, 4.25, and 5-inch bar gill nets for Silver Carp in Pools 16-19 of the Mississippi River.

Table 6: Total length of silver carp captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
3	36	625-649	624 ± 25.5	584	803
3.5	18	650-674	708 ± 73	644	1090
4	468	850-874	860 ± 14.8	450	1142
4.25	347	850-874	856 ± 17	644	1150
5	270	925-949	909 ± 19.41	609	1134

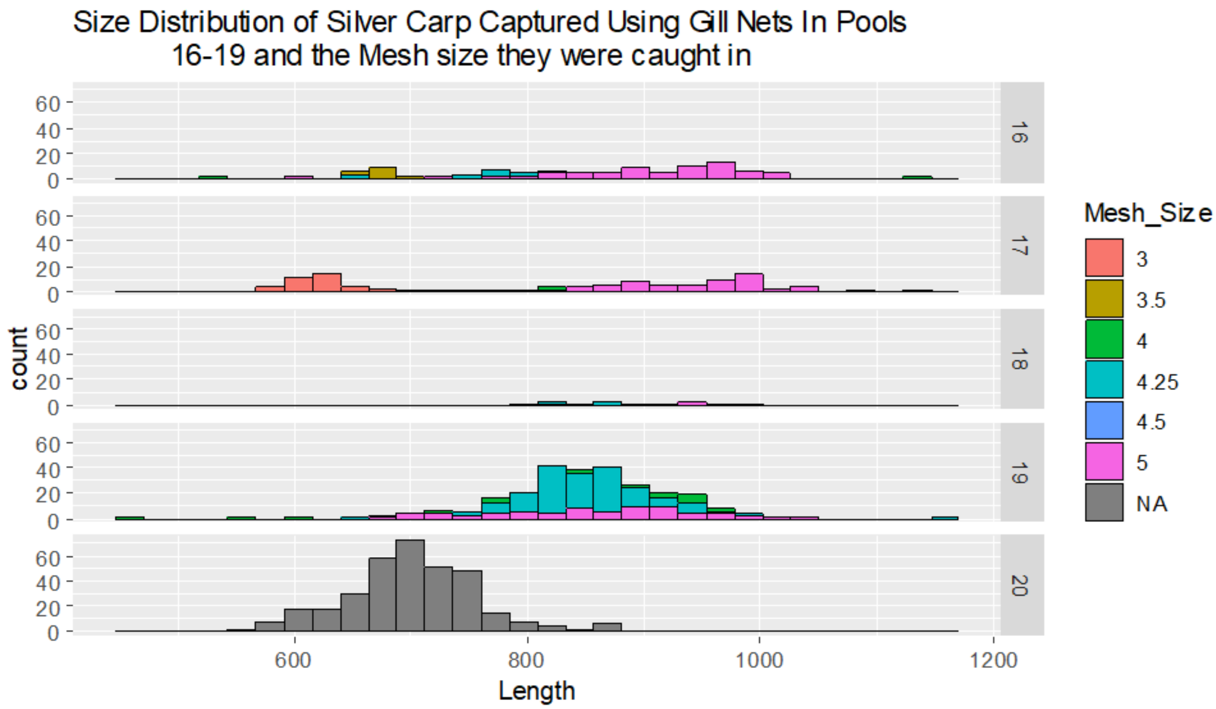


Figure 17: Length frequency histogram for silver carp on Pools 16-20 color coordinated to gill net mesh size on the Mississippi River.

Bighead Carp

Bighead carp were highly variable in the size of fish caught and the size of gillnet they were caught in. The K-S test determined that the 4-inch bar mesh was not significantly different from the 4.25- and 5-inch bar mesh. It also determined that there is a statistically significant difference between the 4.25- and 5-inch bar mesh. Given how bighead carp are generally caught in gillnets, with either just their head wedged in the net or their maxillas' tangled it is not surprising we see these results. As shown in figures 17 and 18 as well as table 7 there is no real separation in any of the mesh sizes used to target bighead carp. The retention curve which had the lowest deviance was common spread retention curve (figure 18) this curve generally fits with how bighead carp become trapped in nets, however, more data on bighead carp will be added to this model to see if there are any shifts in the model deviance favoring other curves. More fish added to these models may also make it possible to determine the best gillnet size for certain sizes of bighead carp.

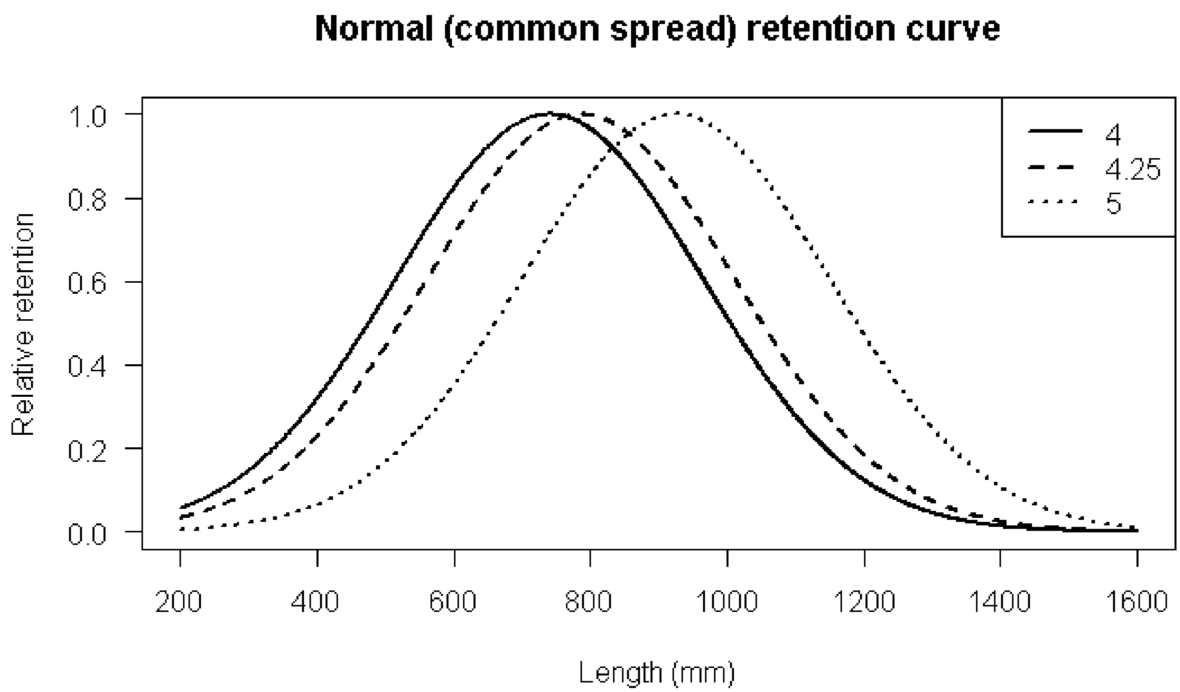


Figure 18: Relative retention of 4, 4.25, and 5-inch bar gill nets for Bighead Carp in Pools 16-19 of the Mississippi River.

Table 7: Total length of bighead carp captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
4	35	1075-1099	1070 ± 52.9	734	1310
4.25	37	1100-1125	1012 ± 51.1	742	1250
5	74	1100-1125	1106 ± 36.1	722	1300

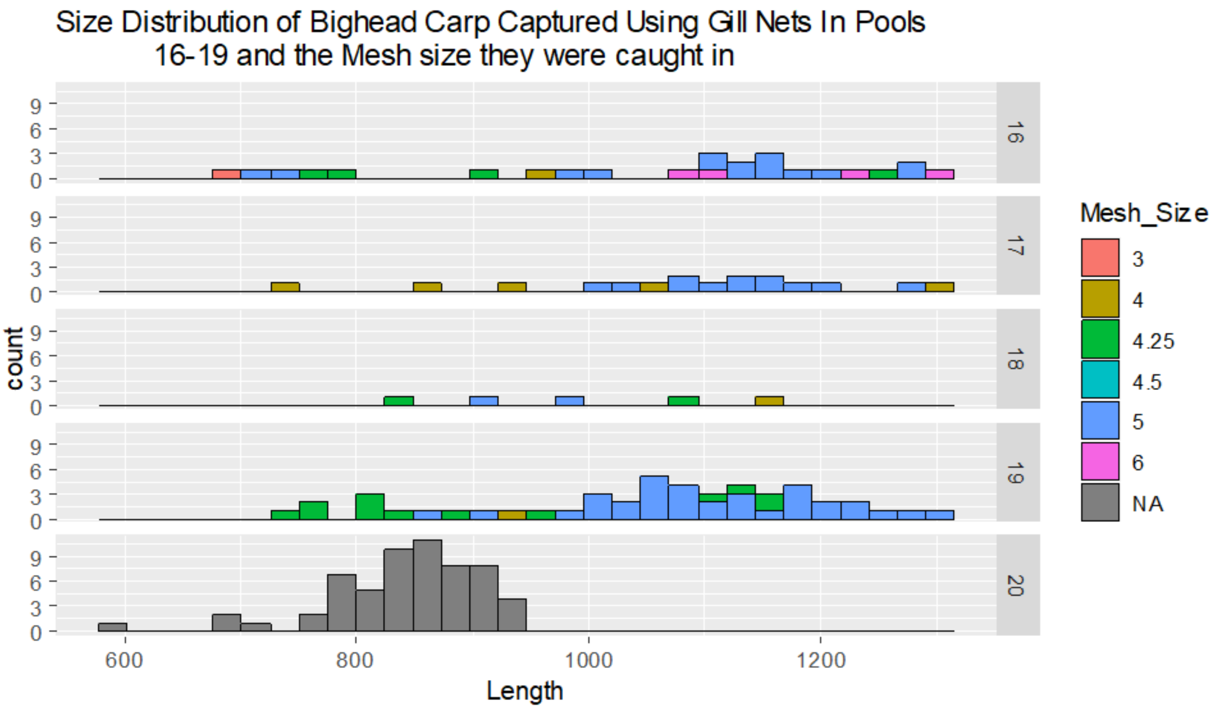


Figure 19: Length frequency histogram for bighead carp on Pools 16-19 color coordinated to gill net mesh size on the Mississippi

Grass Carp

Grass carp were only measured in high numbers in three mesh sizes, 4, 4.25, and 5-inch bar mesh. The K-S test determined that there was no significant difference between 4- and 4.25-inch bar mesh. 4- and 4.25-inch bar mesh have very similar mean capture sizes (table 8). It can be seen in the relative retention curves and length frequency histograms (figures 21 and 22) that there isn't a lot of size separation between gears. The retention curve which had the lowest deviance was the normal retention curve (figure 20) this curve fits with how Grass carp wedged in nets. Due to their cylindrical bodies and few protrusions it is rare that they become tangled by other means. More data will need to be added to further investigate the relationship between grass carp size and gillnet size.

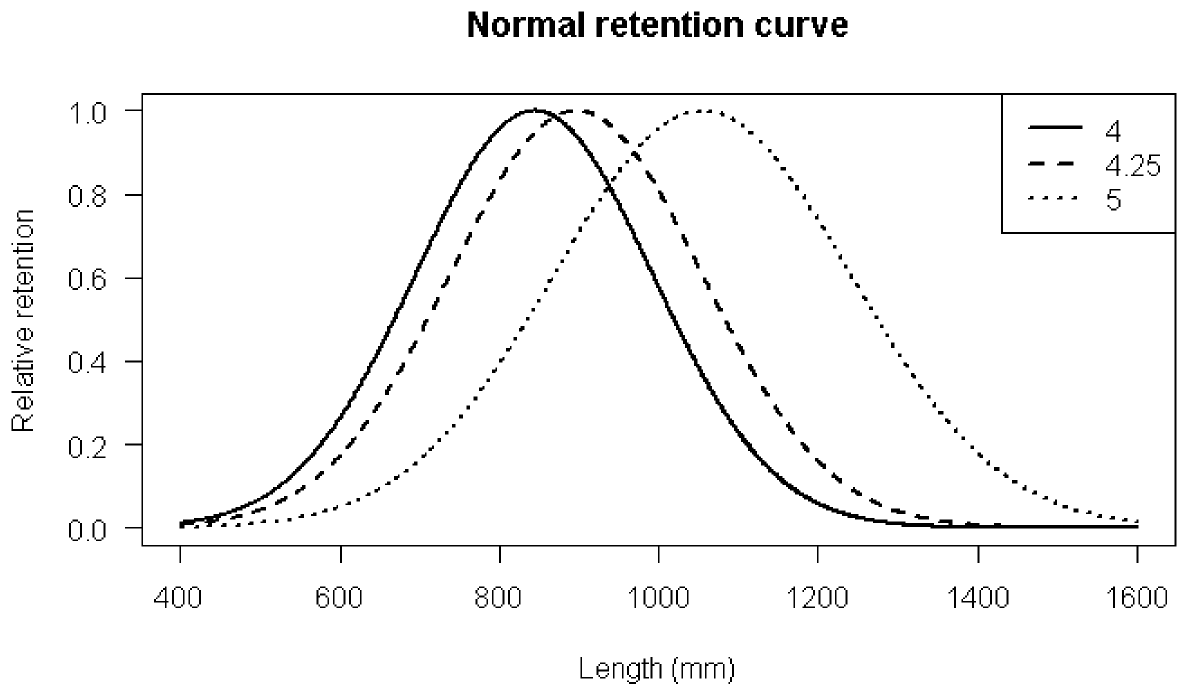


Figure 20: Relative retention of 4, 4.25, and 5-inch bar gill nets for Grass Carp in Pools 16-19 of the Mississippi River.

Table 8: Total length of grass carp captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
4	115	875-899	896 ± 28.5	556	1180
4.25	104	925-949	909 ± 29.8	516	1141
5	97	950-974	953 ± 31.3	569	1133

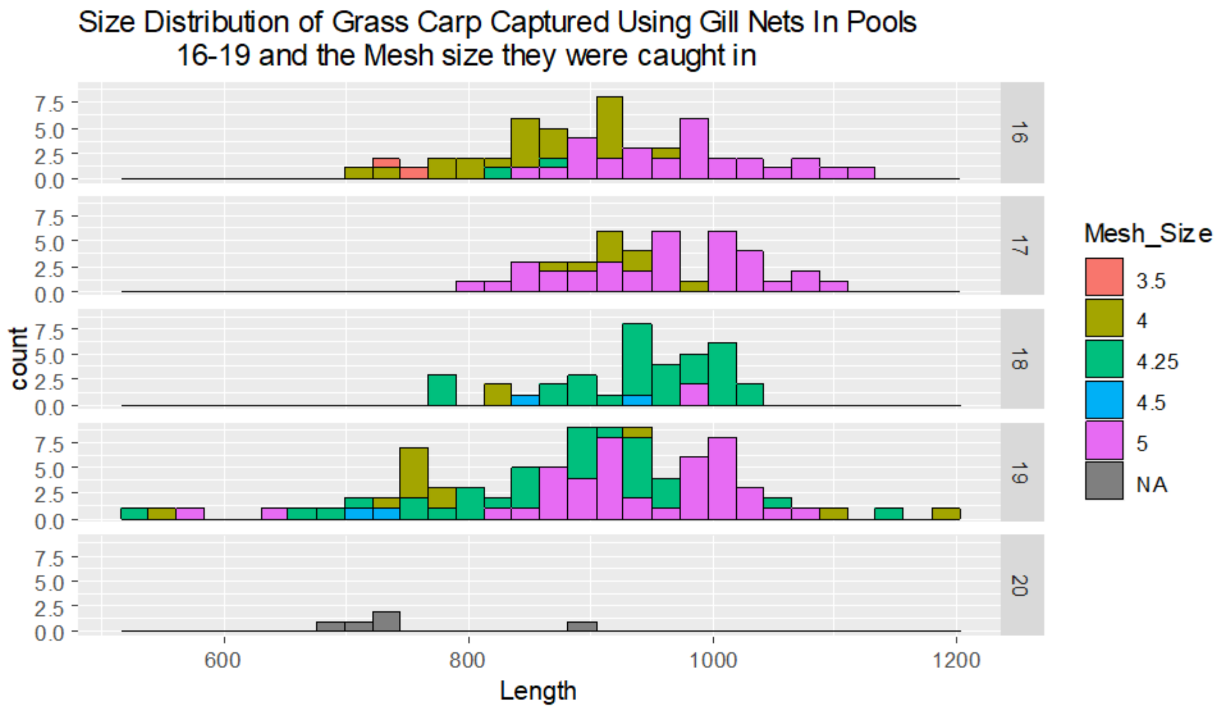


Figure 21: Length frequency histogram for grass carp on Pools 16-20 color coordinated to gill net mesh size on the Mississippi River.

Buffalo Species

For the three buffalo species (black buffalo, bigmouth buffalo, smallmouth buffalo) all mesh sizes used to capture these species were significantly different from one another. With the exception of 4- and 4.25-inch bar mesh in smallmouth buffalo. Curves selected for the buffalo species were all the normal retention curve due to low deviance (figures 22, 24, 26). Due to the body shape and morphology of the Buffalo species they are ideal for wedging themselves into nets. Tables 9, 10, and 11 show mesh sizes and the mean range of fish caught in those mesh sizes. More mesh sizes will need to be added as well as more fish length data.

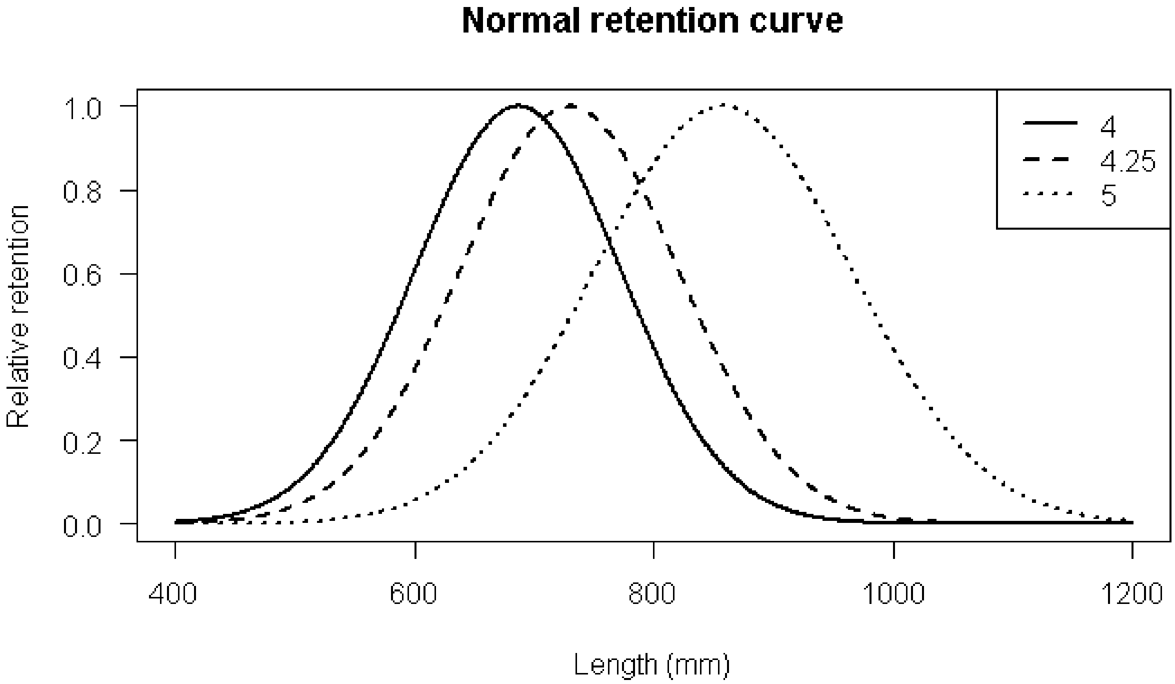


Figure 22: Relative retention of 4, 4.25, and 5-inch bar gill nets for Black Buffalo in Pools 16-19 of the Mississippi River.

Table 9: Total length of black buffalo captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
4	123	650-674	670 ± 28.1	300	910
4.25	64	750-774	720 ± 38.6	550	885
5	55	925-949	763 ± 41.8	520	895

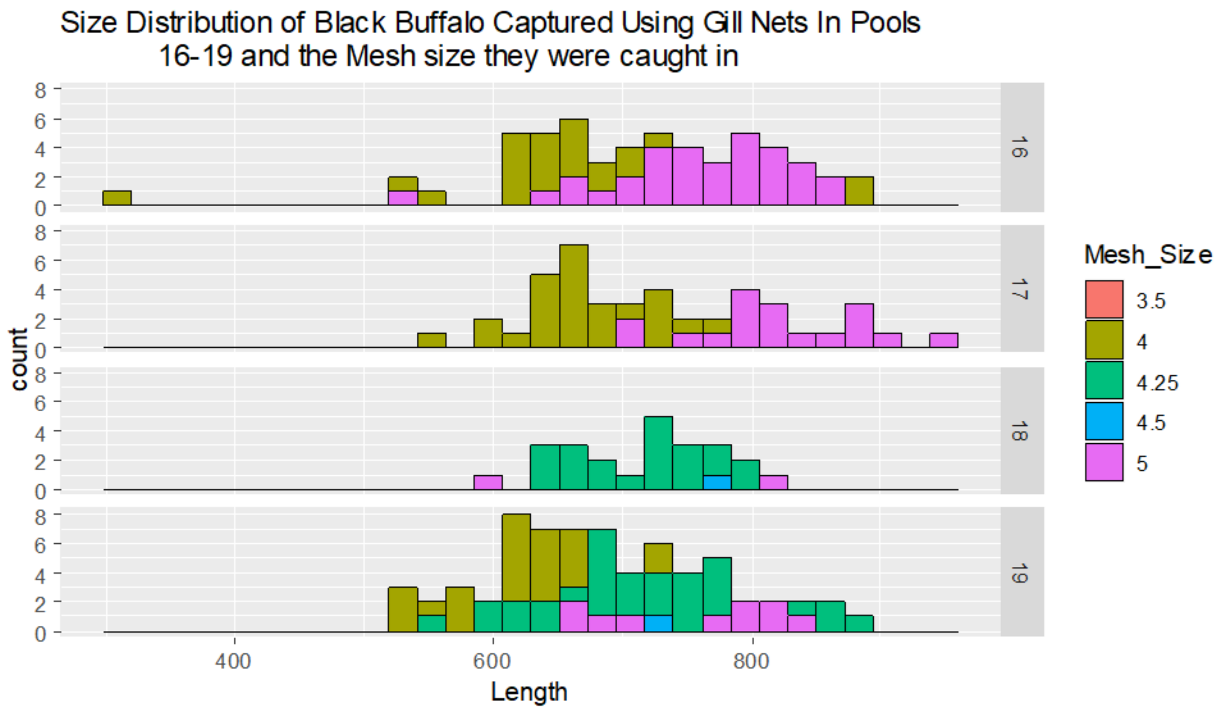


Figure 23: Length frequency histogram for black buffalo on Pools 16-19 color coordinated to gill net mesh size on the Mississippi River.

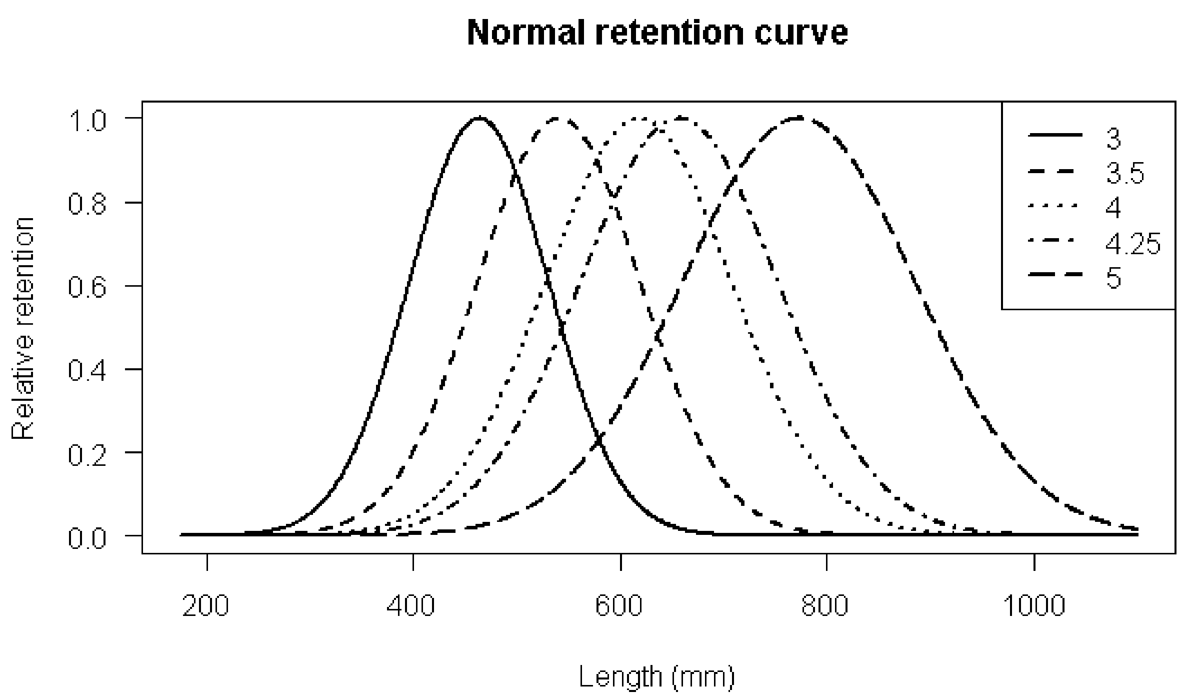


Figure 24: Relative retention of 3, 3.5, 4, 4.25, and 5-inch bar gill nets for Bigmouth Buffalo in Pools 16-19 of the Mississippi River.

Table 10: Total length of bigmouth buffalo captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
3	37	500-524	545 ± 52.6	421	685
3.5	18	525-549	576 ± 72.1	360	750
4	167	625-649	643 ± 23.9	252	886
4.25	64	650-674	675 ± 38.4	517	815
5	83	775-799	712 ± 34	525	852

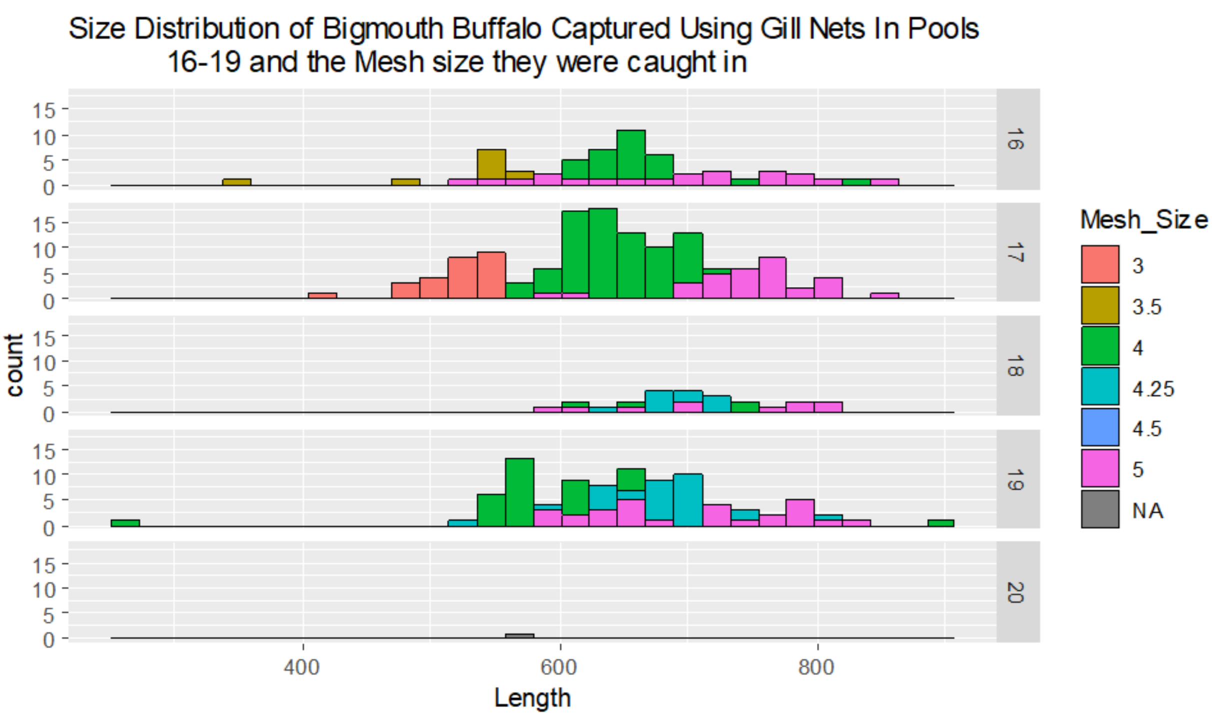


Figure 25: Length frequency histogram for bigmouth buffalo on Pools 16-20 color coordinated to gill net mesh size on the Mississippi River.

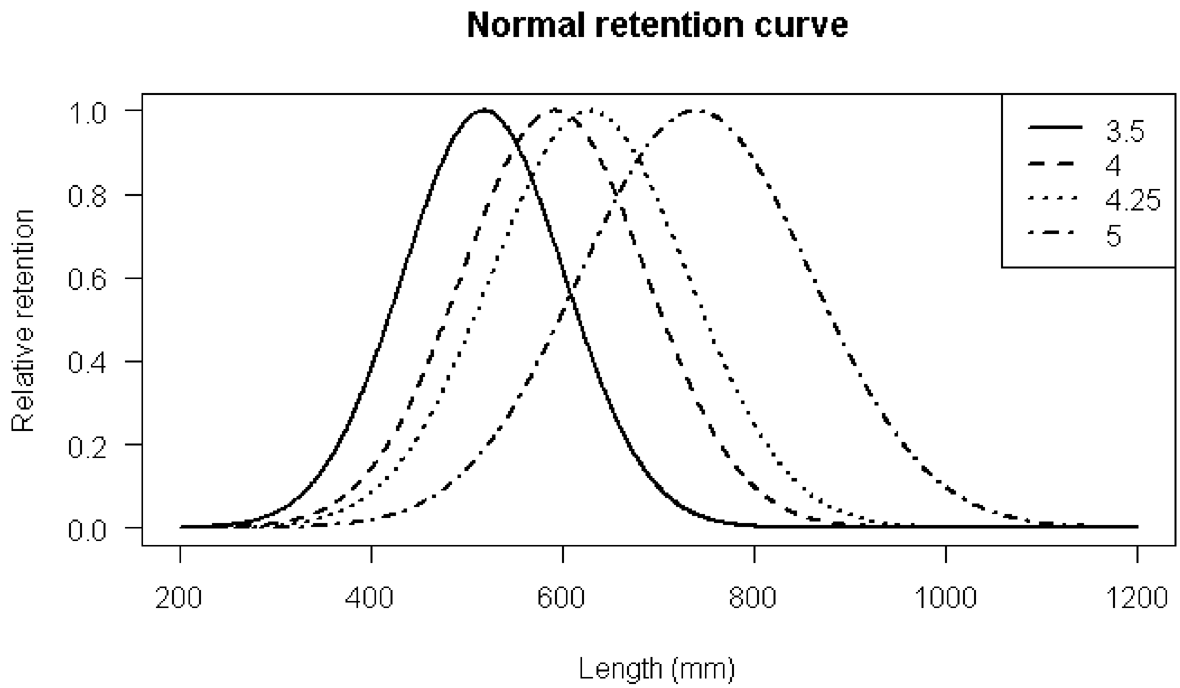


Figure 26: Relative retention of 3.5, 4, 4.25, and 5-inch bar gill nets for Smallmouth Buffalo in Pools 16-19 of the Mississippi River.

Table 11: Total length of smallmouth buffalo captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
3.5	44	525-549	563 ± 45.8	373	732
4	208	600-624	613 ± 21.3	352	851
4.25	49	575-599	637 ± 43.9	489	991
5	95	675-699	698 ± 31.5	441	870

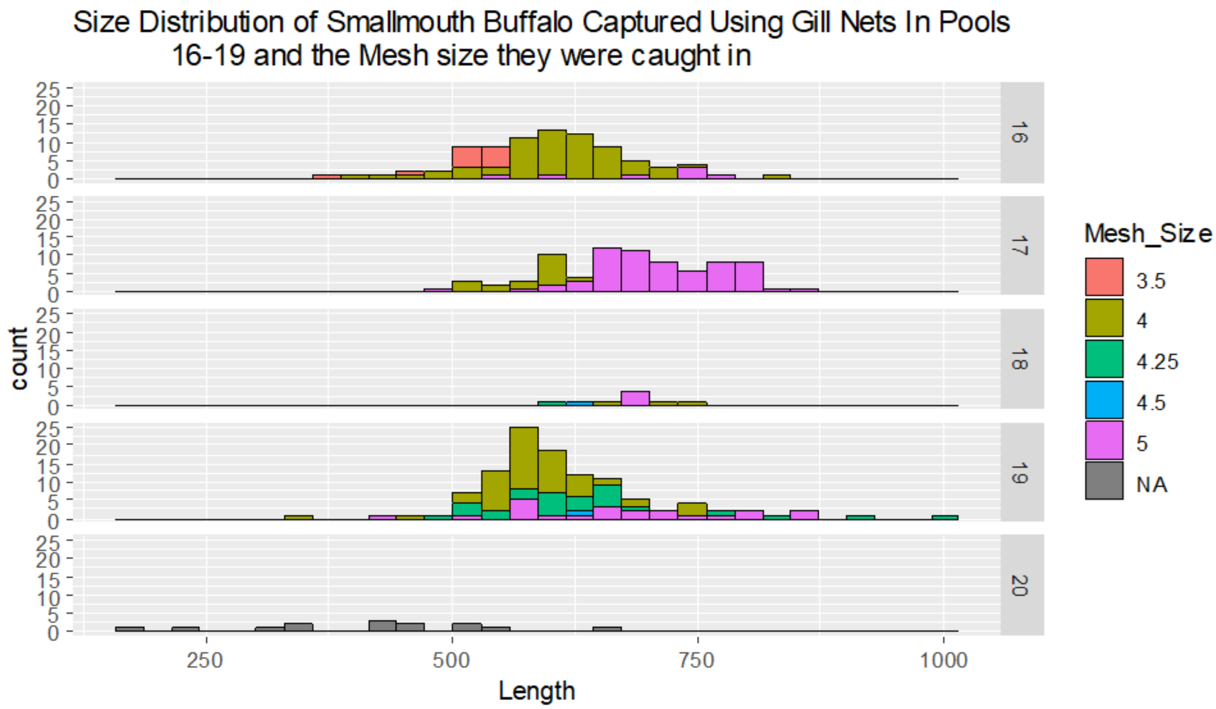


Figure 27: Length frequency histogram for smallmouth buffalo on Pools 16-20 color coordinated to gill net mesh size on the Mississippi River.

Common Carp

Common carp were caught in four different mesh sizes 4, 2.25, 4.5, and 5-inch bar gillnets. A K-S test determined that all meshes caught significantly different length fish. With the exception of 4.5- and 5-inch bar nets. The retention curve selected for common carp was the normal retention curve as seen in figure 28. Table 12 shows mesh sizes and the mean range of fish caught in those mesh sizes. More mesh sizes will need to be added as well as more fish length data to increase the knowledge of mesh size on catch of common carp.

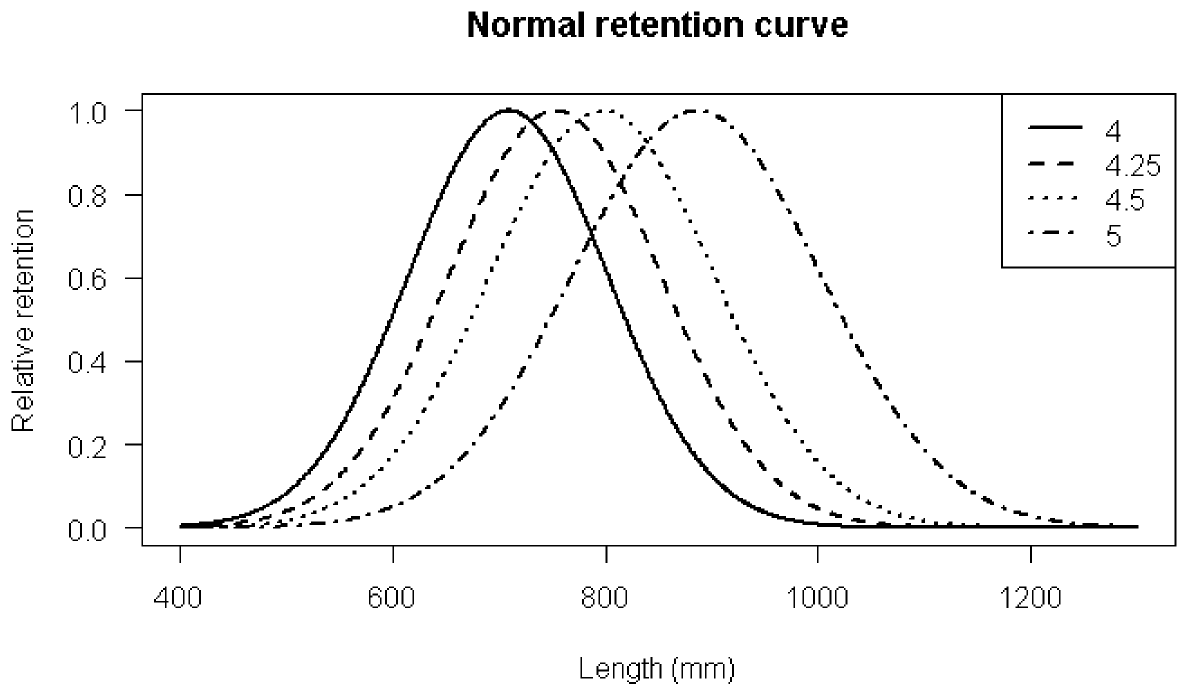


Figure 28: Relative retention of 4, 4.25, 4.5, and 5-inch bar gill nets for Common Carp in Pools 16-19 of the Mississippi River.

Table 12: Total length of common carp captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
4	224	650-674	682 ± 20.6	231	909
4.25	170	725-749	728 ± 23.4	398	883
4.5	42	750-774	754 ± 46.9	354	881
5	126	825-849	760 ± 27.5	404	952

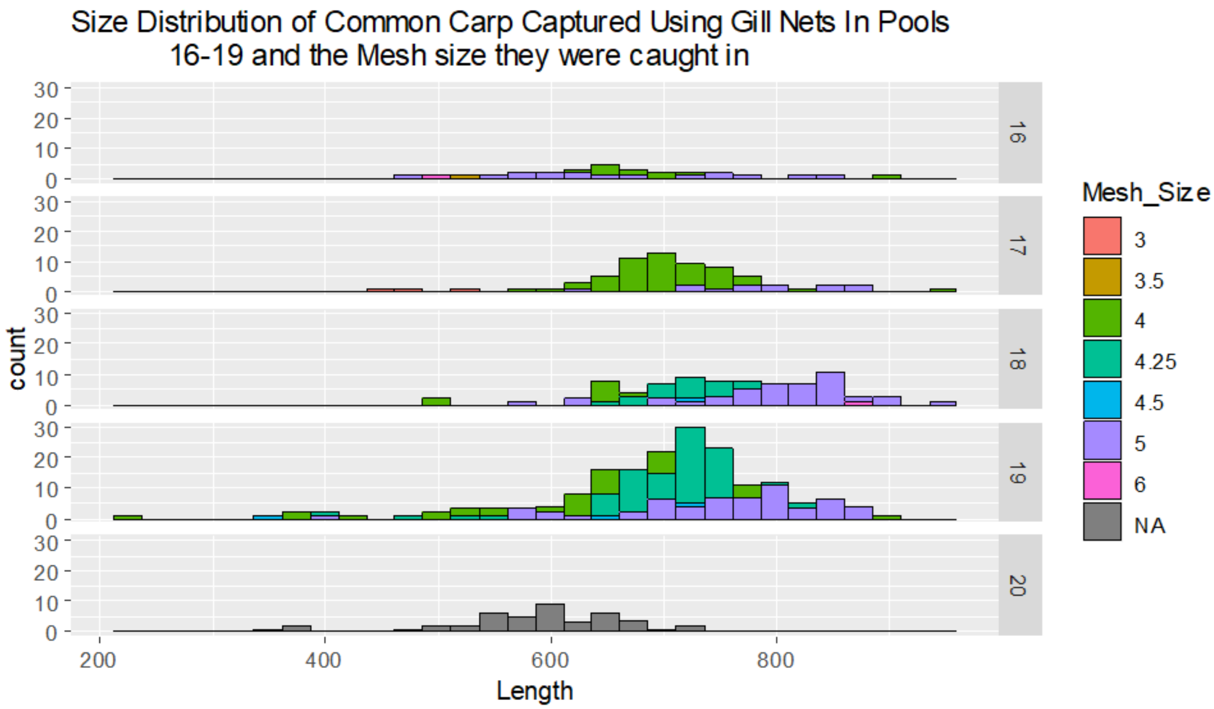


Figure 29: Length frequency histogram for common carp on Pools 16-20 color coordinated to gill net mesh size on the Mississippi River.

Freshwater Drum

Freshwater drum data is interesting when it comes to gillnet selectivity. Freshwater drum are the only fish to have a log normal curve (figure 30) selected which. When this curve is selected it means that the fish caught in the nets are mostly tangled. Most freshwater drum that are caught in gillnets become tangled by the mouth. They are easily removed from the nets and generally are not wedged like other fish species encountered. Most of the mesh sizes are statistically different from one another, except for 4- and 5-inch nets which have a very similar spread on the length frequency histogram (figure 31) and show similar catch size statistics (table 13). More mesh sizes will need to be added as well as more fish length data to increase the knowledge of mesh size on catch of freshwater drum.

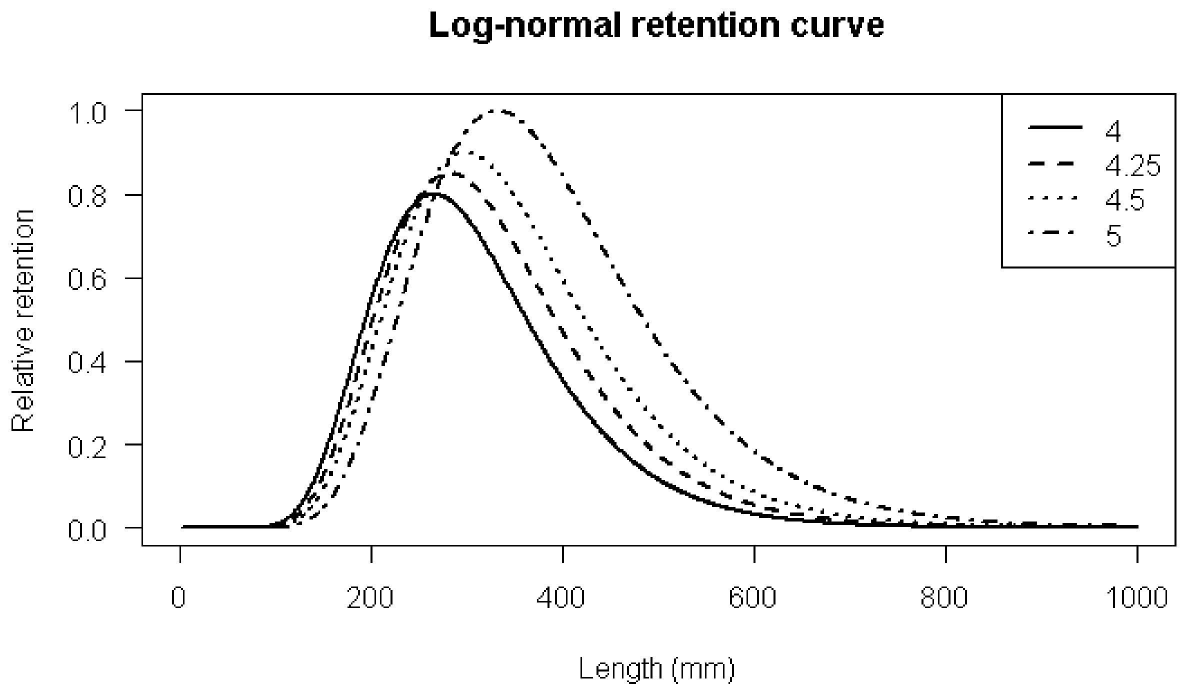


Figure 30: Relative retention of 4, 4.25, 4.5, and 5-inch bar gill nets for Freshwater Drum in Pools 16-19 of the Mississippi River.

Table 13: Total length of freshwater drum captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)	N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
4	176	600-624	591 ± 23.5	315	805
4.25	48	650-674	640 ± 43.7	248	807
4.5	19	625-649	703 ± 69	506	851
5	97	625-649	585 ± 31	379	835

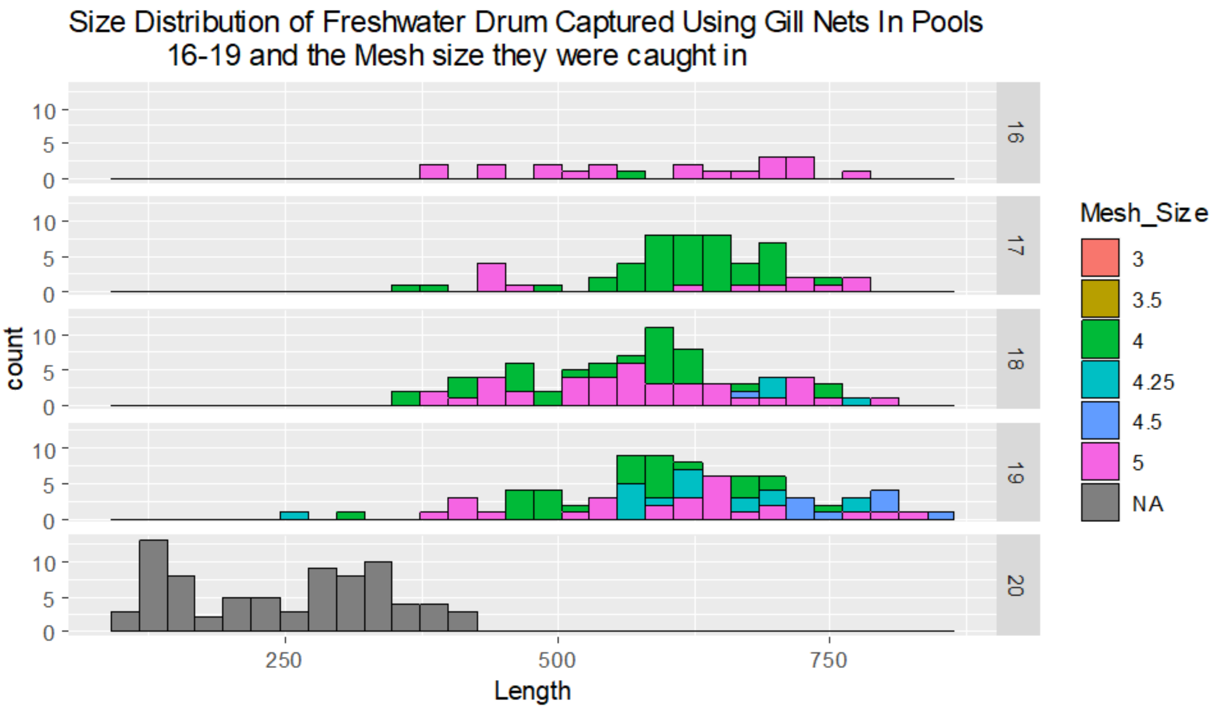


Figure 31: Length frequency histogram for freshwater drum on Pools 16-20 color coordinated to gill net mesh size on the Mississippi River.

Paddlefish

Paddlefish have a highly variable size selectivity at all mesh sizes of gillnets. The normal retention curve was selected (figure 32). Through personal experience I have noticed that Paddlefish get both wedged and tangled in the gillnets that are set. This is due partly to their rostrum, and their large mouths. Table 14 indicates there is a highly variable average size of Paddlefish caught in each gillnet. The K-S test revealed that between all the nets 4 and 4.25, 4 and 5, and 4.25- and 5-inch bar mesh are statistically similar. More mesh sizes will need to be added as well as more fish length data to increase the knowledge of mesh size on catch of Paddlefish.

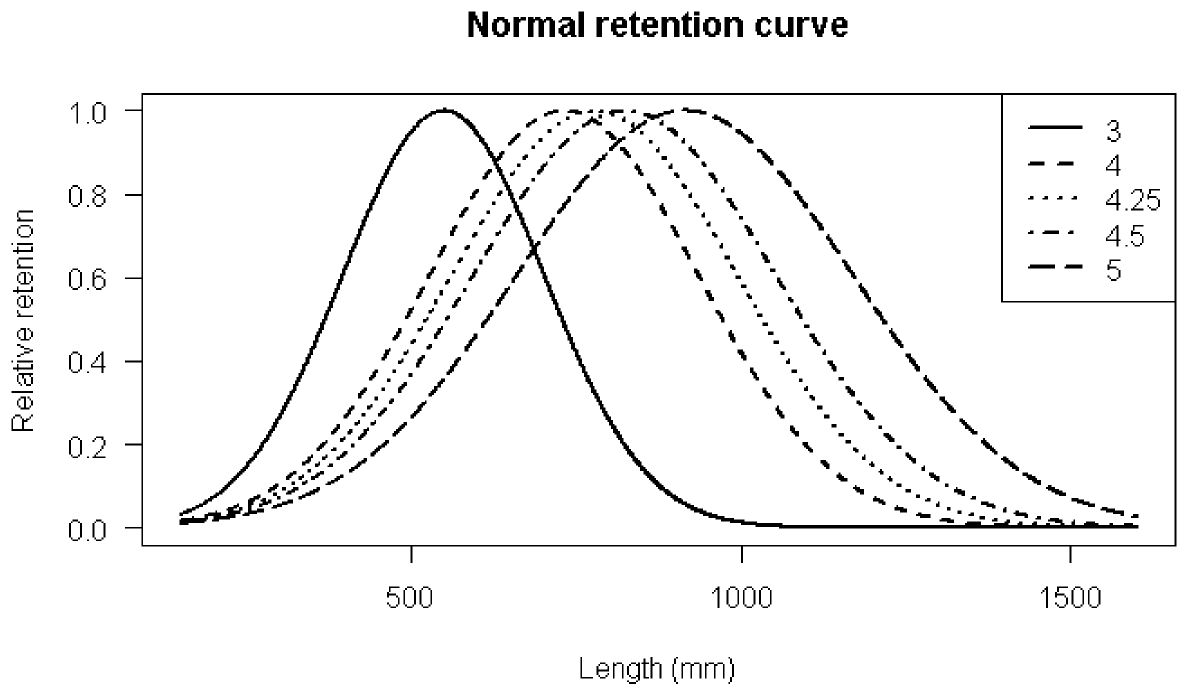


Figure 32: Relative retention of 3, 4, 4.25, 4.5, and 5-inch bar gill nets for Paddlefish in Pools 16-19 of the Mississippi River.

Table 14: Total length of paddlefish captured in Pools 16-19 by their corresponding mesh sizes of gill nets used.

Bar Mesh (in)		N	Modal Length Bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
3		66	650-649	619 ± 38.9	350	930
4		78	850-874	755 ± 35.5	321	1000
4.25		29	800-849	791 ± 59	566	1075
4.5		19	650-674	698 ± 32.7	574	910
5		123	850-874	793 ± 28.3	446	1110

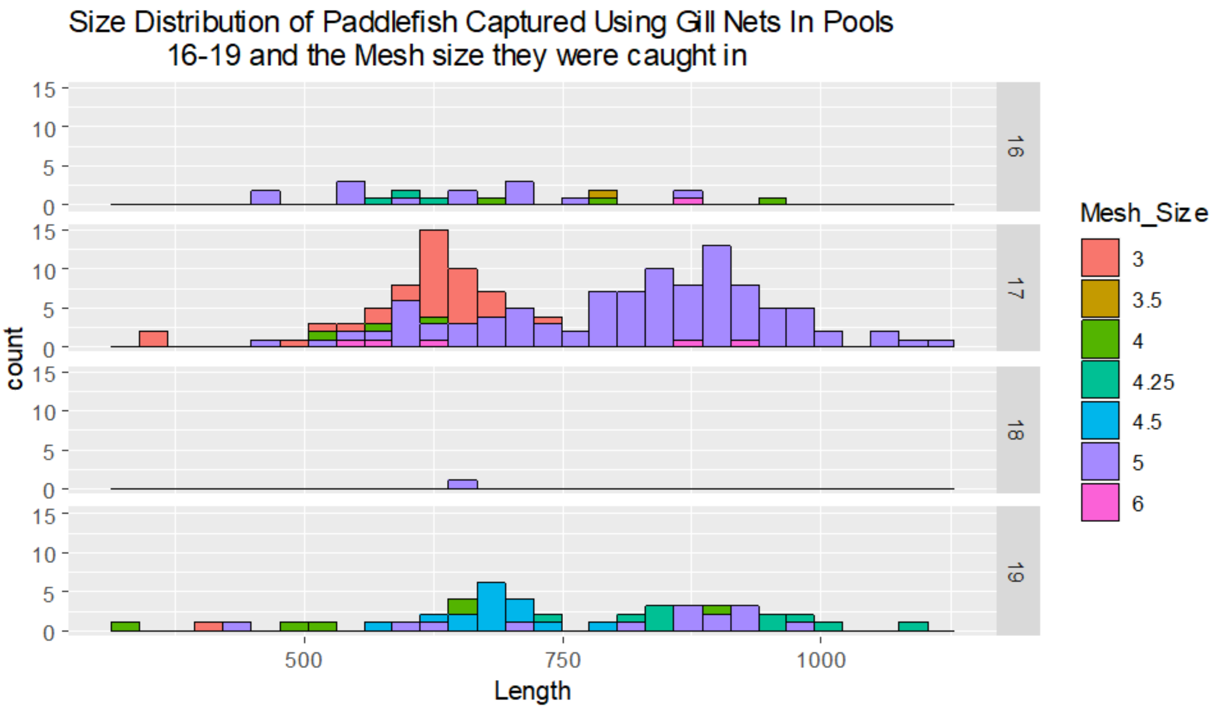


Figure 33: Length frequency histogram for paddlefish on Pools 16-19 color coordinated to gill net mesh size on the Mississippi River.

Recommendation

It is recommended that commercial removal efforts continue to reduce number of bigheaded carps in Pools 16-19 in the Upper Mississippi River (low-density management zone). It is also recommended that efforts continue to determine the relationship between bigheaded carp and commonly encountered bycatch and the gillnet size selectivity. This information is important to collect in order to target bigheaded carp more effectively and efficiently while trying to avoid harming other ecologically and commercially important species.

It is recommended to continue contracted commercial fishermen and increase the number of fishermen per sampling event to increase the total likelihood of bigheaded carp captured. Having additional acoustically tagged bigheaded carp and real-time receivers can offer greater capture success by identifying where schools of bigheaded carp are daily and provide better population estimates.

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