Deterrent Strategy Planning for Asian Carp in the Ohio River Basin

2018 Technical Report

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Geographic Location: Ohio River Basin; Tennessee and Cumberland rivers

Participating Agencies: Tennessee Wildlife Resources Agency (TWRA), Tennessee Technological University (TTU), U.S. Geological Survey (USGS), Kentucky Department of Fish and Wildlife Resources (KDFWR), Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP), Alabama Department of Conservation and Natural Resources, U.S. Army Corps of Engineers (USACE), Tennessee Valley Authority (TVA), Murray State University (MSU), West Virginia Division of Natural Resources (WVDNR), Indiana Department of Natural Resources (INDNR), Ohio Division of Wildlife (ODOW), and U.S. Fish and Wildlife Service (USFWS).

Introduction:

Invasive Asian carps have invaded the Ohio River Basin. In 2007 the Aquatic Nuisance Species Task Force approved the Management and Control Plan for Bighead, Black, Grass, and Silver Carps in the United States (National Plan). In 2014 the Ohio River Basin Asian Carp Control Strategy Framework (Framework) outlined a series of approaches to deliver the National Plan within the Ohio Basin. Integrating state responses in the Ohio River basin with basin-wide and national plans has been a priority to agencies that are also responding to more localized prevention, control, and removal needs.

Currently, few tools are available to control expanding populations of Asian carp. Physical removal of carp through various methods may be effective, but is expensive, and ongoing efforts of this project intend to increase the efficiency and capacity of removal efforts. Non-physical deterrents may also be effective against the spread of Asian carp (electric barrier in the Chicago Area Waterway System), but can be expensive to operate and maintain. The combination of harvest and deterrence may be an approach that reduces harvest targets while still limiting the spread of Asian carp. However, non-physical deterrents remain in the testing phase of development.

Sound deterrents have been developed for the purpose of limiting movements of fish, and those systems show promise in deterring Asian carp. To date, small scale sound barriers have been tested on many native fish and Asian carps in labs, outdoor ponds, and small rivers, but they have not been tested on a larger scale such as lock and dam structures on large rivers where Asian carp are abundant. As a result, the USFWS with the support of many partner agencies and multiple funding sources is planning an experiment testing sound at a lock and dam facility (Lake Barkley Dam).

Given the ongoing effort to test a sound deterrent at Barkley Dam, there is a need to collect baseline movement data on Asian carp that can be used to evaluate a sound deterrent in future years. There is also a need for planning priority locations for implementation of deterrents as they are developed based on the known distribution of Asian carp in the Ohio River Basin. Continued monitoring of Asian carp movements to evaluate a potential barrier are necessary.

Objectives:

1. Characterize the need for deterrents and priority locations for deterrent placement to control movement of Asian Carp in the Tennessee and Cumberland Rivers.
2. Characterize the need for deterrents and priority locations for deterrent placement to control movement of Asian Carp in the Ohio River Basin.
3. Enhance movement information among reservoirs and pools to help define deterrent placement and collect baseline movement data to help inform future deterrent efficacy.

Methods:

Characterize priority locations for deterrent placement in the Tennessee and Cumberland Rivers
A committee was formed to characterize the need for deterrents and priority locations for deterrents to control movement of Asian Carp in the Tennessee and Cumberland Rivers. The committee was comprised of fisheries chiefs from KY, TN, MS, and AL; staff from the Planning Branch of the Nashville District US Army Corps of Engineers; and senior biological staff from the Tennessee Valley Authority. The committee met three times in 2018 (6-18-18; 10-4-18; and 10-23-18). Although attendance varied among meetings, all agencies were represented at the second meeting. The committee considered the current distribution of Asian carp, locations of locks, usage of locks, and available barrier technology to make recommendations.

Characterize priority locations for deterrent placement in the Ohio River
Kentucky Department of Fish and Wildlife Resources staff worked with Ohio River Basin partners to identify potential deterrence sites on the Ohio River. KDFWR reviewed a document by the United States Geological Survey (USGS) detailing upstream fish passage opportunities at Ohio River locks and dams. In addition, KDFWR reached out to Lockmaster's at the United States Army Corps of Engineers to solicit input on practices that may minimize Asian Carp passage or create conditions which favor Asian Carp removal. Markland, Meldahl, Greenup and RC Byrd dam lockmasters were contacted first by phone and then by e-mail to discuss lock and dam complex practices.

Enhance Asian carp movement information
To acquire movement information, fish were surgically implanted with acoustic telemetry tags and telemetry receivers were deployed to detect individual fish movements within the Ohio River sub basin. Within the Tennessee River, of the Ohio River sub basin, every lock and dam has telemetry receivers starting at the downstream end Kentucky Dam and upstream to and including Guntersville Dam. In the Cumberland River, Barkley Dam is outfitted with acoustic receivers and in 2019 the receiver array will be expanded to include Cheatham Dam (in TN) and potentially Old Hickory Dam.

Silver carp were captured through boat electrofishing and then surgically implanted with VEMCO V16 acoustic transmitters, following the protocol developed by MSU and TTU. Tagged fish were also marked externally with a Floy Loop Tag inserted just posterior of the dorsal fin. Silver carp have been tagged in KY, TN, and MS. Tagging occurred when water temperatures were cool and survival and tag retention was high. Once tagging was complete fish were immediately returned to the body of water from which they were captured. To date, an estimated

total of 286 fish with active telemetry tags are at large within the Tennessee and Cumberland rivers (40 tagged in MS waters, 66 tagged in TN waters, and 180 tagged in KY).

Tagged fish were monitored through stationary receivers as well as manual tracking trips made approximately once per week in Kentucky waters by KDFWR. A large network of VEMCO stationary receivers has been deployed throughout the reservoirs, lock chambers, and their tailwaters. A total of 44 VEMCO receivers are currently deployed by cooperating agencies (5 AL, 4 MS, 20 KY, and 15 TTU). New receivers will be deployed in Cumberland River reservoirs in spring 2019 as receivers are available. The first location will be Cheatham Dam.

Two receivers had been previously deployed in Kentucky Lock and Barkley Lock to determine direction of travel for fish that pass through the lock chamber. Stationary receivers are deployed through two primary mounting systems in the reservoirs, anchored bottom mounts, and on navigational buoys. Receivers deployed in the lock chambers throughout the systems are deployed in steel cases lowered in ladder wells to prevent damage by barges and debris traveling through the locks. KDFWR retrieves and downloads stationary receivers in the reservoirs on a bimonthly schedule, and receivers in the lock chambers monthly. TN downloads receivers on a 3 month frequency, however extreme water levels in spring 2019 disrupted the schedule. Manual tracking was accomplished by using a VR100 and omnidirectional hydrophone deployed from a boat. The hydrophone was lowered into the water at 1km intervals and monitored for at least two minutes before moving to the next location. It was determined through range testing that the omnidirectional hydrophone could detect transmitters from a distance of 500m. Therefore, stopping at 1km intervals provided sufficient coverage of the lake. Telemetry data from manual tracking and stationary receivers collected by KDFWR was transferred to Dr. Spier at MSU for analysis.

KDFWR and TWRA participated in numerous conference calls and several in-person meetings regarding the Bio-Acoustic Fish Fence (BAFF) to be deployed in the downstream approach to Barkley Lock. KDFWR provided fish community data, baseline fish passage data from the current telemetry array, and local contacts for the group of researchers developing the study plan around the BAFF installation and testing. Multiple partner agencies have collaborated on the project.

Results and Discussion:

Characterize priority locations for deterrent placement in the Tennessee and Cumberland Rivers

The committee identified the following dams in the TN/Cumberland Basin as high priority locations (Figure 1) where barriers are most warranted based on the 2018 distribution of carp.

1. Guntersville/Nickajack –Two consecutive barriers to protect the upper TN River which currently does not have Silver Carp. Bighead Carp have been observed in very low densities above Nickajack Dam.
2. Kentucky/Barkley – A barrier at each lock would greatly reduce immigration of carp into the Tennessee and Cumberland rivers.
3. Tennessee-Tombigbee – Barrier Jamie Whitten Lock and Dam to prevent carp from entering the Tenn-Tom and eventually the Warrior River. Jamie Whitten Lock and

Dam, located in Prentiss County, MS, impounds Bay Springs Lake, a 5,000-acre reservoir that is considered the headwaters of the Tennessee-Tombigbee Waterway. Lock dimensions are 600 ft x 110 ft and has an 84 ft lift.

4. Pickwick – A barrier at Pickwick would serve multiple roles. It would be a second barrier to block upstream movement of carp in the Tennessee River and Tenn-Tom waterway. Silver carp are thought to have spawned in Kentucky Reservoir in 2015. If spawning becomes more frequent in future years, a barrier at Pickwick could become even more important than barriers on Kentucky or Barkley dams.
5. Cordell Hull – Silver, Bighead, and Black carp have not been observed upstream of Cordell Hull. A barrier is still warranted to protect upstream resources. The combination of infrequent lock use (about 35 cycles/year) and the relatively low abundance of carp in the reservoir below it could continue to prevent movement of carp upstream. Given the low lock use rate, this might be a good location to try carp control efforts that are only deployed during the lock cycle. Another option to consider is de-authorization of navigation at this project (permanently close the lock).

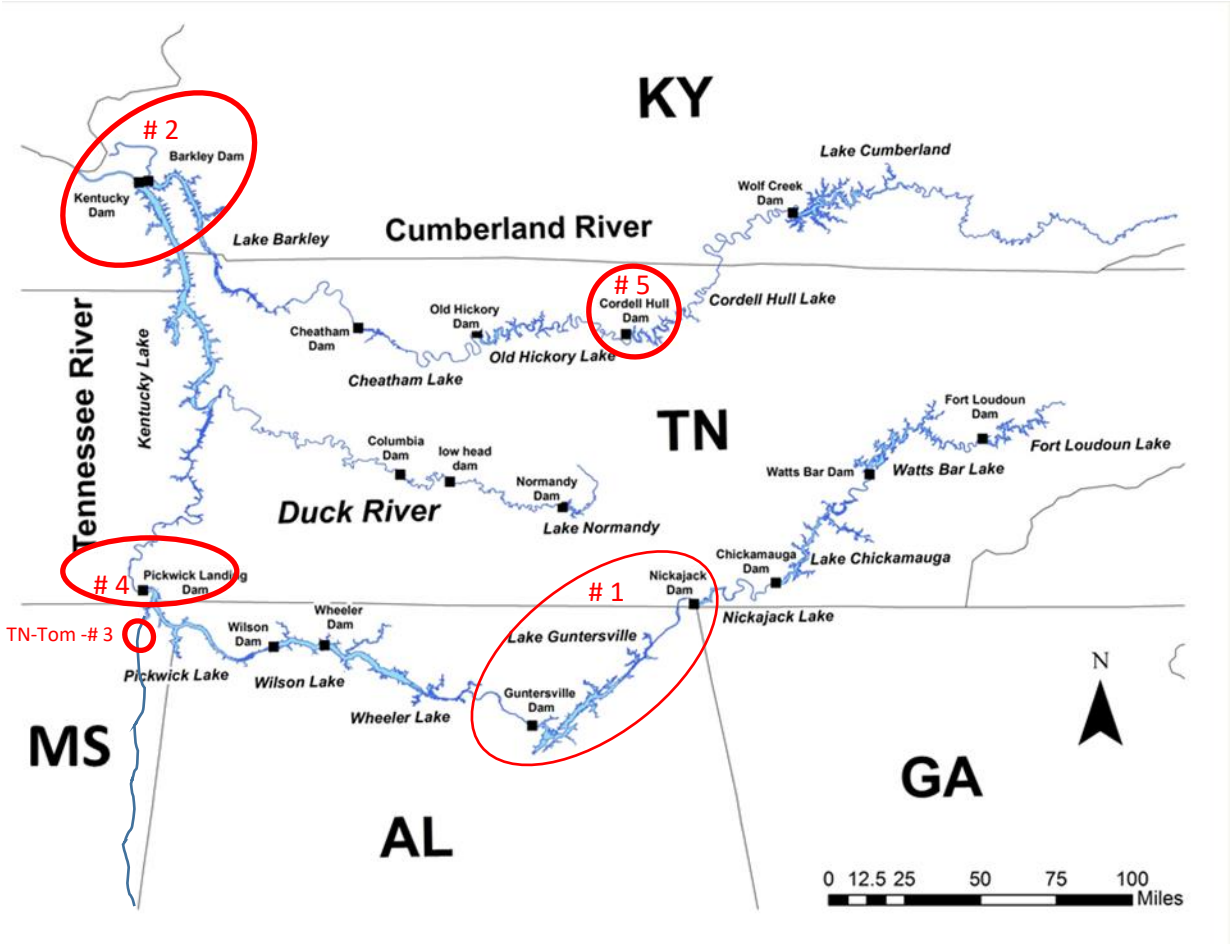

Figure 1. Proposed locations of carp barriers; numbers indicate rank within these high priority sites.

The committee was optimistic that the sound barrier to be tested at Barkley Dam in 2019 will be successful. As such, we recommend pursuing this technology. If sound it is not effective enough, we recommend adding other measures such as CO_2. Lastly, we discussed electric barriers. The committee did not recommend electric barriers at this time due to concerns for safety of people and cargo, lack of effect on small carp, and high cost. Regardless of the barrier used, we acknowledged that a barrier would not have to be 100% effective to have value, but the committee varied in opinion on a lowest acceptable rate (range discussed was 50-80%). Lower efficiencies would be acceptable at Kentucky and Barkley, while we would prefer much higher efficiencies at upstream barriers where we are trying to stop the migration of the leading edge. We recognize that carp control will require both barriers and removal effort.

Ideally the sound barriers would be effective on all species of Asian carp and only minimally impact native species. Impacts on native fish have been raised (see below). The committee identified silver and bighead carp as those most critical species of Asian carp to prevent upstream movement at this time. If barriers work on just the bigheaded carps, but not the black carp or grass carp, the committee would still recommend installing barriers.

1. Are there native species that need upstream passage at this dam?
    a. KY observes that paddlefish movement is important to KY fisheries. No other issues were discussed.

Characterize priority locations for deterrent placement in the Ohio River

During 2017 KDFWR began collecting information from lock masters regarding potential barrier efforts and possible movement pathways for Asian carp through lock and dam facilities between Cannelton L&D and Willow Island L&D. This section of the river includes Asian Carp populations at a variety of different stages with invasion statuses for Silver Carp ranging from established (recruiting) to present (infrequent large adults) or actively invading (Figure 2). KDFWR reviewed the basic structural design of these locks and dams and began reviewing daily water level data from 18 USGS gages that are actively recording the conditions within this section of the Ohio River.

Lockmasters are responsible for the day-to-day operations of their L&D facilities, and their expertise is invaluable to both the federal and state agencies trying to combat Asian Carp. Furthermore, lockmasters can assist in determining which procedural changes suggested by biologists could impede the expansion of invasive species that would cause navigation issues.

In general, the lockmasters responded favorably and most seemed amenable to providing any assistance that they could. However, they reiterated that any efforts to slow the Asian carp must not interfere with the primary objective of the facility: sustaining the conditions required for year round navigation. In fact, because of the L&D's main purpose and its specific design, lockmasters typically respond to flood conditions by making sure that all available dam gates are opened up as much as possible. Open dam gates lead to open river conditions, which are suspected to allow large numbers of Asian Carp to transfer pools.

The USGS has a historical river level data set, with water level gages throughout the middle Ohio River (Figure 3). Data from USGS suggests that fish passage through high lift lock and dam facilities on the main stem Ohio River is likely limited to the lock chambers when a vessel is locking through or during open river days when the gates are fully open (Knight et al., 2003). Open river days on all three pools of interest were more frequent in the winter and spring (Knight et al., 2003). After review of USGS water level and fish passage data, the Markland facility stood out. The Markland lock is a high lift facility which, over the last 26 years, has had far fewer open river days than any other facility below the Racine pool. During that time period the facility only had 27 open river days while most other facilities had well over 100 open river days (Knight et al., 2003). This, coupled with the fact that the pool is within the invasion front of silver carp, makes it a top candidate for barrier installation. In a July 2018 Ohio River Basin meeting KDFWR led discussion on barrier locations along the Ohio River. KDFWR staff recommended at least one primary barrier facility at Markland Lock and Dam. An additional barrier facility at a lock and dam above or below Markland would further limit dispersal. Installation of a sound, bubble curtain, or electric barrier preventing or limiting access to the locks at these facilities represents the greatest opportunity to prevent movement. If a barrier was constructed at the lock the number of open river days would be of chief concern because the barrier would be ineffective during those periods.

KDFWR is working towards enhancing Asian carp movement information in the Ohio River through the complimentary project Asian Carp Telemetry in the Ohio River. This information will be used with historical movements among pools and comparisons of the possible open river conditions at various Locks & Dams to determine the best options for the placement of Asian carp deterrent technologies

Enhance Asian carp movement information

Surgeries were performed on 41 silver carp in the Barkley Dam tailwaters and on 3 silver carp in Kentucky Lake in 2018 (Table 1). TWRA and TTU worked with partners to release 66 silver carp in Tennessee waters and 40 in Mississippi waters of the Tennessee River with acoustic telemetry tags. Boat-mounted hydrophones were used to manually track tagged silver carp on 25 separate trips in Kentucky Lake, and for the first time significant tracking effort was performed in Lake Barkley (9 separate trips during 2018). A large network of VR2W passive receivers has been deployed throughout Kentucky Lake, Lake Barkley, Pickwick Lake, and the locks and dams on the Tennessee River to record long-range movement patterns of tagged silver carp (Figure 4). In 2018, two additional receivers (4 total) were deployed at Barkley Lock to acquire finer scale movement of tagged fish through the lock chamber, as well as in the lock approaches. A VR2W receiver was also deployed in the tailwaters of Barkley Dam to detect tagged fish that may travel downstream of the Dam (Figure 5). Alabama deployed receivers at Guntersville Dam in 2018 to further expand the acoustic telemetry array in the Tennessee River.

Fish Detections

During 2018, 39 positive tag detections were confirmed from receivers in Tennessee and Mississippi waters of the Tennessee River. Within the lower Tennessee River, there were only 2 individuals detected in 2017 and 13 individuals in 2018 from 5 of 15 receivers in Tennessee waters. This is a reflection of the importance of increasing the number of fish tagged in the system and can highlight the movement capability of fish. One individual, that was tagged in

Pickwick Reservoir, traveled to Kentucky Dam and then through the canal into Barkley Reservoir and ultimately back into Kentucky Reservoir and Pickwick Reservoir within one year. Thus, individuals can be highly migratory, but continued tagging and monitoring will be required to understand how representative highly mobile individuals are to the invasive population and if movement cues (i.e., time of year, flows) can be identified to help inform lock management or barrier use.

Additional analyses were conducted by Dr. Tim Spier of MSU for tagged silver carp detected by manual tracking and stationary receivers deployed by KDFWR. During 2018, 22 different Silver Carp were detected via active tracking and 25 different Silver Carp with the VR2Ws of Kentucky Lake (Table 2). In Kentucky waters of Lake Barkley, 40 fish were detected with the boat-mounted hydrophone and 58 on the VR2W receivers (Table 3).

All fish locations were converted to the nearest river kilometer (RK) and then the mean RK was determined for each fish on each date. Movement rates were calculated by determining the change in RK between successive locations for each fish, and then dividing this value by the number of days between successive locations (so, movement rates were recorded as km/day). Only successive locations which were within 2 days of each other were used to calculate movement rates. Mean daily movement rates were averaged weekly for each fish, and then mean daily movement was determined across all fish for each week. In this way, all fish are weighted equally, and no single fish can have a disproportionate influence on the calculations simply because that fish was detected more often.

Mean daily speed (movement rate regardless of direction, i.e. absolute speed in km/day) was averaged weekly and compared to mean daily surface temperature (^{0}C), mean daily discharge (cubic meters per second, CMS), and mean daily lake elevation (meters above sea level) which were also averaged for each week. Mean number of fish analyzed per week was 3.8 fish (range 1 – 13 fish, 3 or more fish were detected in 69% of the weeks). Note that fish were detected each week, so any week which has a mean daily average speed of 0 km/day does not indicate missing data but instead indicates that fish were not moving during that week.

The maximum mean daily speed in any week was 21.4 km/day (N = 4 fish), and the maximum speed recorded for an individual Silver Carp was 60.9 km/day. Movement rates seemed to be loosely related to surface temperature (Figure 6). The Silver Carp had clear seasonal movement patterns during both years; the fish do not move much during the colder months, show a spike in activity early in the spring, and then they maintain a steady rate of activity until water temperatures decline in the fall. A direct comparison of mean speed per week to mean surface temperature per week suggests that movement is consistently low below a threshold temperature but becomes higher and more variable above the threshold (Figure 7). A 2-dimensional Kolmogorov-Smirnov test suggested that the relationship between speed and temperature changed once the temperature rose above 13.3^{0}C (D_{max} = 0.118, $p<0.01$). Silver Carp movement decreased sharply once temperatures rose above 30^{0}C.

The movement of Silver Carp did not seem to be related to discharge levels or lake elevation. Several spikes in activity occurred in both years, but these spikes did not seem to relate to discharge levels or lake elevation.

Silver Carp movement can be studied at several scales; for example, the previous analysis summarized each fish's swimming rate in km/day and then summarized these values by week. Such an analysis is good for looking at overall activity levels across times, and it gives an idea of the distances that a Silver Carp can cover in a day. These values are based upon an "average" location and an "average" time each day, which gives an estimate of the general location of a fish each day. However, this analysis underestimates the swimming rates of fish because it is greatly influenced by the time periods when the fish is not moving much. To understand short-term swimming rates, focus was placed only on those times when a fish was actually moving. That is, swimming speed when a fish was moving from one set of VR2W receivers to the next nearest set of receivers, which is referenced as "On the Move" or OTM swimming speed.

The mean OTM speed of Silver Carp was 1.1 km/hr which would translate into approximately 26.4 km/day (Table 4). Silver Carp which were tagged by other agencies had a higher mean OTM speed which might be due to these fish being more nomadic than the population which were tagged in the lower Kentucky Lake and Lake Barkley systems.

Not only is swimming speed and activity important, but also of interest is the location of the fish within Kentucky Lake over time. To determine the average location of the Silver Carp over time first the average river kilometer (RK) for each fish on each day was calculated. Next, the mean RK for each fish each month, which provides the average location of each fish each month. Finally, the mean RK across all fish each month was determined which provides a general idea of the location of the carp population within Kentucky Lake each month. The median RK for 2017 – 2018 was 63.9 km which is near the mouth of Jonathan Creek, so the mean location of Silver Carp each month was compared to this location. To understand the relative position of Silver Carp, the median value of 63.9 km was subtracted from each month's mean RK to get an adjusted RK. The adjusted RK for a month would be negative if the average location of the fish were downstream from Jonathan Creek, and positive if the average location was upstream from Jonathan Creek.

The Silver Carp showed more obvious directionality of movement in 2018 compared to 2017 (Figure 8). In early 2018, the fish were mostly found in the lower end of the lake, closer to the dam, while later in the year they moved upstream.

Dam Passage

Twenty tagged fish crossed Kentucky and Barkley dams during 2017 – 2018 (Table 5). All of these crossing had robust evidence that the fish crossed, e.g. the fish was detected several km from one side of the dam and then later was detected several km on the other side. Often the crossing fish were detected in or around the lock, but many fish crossed the dam without being detected inside the lock. These missed detections are likely due to low batteries in the receiver and are not due to the inability of VR2W's to detect fish inside the chamber. Several fish were detected inside the lock and on receivers positioned just above and just below each lock; however, these fish were not counted as crossing the dam because it is possible that a fish could be detected on these receivers without actually moving from one side of the dam to the other. Two of the 20 fish that crossed the dam were Paddlefish which were tagged by the Missouri Department of Conservation, and 1 was an unknown fish that has not yet been identified. Three

of the 17 Silver Carp which crossed the dam crossed more than once. All 3 fish started in Kentucky Lake; 1 left through the Kentucky Dam lock and returned through this lock; 1 crossed over into Lake Barkley, left through the Lake Barkley Dam lock, and returned through the Kentucky Dam lock; and 1 left through the Kentucky Dam lock and returned through the Lake Barkley Dam lock. Four of the 20 Silver Carp which crossed the dam were tagged by the MDWFP and the rest were fish tagged by KDFWR and MSU. A few other fish which were tagged by other agencies outside the lake have been detected inside the lakes, and these fish must also have crossed through one of the dams before VR2W's were deployed inside the locks.

Dam crossings were somewhat related to overall Silver Carp activity in that few crossings took place during the colder months when the fish were not very active (Table 5). Once the water began to warm up, the fish began to move more and cross the dams more (Figure 9). Discharge did not seem to influence dam crossings much, except that no crossings occurred during extreme discharge events early in 2018 or later that year. However, water temperatures were colder at this time and the lack of crossing was probably more related to temperature. Rising water levels seemed to trigger dam crossings, but again this could also be related to rising water temperatures and an overall increase in activity.

Further upstream in the Tennessee River, four fish were detected passing through Pickwick Dam. One was detected in the forebay, primary lock and tailwater. The others were detected in the forebay and then again in the tailwater, but not in the lock. In contrast to KDFWR, receiver batteries were strong and a lack of detection in the lock was likely due to noise (e.g., prop wash, sonar). In the upper Tennessee River, there were multiple false detections within lock located receivers, and thus, suggested potential for boat interference and the importance of receivers in the lock approach and tailwater.

Deterrent Efficiency

Installation of the BAFF system in the downstream approach to Barkley Lock has been set for June 1st, 2019 (Figure 10). Crews will have 56 days to complete installation of the necessary equipment, with testing of the BAFF beginning immediately. A research group of professionals tasked with designing the study to test the efficiency of the BAFF deterring Asian carp movement upstream through the Lock was formed in 2018. KDFWR has representatives in this group and has provided information pertinent to the design of the study plan. The research group has begun to develop a study plan proposal with anticipation of a finalized version to be available in April of 2019. Testing of the BAFF is to extend for three years with funding from the USFWS.

Summary and Recommendations:

Silver carp are able to move through lock and dam structures. Once through the locks, Silver Carp readily travel the TN River. The KY-BK canal offers fish access to both reservoirs, fish have been detected moving through the canal into Barkley Reservoir and vice versa. Receivers placed in the Cumberland River during 2019 will help inform passage and barrier efficacy.

Data sharing of telemetry data among various agencies is encouraged with advancement. A shared document exists, however further sharing and integration into a larger framework should

be discussed. For example, the sharing of .vrb databases and data quality protocol discussion would be a welcomed asset to this project and allow multiple agencies the opportunity to look at datasets across state lines. Incorporating Ohio River and Ohio River tributary data within a national framework (GLATOS and USGS) could facilitate data sharing and a more comprehensive national data sharing community.

Test barriers should be deployed as soon as possible at each location identified in the Tennessee and Cumberland rivers. The committee should meet annually to reconsider the 2018 recommendations to address any changes in distribution of Asian carp or available technology.

Development of a plan for ideal barrier locations on the Ohio River. Although the lockmasters were amenable to assisting where needed, they did not provide any specific suggestions for ideal barrier locations. The 2003 USGS report "Upstream Fish-Passage Opportunities at Ohio River Mainstream Dams" by Knights, Wlosinski, Kalas, and Baley may serve as a guiding document for ideal barrier placement. The report covers USGS opinions and research as to the specific ability of Asian Carp to pass through main stem Ohio lock and dam facilities at varying water levels. The Markland Locks and Dam facility has potential for being an effective barrier location and more effort should be placed into identifying the technical hurdles to installing a system before seeking funding for the project.

Continued tagging to increase the number of marked fish in the Tennessee and Cumberland river systems, tributaries to the Ohio River. Continued maintenance of receiver arrays. Sharing data across jurisdictions. Determine whether high water levels and flows in spring 2019 compromised the current receiver array, for example, were any receivers lost due to sedimentation or have reduced detection of potential fish passage. KDFWR and MSU will direct additional effort toward 24-hour tracking to collect more fine-scale, diurnal movement data to inform removal efforts. Tagging of silver carp will continue in 2019 and some native fish will also be tagged in preparation of the BAFF to be installed in the downstream approach of Barkley Lock. KDFWR will continue to support the research and data collection efforts needed for testing of the BAFF.

Literature Cited:

Knights, B. C., J. H. Wlosinski, J. A. Kalas, and S. W. Bailey. 2003. Upstream fish passage opportunities at Ohio River Mainstem Dams. Completion report prepared for U.S. Army Engineer District, Nashville, CELRN-PM-P, P.O. Box 1070, Nashville, TN 37202-1070 by U.S. Geological Survey, Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Road, La Crosse, Wisconsin, 54603.

Table 1. Summary of Silver Carp surgically implanted with acoustic transmitters in Kentucky Lake and the Lake Barkley tailwaters during 2018.

	# Tagged		Mean TL (mm)		Mean W (g)		
Surgery Date	F	M	F	M	F	M	Release Location
2018-01-25	17	7	747	729	4,128	3,643	Barkley Tailwaters
2018-04-19*	12	4	690	724	3,496	3,830	Barkley Tailwaters
2018-11-08	2	1	558	537	1,858	1,592	Hancock Bio. Stat.
Total	31	12	713	711	3,737	3,534	

* 1 Silver Carp of unknown sex was also tagged on this date

Table 2. Summary of live Silver Carp detections by origin, detection type, and year for Kentucky Lake and the Lower Tennessee River. Table values indicate the number of different individuals detected in each category.

Agency fish	2016		2017		2018	
were tagged by	Manual	VR2W	Manual	VR2W	Manual	VR2W
KDFWR	33	30	21	26	22	25
MDWFP					1	9
TWRA					5	10

[1]KDFWR = Kentucky Department of Fish and Wildlife Resources, MDWFP = Mississippi Department of Wildlife, Fisheries, and Parks, TWRA = Tennessee Wildlife Resource Agency

Table 3. Summary of live Silver Carp detections by origin, detection type, and year for Lake Barkley and the Lower Cumberland River. Table values indicate the number of different individuals detected in each category.

Agency fish	2017		2018	
were tagged by	Manual	VR2W	Manual	VR2W
KDFWR[1]	1	23	40	58
MDWFP			1	8
TWRA			1	2
USFWS			1	1

[1]KDFWR = Kentucky Department of Fish and Wildlife Resources, MDWFP = Mississippi Department of Wildlife, Fisheries, and Parks, TWRA = Tennessee Wildlife Resource Agency, USFWS = U. S. Fish and Wildlife Services

Table 4. Mean "On the Move" speed (OTM) for Silver Carp in Kentucky Lake, 2017 – 2018. OTM speed represents the swimming speed of a fish when it is swimming from one set of VR2W receivers to the next nearest set of receivers.

Agency	Mean Swimming Speed (km/hr)	s.d.	N	Range (km/hr)
KDFWR[1]	1.1	0.6	20	(0.2 – 2.4)
MDWFP	2.8	1.0	10	(1.8 – 4.4)
TWRA	1.6	0.7	5	(0.6 – 2.3)

[1]KDFWR = Kentucky Department of Fish and Wildlife Resources, MDWFP = Mississippi Department of Wildlife, Fisheries, and Parks, TWRA = Tennessee Wildlife Resource Agency

Table 5. Summary of dam crossings at Kentucky Lake and Lake Barkley, 2017 – 2018.

Dam	Transmitter	When Crossed	Direction	Detected in Lock during Passage	Species	Agency[1]	Release Location
Kentucky	A69-1601-55722	2017-05-02	upstream	Y	Paddlefish	MDC	Outside Lakes
Kentucky	A69-1601-54748	2017-05-17	upstream	Y	Paddlefish	MDC	Outside Lakes
Kentucky	A69-1601-51729	2018-01-26*	downstream	N	Silver Carp	KDFWR	HBS Dock
Barkley	A69-1601-54220	2018-04-15*	upstream	N	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1601-52072	2018-04-24	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1601-51748	2018-04-28	downstream	N	Silver Carp	KDFWR	Camp Currie
Kentucky	A69-1601-56736	2018-04-29*	downstream	N	Silver Carp	MDWFP	Indian Creek
Barkley	A69-1601-56732	2018-05-01*	downstream	N	Silver Carp	MDWFP	Indian Creek
Kentucky	A69-1601-56725	2018-05-01*	downstream	N	Silver Carp	MDWFP	Indian Creek
Kentucky	A69-1601-56733	2018-05-03	downstream	N	Silver Carp	MDWFP	Indian Creek
Barkley	A69-1602-28451	2018-05-09	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1602-29250	2018-05-26	upstream	Y	unknown	unknown	unknown
Barkley	A69-1602-28427	2018-06-08	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Barkley	A69-1602-28432	2018-06-24	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1601-51748	2018-06-27	upstream	Y	Silver Carp	KDFWR	Camp Currie
Barkley	A69-1602-28485	2018-07-04	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Barkley	A69-1601-56733	2018-07-06	upstream	Y	Silver Carp	MDWFP	Indian Creek
Barkley	A69-1602-28424	2018-07-10	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Barkley	A69-1602-28453	2018-07-23	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1602-28444	2018-08-09	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1601-52012	2018-08-21*	downstream	N	Silver Carp	KDFWR	Sledd Creek
Barkley	A69-1601-52079	2018-09-10	upstream	Y	Silver Carp	KDFWR	Barkley Tailwaters
Kentucky	A69-1601-56732	2018-09-29	upstream	Y	Silver Carp	MDWFP	Indian Creek

*Crossing date is approximate because not enough detections are available to pinpoint crossing.

[1]KDFWR = Kentucky Department of Fish and Wildlife Resources, MDC = Missouri Department of Conservation, MDWFP = Mississippi Department of Wildlife, Fisheries, and Parks, TWRA = Tennessee Wildlife Resource Agency

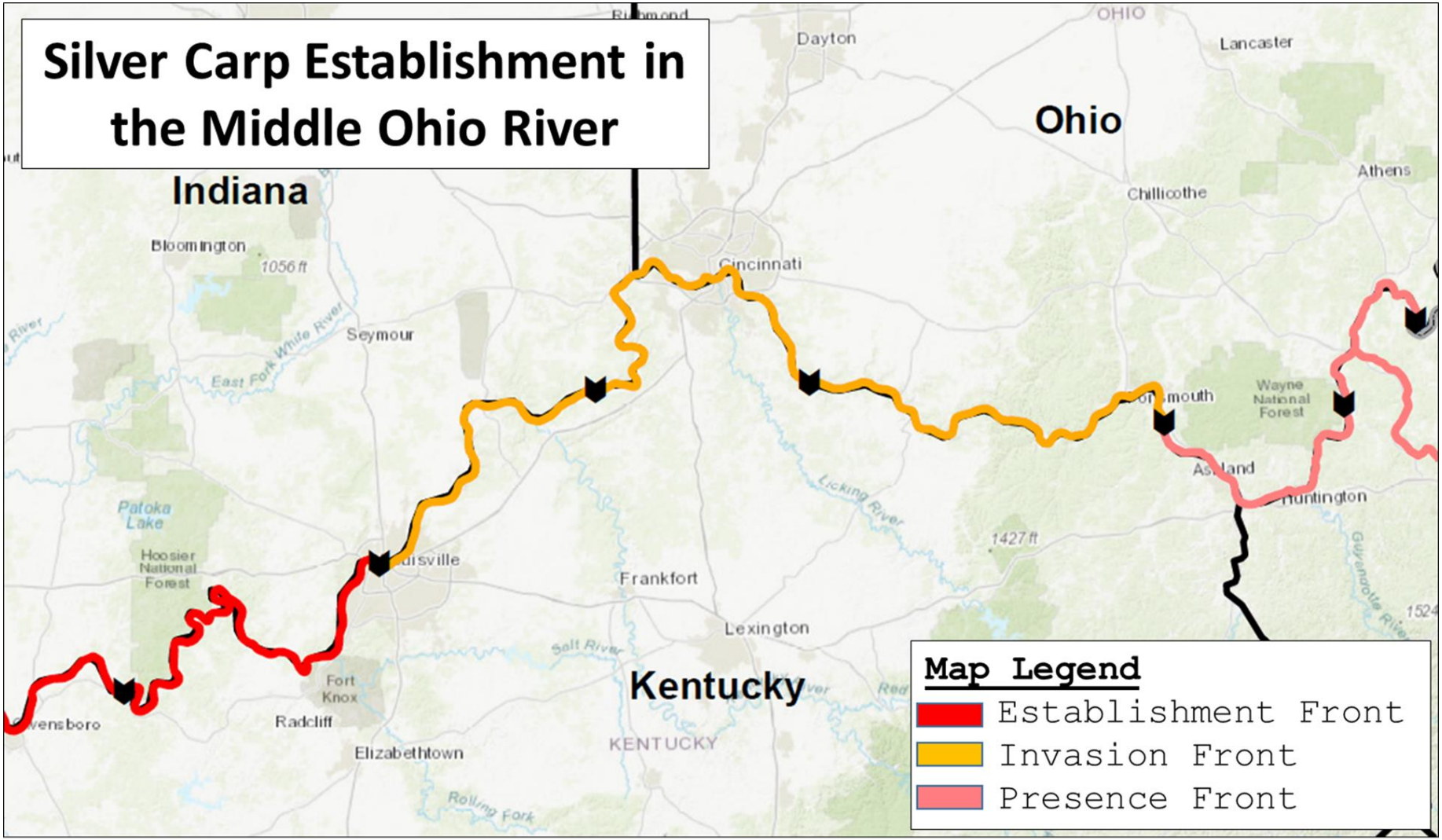

Figure 2. A map of the middle Ohio River (river miles 757 – 238) including lock and dam facilities (black dots) and range of Asian carp presence in the middle Ohio River.

Gage ID #	Location	OHR Pool	RM #	Pool Stage	Flood Stage	Gage "Zero" Elevation	Normal Pool Elevation	Flood Stage Elev.	Action Stage	Mod. Flood Stage	Maj. Flood Stage	Pool Elev.	Date of Highest	Highest Reading	Date of Lowest	Lowest Reading
03151000	Parkersburg_WV	Bellville	184.4	21.40	36.00	560.60	582.00	596.60	34.0	38.0	42.0	582.0	2015-04-12	34.67	2016-07-04	20.37
03201500	Point Pleasant_WV	RC Byrd	265.1	24.92	40.00	513.08	538.00	553.08	38.0	44.0	48.0	538.0	2011-03-12	46.68	2016-04-02	23.70
03206000	Huntington_WV	Greenup	311.5	25.84	50.00	489.16	515.00	539.16	48.0	55.0	59.0	515.0	2015-03-07	51.46	2016-07-04	24.39
03217200	Portsmouth_OH	Meldahl	354.1	15.53	50.00	469.47	485.00	519.47	35.0	57.0	66.0	485.0	2015-03-15	53.31	2014-10-03	13.45
03255000	Cincinnati_OH	Markland	470.5	26.77	52.00	428.23	455.00	480.23	40.0	56.0	65.0	455.0	2015-03-15	57.52	2015-09-02	25.85
03277200	Markland L&D	McAlpine	531.5	12.00	51.00	408.00	420.00	459.00	49.0	62.0	74.0	420.0	2015-03-15	53.02	2015-08-15	11.69
03292494	L-ville Water Tower	McAlpine	600.6	13.40	24.00	406.60	420.00	430.60	22.0	31.0	39.0	420.0	2015-03-16	31.33	2016-12-05	12.30
03293551	L-ville 31 Bridge	McAlpine	603.6	12.80	23.00	407.20	420.00	430.20	21.0	30.0	38.0	420.0	2015-03-16	30.27	2016-10-22	12.06
03294600	Kosmosdale_KY	Cannelton	627.1	10.25	54.60	372.75	383.00	427.40	52.6	64.6	72.6	383.0	2011-03-11	89.19	2011-07-28	5.02
03303280	Cannelton L&D	Newburgh	720.9	10.00	42.00	348.00	358.00	389.33	40.0	46.0	50.0	358.0	2015-03-17	47.33	2014-09-25	9.94

Figure 3. USGS Water gauges of interest on the main stem Ohio River, including typical height and highest recorded water levels.

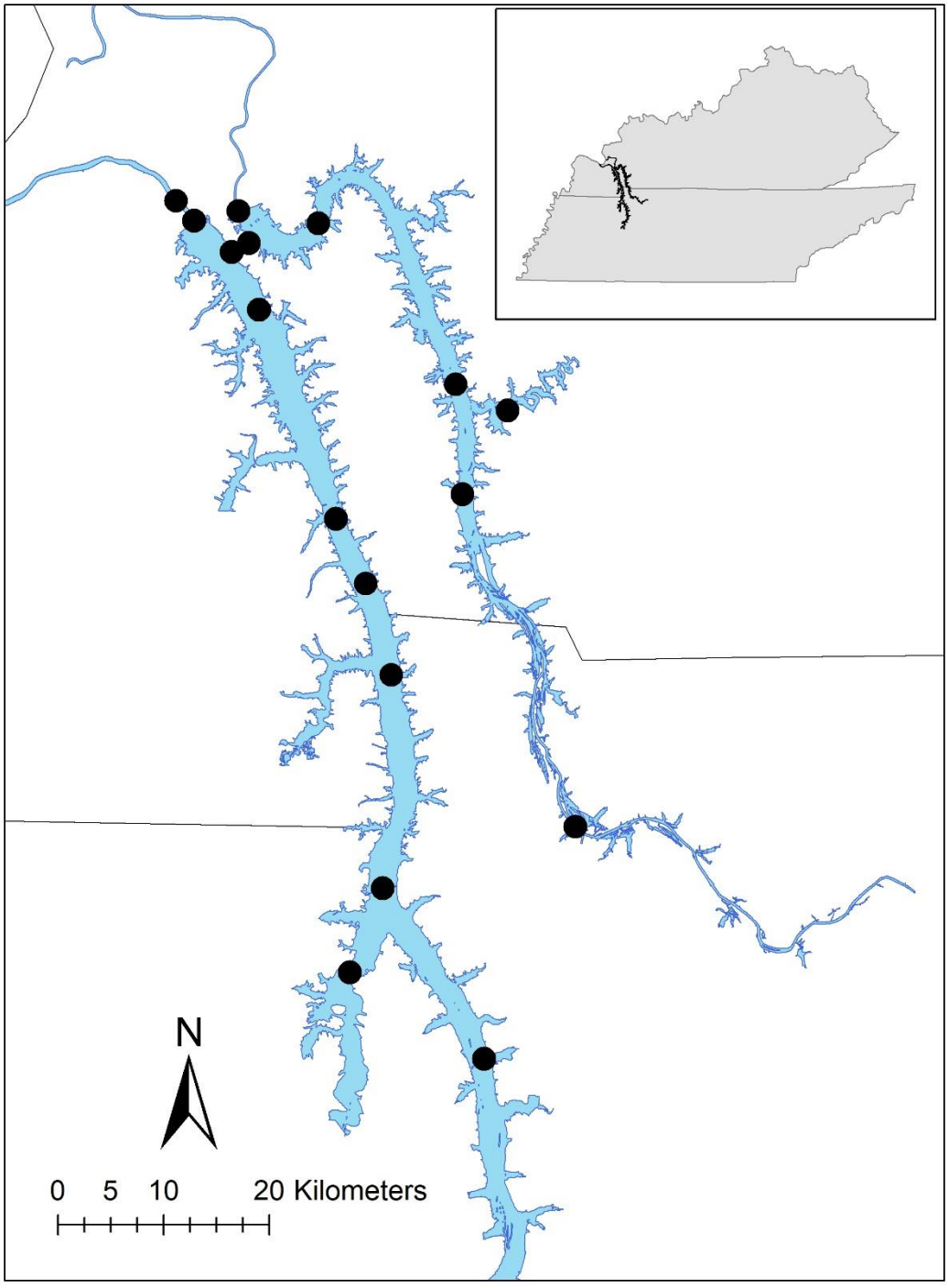

Figure 4. Location of VR2W passive receivers deployed throughout Kentucky Lake and Lake Barkley. Black dots indicate the location of one or more receivers.

Figure 5. Yellow dots indicate location of passive VEMCO VR2W receivers deployed around the Lake Barkley Lock and tailwaters.

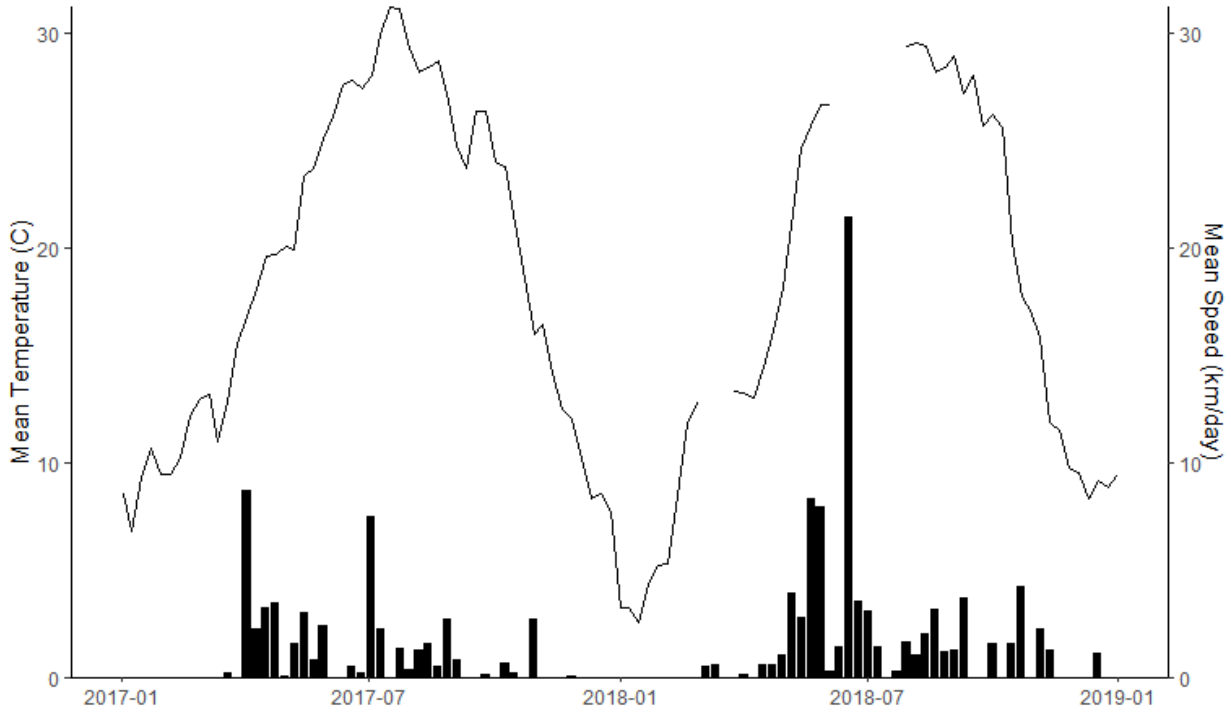

Figure 6. Mean weekly surface temperature (C, solid line) and mean weekly swimming speed (km/day, black bars) for Silver Carp in Kentucky Lake, 2017 – 2018.

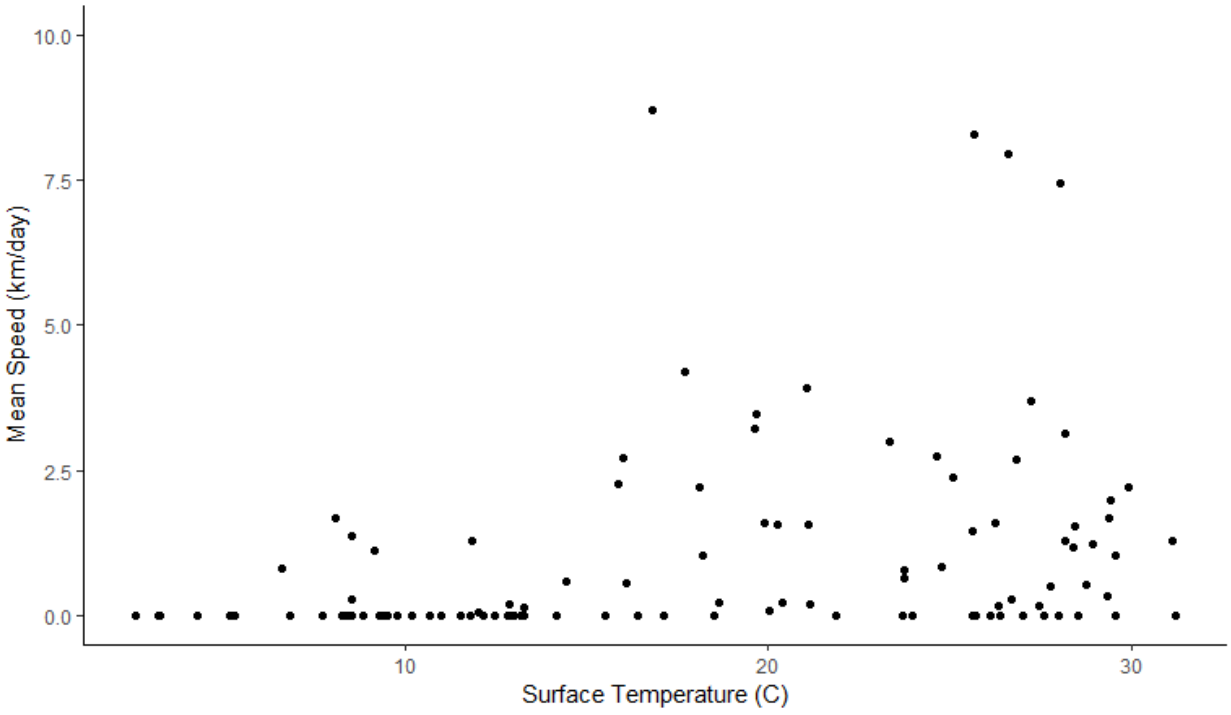

Figure 7. Comparison of Silver Carp mean weekly swimming speed (km/day) and mean weekly surface temperature (C). A 2-dimensional Kolmogorov-Smirnov test suggests that the relationship between speed and temperature changes once temperatures rise above 13.30C (Dmax = 0.118, p = 0.000).

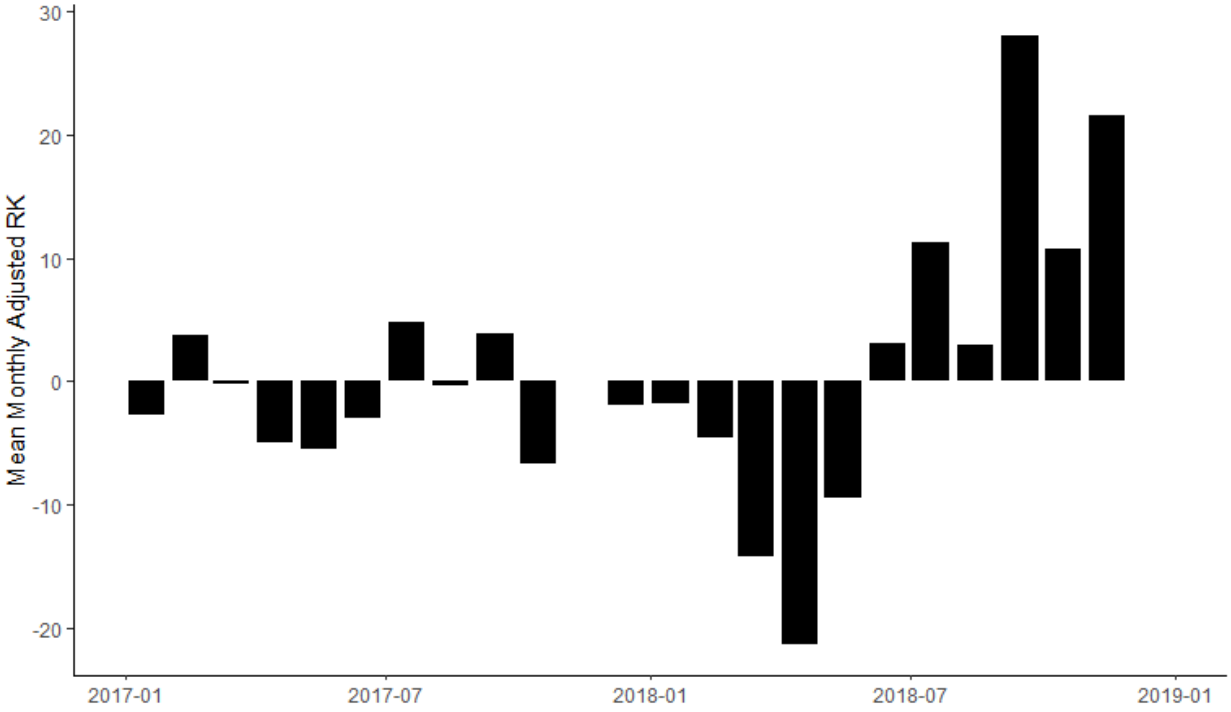

Figure 8. Mean monthly adjusted river kilometer (RK) for Silver Carp in Kentucky Lake. The RK is adjusted relative to RK 63.9 which is the median RK over 2017 – 2018 and which is near the mouth of Jonathan Creek. Negative values represent locations downstream from Jonathan Creek while positive values indicate locations upstream from Jonathan Creek. The Kentucky Lake Dam is at RK 36 which would be an adjusted RK of -27.9.

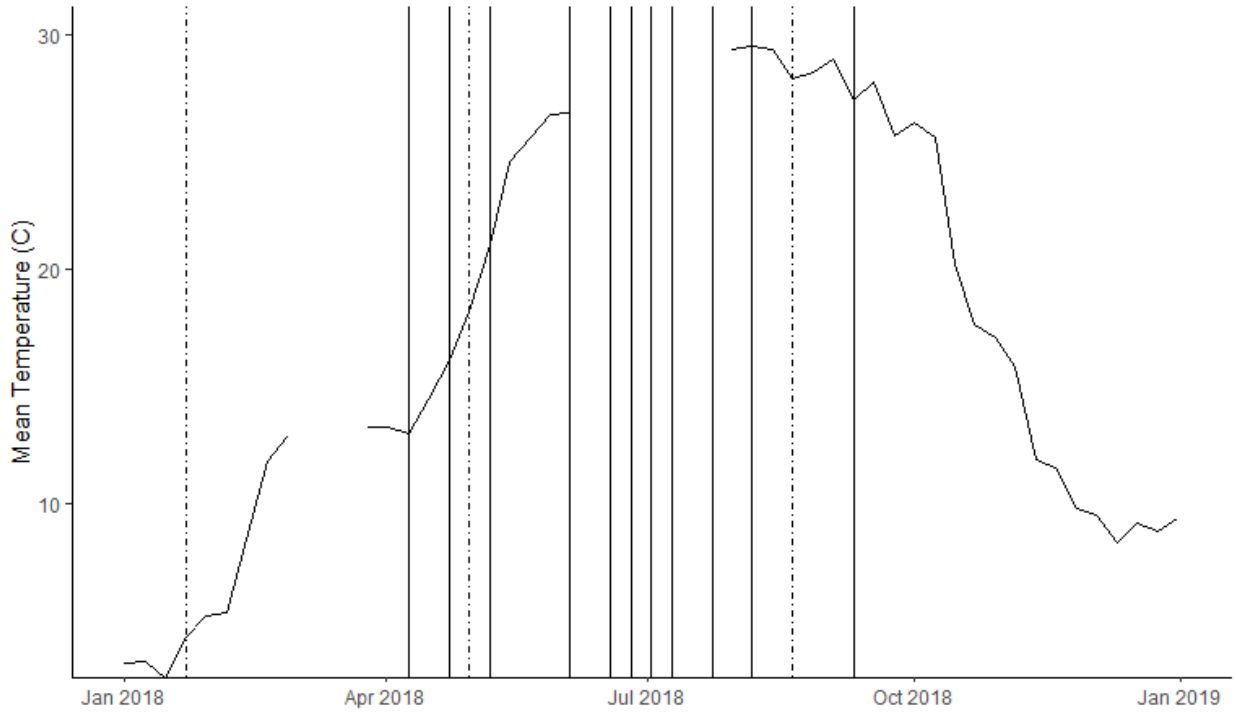

Figure 9. Silver Carp weekly dam crossings and surface temperature (°C) of Kentucky Lake. Dashed lines indicate downstream crossings and solid lines indicate upstream crossings. Dam crossings include both Kentucky Lake Dam and Lake Barkley Dam.

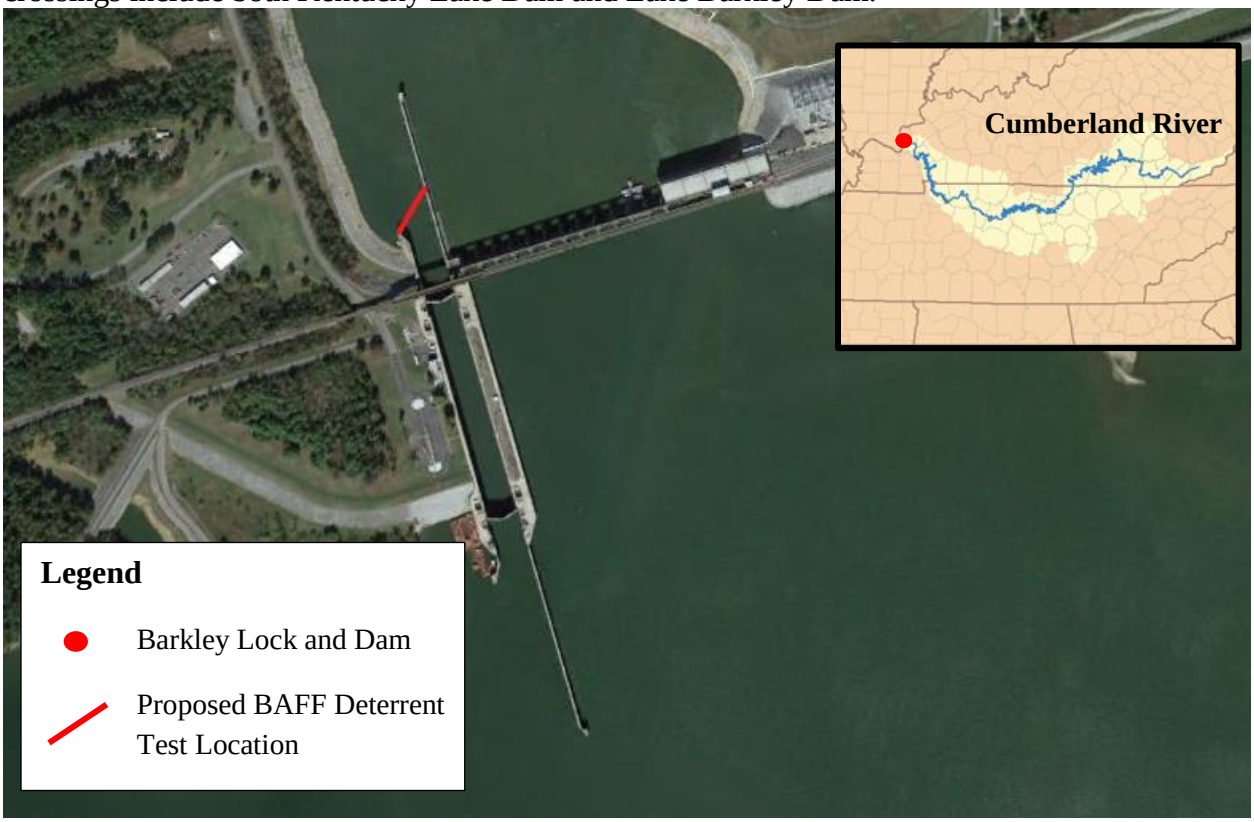

Figure 10. Proposed location for installation of Bio-Acoustic Fish Fence (BAFF) deterrent system for testing at Lake Barkley Lock and Dam on the Cumberland River.