Distribution, movement, and lock and dam passage of Asian carp in the Ohio River through acoustic telemetry 2017 Report

Geographic Location: The Ohio River from Cannelton pool near Leavenworth, IN, to just upstream of the Willow Island Lock and Dam near Eureka, WV.

Participating Agencies: US Fish and Wildlife Service (USFWS), Kentucky Department of Fish and Wildlife Resources (KDFWR), Ohio Department of Natural Resources Division of Wildlife (ODNR DOW), West Virginia Division of Natural Resources (WVDNR), Indiana Department of Natural Resources (INDNR)

Statement of Need: The bigheaded carps, herein referred to as Asian carp, include the Silver Carp (*Hypophthalmichthys molitrix*) and Bighead Carp (*H. nobilis*) as well as hybrids between these species. Asian carp are highly invasive fishes that have been expanding their range in the U.S. since the early 1980's when they first began to appear in public waters (Freeze and Henderson 1982; Burr et al 1996). Asian carp have been shown to exhibit very high reproductive potentials with high fecundity and the potential for a protracted spawning period (Garvey et al. 2006). Populations of Asian carp have grown exponentially because of their rapid growth rates, short generation times, and dispersal capabilities (DeGrandchamp 2003; Peters et al. 2006; DeGrandchamp et al. 2008). Tsehaye et al. (2013) stated that high reproductive capacity of both species, in particular Silver Carp ensure that attempts to exclude or remove individuals will require a massive undertaking (>70% exploitation) that targets all age classes and sizes. Any information that we can learn about Asian carp distribution, abundance, and/or biology that could facilitate targeting susceptible life stages could therefore limit population expansion.

Populations of Asian carp have become well established in the lower and middle reaches of the Ohio River and successful reproduction is suspected as far upstream as the Falls of the Ohio at Louisville, Kentucky. The upper reaches of the Ohio River as well as many upper basin tributary streams may not currently be inhabited by Asian carp. The need exists to prevent the establishment of these species into the upper portions of the Ohio basin

The Great Lakes and Mississippi River Interbasin Study (GLMRIS) identified six different possible routes for ANS to access the Great Lakes Basin through tributaries of the Ohio River. Because of these potential connections between Ohio River tributaries and Lake Erie, natural resource managers are concerned about the potential for the invasion of Asian carps into the Great Lakes Basin through the upper Ohio River watershed. If Asian carp gain entry into the Great Lakes they could pose a significant threat to established fisheries by competing with economically and recreationally important fishes for limited plankton resources (Sparks et al. 2011). They would also pose a very real danger to recreational boaters. Although predictions of the effects of Asian carp on the Great Lakes ecosystem vary widely, negative impacts on the fishery and recreational use of these resources are expected such that prevention is the preferred management action.

The overall goal of these efforts is to understand the distribution and movement patterns of Asian carp in the middle and upper Ohio River. Understanding these aspects of Asian carp biology in the Ohio River will assist efforts to minimize their further spread in the basin and reduce the size of existing populations.

Project Objectives:

1. Understand use of tributaries as potential sources for recruitment and routes of invasion into adjacent basins.
2. Delineate the upstream population distribution and potential for further upstream dispersal.
3. Help inform contract fishing and agency sampling efforts utilizing telemetry data.
4. Quantify passage of Asian carp at Ohio River locks and dams.

Project Highlights:

- In 2017, the project's extensive array of 158 stationary receivers logged more than 8 million detections from a total of 263 tagged Silver and Bighead carp that were spread across five different pools of the Ohio River.
- Over the course of this study, most of the fish being detected by receivers were found in the same pool where they were originally tagged. Between their first and last detections of 2017, more than 80% of the tagged carp detected last year had moved a net total of five miles or less in either an upstream or a downstream direction.

- Tributary usage by tagged carp in the Cannelton, McAlpine and Markland pools was significantly greater than their use of the mainstem Ohio River, but in the Capt. A Meldahl Pool, tagged carp appeared to occupy the mainstem river more often than any of its tributaries.
- Asian carp have a greater probability (0.18) of moving from the mainstem river into tributaries than moving from tributaries into the mainstem (0.13).
- Preliminary pool-to-pool transition probabilities are still quite small for both Bighead and Silver Carp
- Annual survival of tagged Silver Carp was estimated at nearly 77%, while tagged Bighead Carp survival was more than 85%, but with greater confidence interval margins.

Methods: Ultrasonic telemetry was used to track the movements of Asian carp and evaluate their ability to pass the lock and dam systems upstream of current known populations.

Ultrasonic Transmitter Tagging: Adult Bighead and Silver carp were surgically implanted with ultrasonic transmitters (Vemco, Model V16-6H; 69 kHz) which provide individual identification. These VEMCO V16-6H transmitters encode their unique Tag ID number into an ultrasonic signal that is randomly transmitted every 20 – 60 seconds. Because of this relatively long period between signals, the selection of a high-capacity lithium battery and the lack of extra sensors have all contributed to the transmitter's above-average battery life of 1,825 days, or 5 years. Gill nets and Direct Current (DC) boat electrofishing were used to capture Asian carp for tagging. The efforts were concentrated in habitats that are attractive to Asian carp such as side channels, backwaters, and tributary creeks and rivers. The majority of the 2017 sampling efforts occurred during the spring/summer, and they were concentrated in the Markland and Meldahl pools. The main purpose of these efforts was to replace the tagged Bighead and Silver Carp from 2013-2014, which were originally implanted with transmitters that will start shutting down during summer 2018. Other efforts in 2017 included those in the early fall that were focused on tagging additional fish from the higher density Asian Carp population in the lower Cannelton Pool. After being implanted with a transmitter, the total length, weight and sex of each carp was recorded, and then prior to release, an external aluminum jaw tag was applied to its dentary bone (lower jaw) (National Tag Co. #1242 F9), which allowed for quick identification if the tagged carp was ever recaptured.

Ultrasonic receiver array: A complete array, with both VR2W's and VR2AR's, was established following the redeployment of overwintering receivers to their respective mainstem sites during late March 2017. The project's array consisted of receiver stations that were established across three different site types, which included the mainstem Ohio River, the first two miles of major tributaries and above/below Lock & Dam (L&D) facilities. Most of these efforts in 2017 were focused on establishing new stations to improve the receiver coverage in tributaries that were most likely to contain Asian Carp. Finally, during mid-December 2017, VR2W receivers were once again pulled from stations located in the mainstem Ohio River and kept in overwinter storage to avoid further losses of equipment caused by ice flows.

Mobile Tracking: Active tracking was used in concert with netting and electrofishing to help locate tagged fish and increase the likelihood of capturing additional fish to tag. During each effort, tagged fish were located with a portable hydrophone and receiver (Vemco Model VH110-10M and Vemco Model VR100, respectively).

Collection & Management of Tagged Carp Detections: With the project's array more than doubling since 2013, the participating agencies redistributed the receiver responsibilities in order to improve the efficiency of the monthly efforts to offload new telemetry data from each receiver station. As a result, in 2017, the KDFWR concentrated its efforts on maintaining/offloading the ~40 receiver stations found within the initial 170 miles of the array, while the USFWS and ODOW shared responsibility for the 100+ receivers that were spread throughout the array's upper 330 miles. These efforts to offload new telemetry data were conducted monthly from April to November 2017. Upon completion of their offloading efforts each month, project biologists combined the newest tag detections into a monthly dataset and then shared it with other agencies via a file transfer protocol (FTP) site. As in previous years, the KDFWR resumed efforts to remove all duplicate/erroneous detections from the datasets that all agencies had obtained throughout 2017. All remaining detections were imported into the 2017 telemetry database, which was subsequently reduced to create datasets consisting of hourly/daily detections of tagged carp. Biologists used these datasets to track Asian Carp movements on broader scale (i.e. pool transfers) and/or over longer periods (i.e. weeks & months). An analysis of the entire 2017 telemetry dataset was also completed using R and the VTrack package (v1.11), which consisted of specific tools for analyzing the larger telemetry datasets. All other GIS work for the 2017 Telemetry Project was conducted with ArcMap (v10.5).

Other Statistical Analyses: Pool-to-pool transition probabilities, mainstem river to tributary transition probabilities, annual survival, and detection probabilities were estimated using the "Multi-state with Live Recaptures" analysis in Program MARK (G.C. White, Dept. of Fish, Wildlife, and Cons. Bio., Colorado State University, Fort Collins, CO). Encounter histories were constructed for each individual by determining the pool of last known detection for each month for each year (June 2013 through December 2017). Because individuals were tagged throughout the duration of this study, not all individuals have a complete encounter history (maximum of 55 possible time periods). Encounter histories of tagged carp that had been harvested or whose tag's battery had expired were right censored and removed from the estimation procedures. These encounter histories were then used to construct models to estimate pool transition, survival, and detection probabilities for each species by pool and month. Numerous models were constructed that tested whether data supported more complex models beyond time-invariant parameter estimates (e.g., survival constant across all months vs variable across months) and spatially invariant parameter estimates (e.g., survival is constant across all pools vs variable across pools). The best models for each species were selected based on the Akaike's information criterion corrected for small sample size (AIC_c); a difference in AIC_c values exceeding 2 was taken as evidence that a model outperformed a competing model, with smaller values being better.

Results and Discussion:

Receiver Array Placement: After VR2W's were redeployed to mainstem sites in March 2017, and all of the new receiver stations had been established in tributaries, the project's 500-mile telemetry array in 2017 included at least some portion of nine different pools and contained a total of 158 receiver stations (Figure 1). There were five VR2AR acoustic release receivers that were never recovered from their last deployment sites approximately one mile upstream of the Markland, Capt. A. Meldahl, Greenup, R. C. Byrd, and Belleville dams during April. Additionally, one VR2AR receiver was lost at the mouth of the Kanawha River. Only one of the lost VR2AR receivers was replaced (upstream of the Belleville dam). The VR2AR receivers in Ohio Brush Creek and Big Sandy River were retrieved, data offloaded, and redeployed. In addition, the extensive efforts to improve/establish the telemetry coverage in tributaries located throughout the array had succeeded in creating 33 new receiver stations across 18 different tributaries, which included 15 creeks, streams and small rivers that had never been monitored for tagged carp (Figure 2).

As previously noted, the telemetry array consists of many individual receiver stations that can be grouped according to a site's habitat type and the pool that it's located in. The locations for new stations in 2017 were limited to tributaries and L&D's because the receiver distribution was already skewed towards mainstem sites, which represented nearly 70% of the established receiver stations at the end of 2016. However, by the completion of the 2017 receiver work, the limited site selection helped improve the distribution of the project's telemetry array, which ultimately finished out the year with a combination of 76 mainstem (48%), 54 tributary (34%) and 28 L&D (18%) sites (Table 1).

Fish Tagging Efforts– Over the summer and fall of 2017, the USFWS and KDFWR used a combined 5+ weeks of gill netting and pulsed-DC electrofishing to successfully implant transmitters into a total of 107 Asian Carp, which was composed of 98% Silver Carp (n = 105) and 2% Bigheads (n = 2) (Table 2). After field crews from both agencies tagged only 17 Asian Carp during 4+ weeks of sampling the lower density populations in Markland and Meldahl, the USFWS field crews eventually moved downstream in early October to target higher densities of Asian Carp in the lower Cannelton Pool. They were able to collect/tag an additional 90 Silver Carp in a single week of sampling.

From 2013 through 2017, a total of 508 Asian carp have been surgically implanted with acoustic transmitters from the Cannelton, McAlpine, Markland, Capt. A. Meldahl, and R. C. Byrd pools of the Ohio River (Table 2). Even with tagging efforts occurring in six different pools since 2013, more than 83% of the project's tagged carp were collected from the higher density populations in Cannelton and McAlpine. A length frequency distribution of all 500+ tagged carp indicated that 84% of Silver Carp obtained from "high-density" populations (Cannelton & McAlpine) had total lengths of less than 900 mm, but in contrast, a similar proportion (81%) of the Silver Carp from lower density pools (Markland & Meldahl) actually had total lengths of 900 mm or more (Table 3). A similar evaluation of tagged Bighead Carp showed that 98% had total lengths exceeding 1000 mm, but no notable size differences were found between Bighead Carp sampled from different pools (Table 4).

Fish Detections: In 2017, project biologists completed numerous efforts to error-check and format the telemetry datasets that were offloaded monthly by field crews from the KDFWR, ODOW, USFWS and WVDNR. Upon importing the final datasets into the database, it was determined that between 01 January 2017 and 14 December 2017, eighty-one (51.2%) of the 158 receivers in the array made a combined total of ~8,175,000 detections of tagged Asian Carp (Table 5). Further analysis determined that the database contained at least one detection from 263 (51.8%) of the 508 total carp that have been tagged over the past five years. However, this total also included the 90 Silver Carp that were recently tagged (October 2017) in the lower half of the Cannelton pool, which was up to 50 miles downstream of the closest receiver. This could reduce the detection percentage until additional receivers are placed in this area of the pool or until these recently tagged fish move upstream into the receiver array. The 2017 database was also reduced to create two separate datasets of 346,478 hourly and 35,064 daily detections, which were later used to analyze the large-scale movements.

Although many receivers had similar numbers of tagged carp detections, there were "hot spots" where substantially more detections were recorded (Figure 3). The area containing the largest proportion of detections (82%) was the McAlpine Pool, which was not unexpected from a mid-sized pool (~75 miles) containing 22 active receivers and as many as 237 tagged carp. Overall, the McAlpine receivers made a total of 6.7 million detections of 164 unique carp during 2017. This was more than 10 times higher than the Meldahl Pool receivers credited with making 573,578 tagged carp detections, which is the project's 2nd highest total in 2017 (Table 5).

Fish Movements – During 2017 the majority of tagged fish in this study remained close to the area in which they were initially detected at the start of the year. Over 81% of the tagged fish detected during this study had a net upstream or downstream movement of five miles or less (Figure 4). The mean monthly ranges were also determined for Bighead Carp and Silver Carp that were recorded by a least two receivers during 2017. These ranges were established by first separating all hourly detections by pool and then calculating the distance (in river miles) between the most upstream and most downstream detections for each tagged carp over a specific time period (i.e. month). When the monthly distances were compared for both carp species in the McAlpine, Markland and Meldahl pools, the results indicated that Bighead Carp tend to cover a larger stretch of river during most months, with the exception of April 2017, when Silver Carp in Markland had a mean range that was more than double that of Bighead Carp (Figure 5). Regardless of the pool, both species appeared to be quite active between April and August 2017, but during these 5 months, the Bighead Carp often exhibited greater distances between their most upstream and downstream detections (Figure 6). Even though they had been relatively active, Bighead Carp movements ended abruptly during September. In contrast, the Silver Carp were still active in October and November, but their mean ranges during these fall months were noticeably reduced compared to spring and summer.

Model Selection – The best model selected for Silver Carp provided time and state invariant survival estimates, probability of detection estimates that varied over space and time, and movement estimates that varied for each pool. The closest competing model of the remaining 119 models that were tested had a ΔAIC_c of 75 and included an additional 132 parameters. Of the 104 models run for Bighead Carp, the top model selected provided time invariant survival estimates, probability of detection estimates that varied over space and time (i.e., seasonally), and movement estimates that varied for each pool. The ΔAIC_c of the next closest model was nearly 4.5 and included an additional two parameters. The model selected to determine differences in survival, detection probabilities, and transition probabilities between mainstem river habitats and tributary habitats had time dependent survival, detection probabilities that varied over space and time, and movement estimates that varied between the mainstem and its tributaries. Of the 65 models run, one closely competing model ($\Delta AIC_c < 2$) was not selected due to its greater level of complexity (an addition of 11 parameters) while explaining for less of the variability in the data.

Tributary Use – Tributary use within Cannelton, McAlpine, Markland, and Capt. A. Meldahl pools was analyzed by comparing the number of unique tags detected daily by receivers located either in the mainstem Ohio River or in its tributaries. A paired two-tailed t-test was used to determine whether the number of tagged fish located within tributaries was significantly different than those located by mainstem receivers. Based on unique detections per day, tributary use was higher than the mainstem in Cannelton ($p < 0.0001$), McAlpine ($p < 0.0001$), and Markland pools ($p < 0.0001$), whereas use of the mainstem habitat was higher in the Capt. A. Meldahl pool compared to tributaries ($p < 0.0001$). Detection and transition probabilities between the mainstem Ohio River and its tributaries for 2017 were analyzed using multi-state modeling in Program MARK. Probability of detection was significantly higher in tributaries than in the mainstem river throughout all months, except for December, when detection probabilities were higher in the mainstem river (Figure 7). During any given time period, telemetered fish within the mainstem river had an 18% chance of moving from the mainstem into tributaries, whereas those already in tributaries were 7 times more likely to remain in tributaries that to transition to mainstem habitats. That said, individuals already in mainstem habitats were 4.6 times more likely to remain in the mainstem habitat as opposed to transition to tributaries even when accounting for differences in detection probabilities between these two habitats. This further demonstrates the two dichotomies of individual behaviors in which there are individuals that could be highly mobile and those that are more sedentary.

Dam Passage – Throughout this study, there have been 41 dam passage events by 16 Silver Carp and seven Bighead Carp. Of these 23 fish, three Bighead Carp and four Silver Carp were responsible for 20 (48.78%) of the passage events. Sixteen of the 41 (39%) passage events were in an upstream direction by three Bighead Carp (eight passes), six Silver Carp (seven passes), and one unidentified tagged fish (one pass). Of the tagged Bighead and Silver Carp, 16.28% and 3.46% were found to pass through dam structures, respectively. During 2017, ten Asian Carp (two Bighead Carp, six Silver Carp, two unidentified tagged carp) passed through dams on 15 occasions with six being in an upstream direction *(Table 6)*. Of the 15 passage events, five are thought to be through the use of the lock chambers. Preliminary pool to pool transition probabilities were found to be highest for Silver Carp from McAlpine pool to Markland pool (0.12 ± 0.01) and from Cannelton pool to Markland pool (0.10 ± 0.02) (Table 7). For Bighead Carp, transitions from Markland pool to McAlpine pool (0.28 ± 0.05), Cannelton pool to McAlpine pool (0.27 ± 0.10), and Capt. A. Meldahl pool to McAlpine pool (0.14 ± 0.03) showed the highest probabilities (Table 8). For both Silver Carp and Bighead Carp in any navigation pool along the Ohio River, staying within the same pool accounted for the most likely observation.

The 2017 hourly detection data also contained eight instances where tagged carp initially appeared to transfer pools, but a closer examination of the details surrounding each event raised some doubt as to whether a pool transfer actually occurred (Table 9). There were seven tagged carp (5 Silver Carp, 1 Bighead and an unknown) in 2017 that had made “possible” pool transfers. In each occurrence, the only detection(s) of the tagged carp in the adjacent pool came from a receiver in the upstream/downstream approach that was located on the opposite side of the L&D that each carp supposedly transferred through. It may be possible for an ultrasonic signal to bounce around a lock chamber and be picked up by the receiver on the other side of the gate. All seven tagged carp returned to their original pool soon after the detections were made in the opposite approach, which lends credence to the original hypothesis. Each event will remain a “possible” pool transfer until the tagged carp is detected in the adjacent pool by a receiver that is not directly associated with the L&D. Finally, there was an additional pool transfer involving a Bighead Carp that moved downstream into the McAlpine Pool via the Markland L&D without a single detection, but it was then detected by a receiver in the Kentucky River before returning to the Markland Pool by once again moving undetected through Markland L&D. Because of the high speed required to complete the trip and the need to pass many receivers without detection, it is highly unlikely that this event actually occurred, and as a result, it has been officially marked as an “Invalid Transfer”.

Survival – The annual survival estimate of tagged Asian carp was calculated in Program MARK using a multi-state live-capture model. Silver Carp survival was estimated to be 76.98% (95% C.I. = 71.63 – 81.47%) throughout all pools. Bighead Carp were found to have a slightly higher annual survival rate at 85.32% (95% C.I. = 61.46 – 95.17%), however, the 95% confidence interval was less constricted than the Silver Carp estimate due to the lower sample size of Bighead Carp in the study. Given that only one of these fish were known to have been harvested, we believe that this estimate provides a robust estimate of natural mortality (e.g., 95% CI = 18.53% - 28.02% for Silver Carp; 95% CI = 4.83% - 38.54% for Bighead Carp).

Recommendations:

After following recommendations outlined in the project report from last year, data relative to tributary use has greatly increased and is providing a unique insight into overall use, as well as factors influencing use of tributaries versus mainstem habitats. However, continued monitoring of tributaries will provide a more in depth understanding of the importance of this habitat type to Asian carp. Continued monitoring of dam passage and inter-pool movement will not only strengthen current passage estimates, but also increase the accuracy of survival and detection probabilities. Movement estimates will also need to be formatted for incorporation into the spatially explicit population model being developed for the Ohio River. Finally, upstream movement estimates appear to be very low whereas downstream movement below Cannelton pool is not well known. A recent detection of a tagged Asian carp in Lake Barkley originating from Cannelton pool begs the question as to if and how Kentucky Lake or Lake Barkley serve as a population sink for the Ohio River population, thereby reducing upstream range expansion on the Ohio River. With the proposed deterrent technologies at Barkley Lock, one hypothesis that should be considered is whether blocking a potential population sink of the Ohio River population will increase upstream movement rates. Continued evaluation of the movement of Asian carp through Kentucky and Barkley Dams, as well as movement downstream of Cannelton Locks and Dam will help evaluate what effects these barriers will have on the upper pools of the Ohio River. Modeling simulations will help us better understand how management decisions affect the Asian carp population at much larger scales.

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Figures and Tables:

Table 1. Total numbers and distribution (%) of receivers to the three habitat types that were utilized for the project's telemetry array in 2017 (L&D = Lock and Dam, RM = river miles).

Ohio River Pool	Mainstem		L&D		Tributary		Total # of 2017 Sites	% of All 2017 Sites	RM added to Array	RM per Mainstem Receiver
	# of Sites	% Sites in Pool	# of Sites	% Sites in Pool	# of Sites	% Sites in Pool				
Cannelton	7	77.8	0	0.0	2	22.2	9	5.7	54	7.7
McAlpine	9	47.4	0	0.0	10	52.6	19	12.0	75	8.3
Markland	10	34.5	4	13.8	15	51.7	29	18.4	95	9.5
Meldahl	24	63.2	4	10.5	10	26.3	38	24.1	95	4.0
Greenup	9	47.4	4	21.1	6	31.6	19	12.0	62	6.9
RC Byrd	4	36.4	4	36.4	3	27.3	11	7.0	42	10.5
Racine	3	33.3	4	44.4	2	22.2	9	5.7	33	11.0
Belleville	9	47.4	4	21.1	6	31.6	19	12.0	42	4.7
Willow Island	1	20.0	4	80.0	0	0.0	5	3.2	3	3.0
Totals	76	48.1	28	17.7	54	34.2	158	100.0	501	6.6

Table 2. Total numbers of the Bighead Carp and Silver Carp collected from five pools of the Ohio River and then implanted with transmitters for the AC Telemetry Project in 2013 - 2017

Year	Species	Pool					All Pools
		Cannelton	McAlpine	Markland	Meldahl	RC Byrd	
2013	Silver Carp	-	-	-	6	-	6
	Bighead Carp	-	-	-	13	-	13
2014	Silver Carp	-	115	6	10	-	131
	Bighead Carp	-	4	4	0	-	8
2015	Silver Carp	-	22	3	5	-	30
	Bighead Carp	-	1	1	5	-	7
2016	Silver Carp	92	94	6	0	0	192
	Bighead Carp	4	1	4	2	3	14
2017	Silver Carp	90	-	12	3	-	105
	Bighead Carp	0	-	2	0	-	2
2013-2017	Silver Carp	182	231	27	24	0	464
	Bighead Carp	4	6	11	20	3	44
All Years	All Species	**186**	**237**	**38**	**44**	**3**	**508**
	% of Total	36.6	46.7	7.5	8.7	0.6	100.0
Mean TL (mm)	Silver Carp	826.5	859.5	909.2	961.3	-	852.8
	Bighead Carp	1139.8	1169.0	1175.1	1154.5	1210.0	1164.1

Table 5. The total detections (Total Dtxns) and the numbers of unique AC offloaded from receivers in 2017 and then grouped by season, pool and site type.

~~Table 3. The length frequency distribution of Silver Carp that were tagged in 2013-2017 after being collected from four different pools that are~~ characterized as having a higher (Cannelton & McAlpine) or lower (Markland & Meldahl) density population of Asian Carp.

Species	Pool	2 cm Size Classes																						Total
		66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	
Silver Carp	Cannelton	2	2	2	3	4	11	20	27	29	35	25	7	6	2	3	1	1	2					182
	McAlpine	1	0	1	2	0	3	7	24	29	43	35	34	25	5	5	7	2	2	0	0	0	1	226
	Both Pools	3	2	3	5	4	14	27	51	58	78	60	41	31	7	8	8	3	4	0	0	0	1	408
	Markland										2	4	3	6	4	6	2							27
	Meldahl												1	6	1	4	4	2	2	3	0	1		24
	Both Pools										2	4	4	12	5	10	6	2	2	3	0	1		51
	All Pools	3	2	3	5	4	14	27	51	58	80	64	45	43	12	18	14	5	6	3	0	1	1	459

Table 4. The length frequency distribution of Bighead Carp collected & tagged from five different pools in 2013 - 2017.

Species	Pool	2 cm Size Classes																				Total
		94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	
Bighead Carp	Cannelton	-	-	-	-	-	-	1	0	0	1	0	1	1								4
	McAlpine								1	1	1	0	0	0	1	1	0	1				6
	Markland				1	0	0	0	0	1	0	2	3	1	0	1	0	0	0	1	1	11
	Meldahl	1	0	0	0	0	0	2	2	2	2	0	3	1	1	2	1	1	2			20
	RC Byrd														2	1						3
	Total	1	0	0	1	0	0	3	3	4	4	2	7	3	4	5	1	2	2	1	1	44

Season	Site Type	Cannelton Total Dtxns	Cannelton Unique AC	McAlpine Total Dtxns	McAlpine Unique AC	Markland Total Dtxns	Markland Unique AC	Meldahl Total Dtxns	Meldahl Unique AC	Greenup Total Dtxns	Greenup Unique AC	RC Byrd Total Dtxns	RC Byrd Unique AC	Racine Total Dtxns	Racine Unique AC	Total Total Dtxns	Total Unique AC
Winter	Main	77	2	30,454	10	0	0	2,553	10	0	0	0	0	0	0	33,084	22
	Trib	0	0	394,288	49	0	0	93,974	10	0	0	0	0	0	0	488,262	59
	L&D	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
	All	77	2	424,743	54	0	0	96,527	10	0	0	0	0	0	0	521,347	66
Spring	Main	7	2	73,251	124	758	6	3,934	15	0	0	14	1	8	1	77,972	149
	Trib	0	0	1,686,649	142	116,834	5	18,596	12	0	0	0	0	0	0	1,822,079	159
	L&D	0	0	77	4	0	0	1,101	8	261	6	23,331	2	0	0	24,770	14
	All	7	2	1,759,977	146	117,592	7	23,631	16	261	6	23,345	3	8	1	1,924,821	175
Summer	Main	16,041	25	169,135	128	3,360	9	75,315	17	49	2	0	0	30	1	263,930	178
	Trib	115,300	17	2,089,275	136	107,597	15	88,145	14	0	0	7,466	4	0	0	2,407,783	185
	L&D	0	0	430	3	835	1	2	1	34	2	583	2	96	1	1,980	7
	All	131,341	38	2,258,840	151	111,792	19	163,462	18	83	4	8,049	5	126	1	2,673,693	226
Fall	Main	3,146	7	337,222	99	3	1	131,704	15	64,047	1	0	0	0	0	536,122	123
	Trib	178,424	38	1,715,724	102	186,213	11	104,634	14	0	0	6,632	2	0	0	2,191,627	167
	L&D	0	0	0	0	0	0	0	0	0	0	71	1	0	0	71	1
	All	181,570	39	2,052,946	121	186,216	12	236,338	16	64,047	1	6,703	3	0	0	2,727,820	191
All	Main	19,271	28	669,292	148	4,121	10	245,975	17	96,834	2	14	1	38	1	1,035,545	201
	Trib	311,439	41	6,029,513	151	430,911	16	326,500	15	0	0	14,098	5	0	0	7,112,461	225
	L&D	0	0	508	7	835	1	1,103	8	295	8	23,985	3	96	1	26,822	19
	All	330,710	60	6,699,313	164	435,867	20	573,578	18	97,129	9	38,097	7	134	1	8,174,828	263

Table 6. Pool-to-Pool transfers in 2017 that were validated when the tagged AC were detected by at least one receiver (mainstem and/or tributary) located beyond the initial Lock and Dam (L&D) site that divided the two pools.

Transmitter ID	Species	Sex	Tagging Pool	Tag Year	Pool with... First Detection	Pool with... Most DS Detection	Pool with... Most US Detection	Pool with... Last Detection	Transfer Direction	Notes
A69-1601-23996	SVC	M	McAlpine	2014	McAlpine	Cannelton	McAlpine	Cannelton	DS	Moved from McAlpine into the Cannelton Pool during late June; Remained in Cannelton through the end of 2017.
A69-1601-24009	N/A	na	N/A	na	RC Byrd	Greenup	RC Byrd	Greenup	DS	Used a lock on 7/26 to move from RC Byrd to Greenup; Stayed <5 mi below RC Byrd L&D through the end of 2017.
A69-1601-27347	SVC	M	Markland	2016	Markland*	McAlpine	Markland*	McAlpine	DS	In Markland through 2016 & then moved into McAlpine on 1/13/2017; No contact since a 1/15 detection in KY River.
A69-1601-56475	BHC	F	Markland	2017	Markland	McAlpine	Markland	McAlpine	DS	Moved from Markland to McAlpine on 8/01 via the L&D's 600-ft lock chamber; Still in lower McAlpine at end of 2017
A69-1601-57948	SVC	M	McAlpine	2016	Cannelton	Cannelton	McAlpine	McAlpine	US	Moved from Cannelton up to McAlpine in late June; Still in lower McAlpine when 2017 ended.
A69-1601-57962	SVC	F	McAlpine	2015	McAlpine	Cannelton	McAlpine	McAlpine	Both	Moved from McAlpine to Cannelton in early June 2017, but then returned to the McAlpine Pool in August.
A69-1601-57975	SVC	M	McAlpine	2015	McAlpine	Cannelton	McAlpine	Cannelton	DS	Transferred from McAlpine to the Cannelton Pool in June 2017; Detected in the Salt River by the end of the year.
A69-1601-58058	SVC	F	McAlpine	2016	McAlpine	Cannelton	McAlpine	McAlpine	Both	Moved from McAlpine to Cannelton in May 2017; Returned to McAlpine in June & was still there when 2017 ended.

Table 7. Pool-to-pool transition probabilities of Silver Carp in the Ohio River through acoustic telemetry – 2013 to 2017 based on the best model (preliminary results). The best model ($\Delta AIC_c > 2$) for Silver Carp provided time and state invariant survival estimates, probability of detection estimates that varied over space and time, and movement estimates that varied for each pool. Note that transition probabilities were not estimated above Capt. A. Meldahl pool due to the lack of movement data above this reach of the river.

Departure pool	Destination pool			
	Cannelton	McAlpine	Markland	Meldahl
Cannelton	0.89	0.01	0.10	0.00
McAlpine	0.02	0.86	0.12	0.00
Markland	0.00	0.08	0.92	0.00
Meldahl	0.00	0.00	0.01	0.99

Table 8. Pool-to-pool transition probabilities of Bighead Carp in the Ohio River through acoustic telemetry – 2013 to 2017 based on the best model (preliminary results). The best model ($\Delta AIC_c > 2$) for Bigheaded Carp provided time invariant survival estimates, probability of detection estimates that varied over space and time (i.e., seasonally), and movement estimates that varied for each pool.

	Destination pool						
Departure pool	Cannelton	McAlpine	Markland	Meldahl	Greenup	R. C. Byrd	Racine
Cannelton	0.66	0.27	0.00	0.08	0.00	0.00	0.00
McAlpine	0.00	0.98	0.01	0.01	0.00	0.00	0.00
Markland	0.00	0.28	0.72	0.00	0.00	0.00	0.00
Meldahl	0.00	0.14	0.01	0.84	0.01	0.00	0.00
Greenup	0.00	0.00	0.00	0.00	0.91	0.09	0.00
R. C. Byrd	0.00	0.07	0.00	0.00	0.00	0.89	0.04
Racine	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 9. Pool-to-Pool transfers in 2017 that could not be validated. These events have been categorized either as 1) “Possible Transfers” of tagged AC that were only detected by receivers associated with the initial L&D site, or as 2) “Invalid Transfers” that were based solely on what were later identified as False detections.

Transmitter ID	Species	Sex	Tagging Pool	Tag Year	Pool with First Detection	Pool with Most DS Detection	Pool with Most US Detection	Pool with Last Detection	Transfer Direction	Notes
POSSIBLE										
A69-1601-24005	N/A	na	N/A	N/A	RC Byrd	Greenup	RC Byrd	RC Byrd	Both?	Only Greenup detection came from the lower approach of RC Byrd L&D. The other 23,834 detections in 2017 came from receivers in the RC Byrd Pool;
A69-1601-27339	SVC	na	Meldahl	2014	Meldahl	Meldahl	Greenup	Meldahl	Both?	Most of the 6000+ detections in 2017 came from Meldahl, except for the ~20 detections in early May that occurred in the upper approach of Greenup L&D;
A69-1601-27380	SVC	na	Meldahl	2014	Meldahl	Meldahl	Greenup	Meldahl	Both?	Approx. 13,000 detections in 2017 came from VR2’s in the Meldahl Pool, which doesn’t include the 18 times it was found in the US approach of Greenup L&D;
A69-1601-27381	SVC	na	Meldahl	2014	Meldahl	Meldahl	Greenup	Meldahl	Both?	Detected in Meldahl throughout 2017, except between 5/2 and 5/21 when ~30 detections were made by a VR2 in the US approach of Greenup L&D;
A69-1601-27404	SVC	na	Meldahl	2014	Meldahl	Meldahl	Greenup	Meldahl	Both?	Except for 1 detection made on 4/18 in the US approach Greenup L&D, Tagged AC #27404 spent all of 2017 in the Meldahl Pool.
A69-1601-27414	SVC	na	Meldahl	2014	Meldahl	Meldahl	Greenup	Meldahl	Both?	Aside from 8 detections in May that were made in the US approach of Greenup L&D, Tag #27414 was only detected by Meldahl VR2’s during 2017.
A69-1601-56546	BHC	F	Meldahl	2016	Meldahl	Meldahl	Greenup	Meldahl	Both?	Detected only by VR2’s from the Meldahl Pool during 2017, with the exception of a single detection made in the US approach of Greenup L&D on 6/21;
INVALID										
A69-1601-57990	BHC	M	Markland	2016	McAlpine	McAlpine	Markland	Markland	US	Identified as a transfer after being falsely detected by a VR2W in the KY River; But Tagged AC #57990 actually spent the entire year in the Markland Pool;

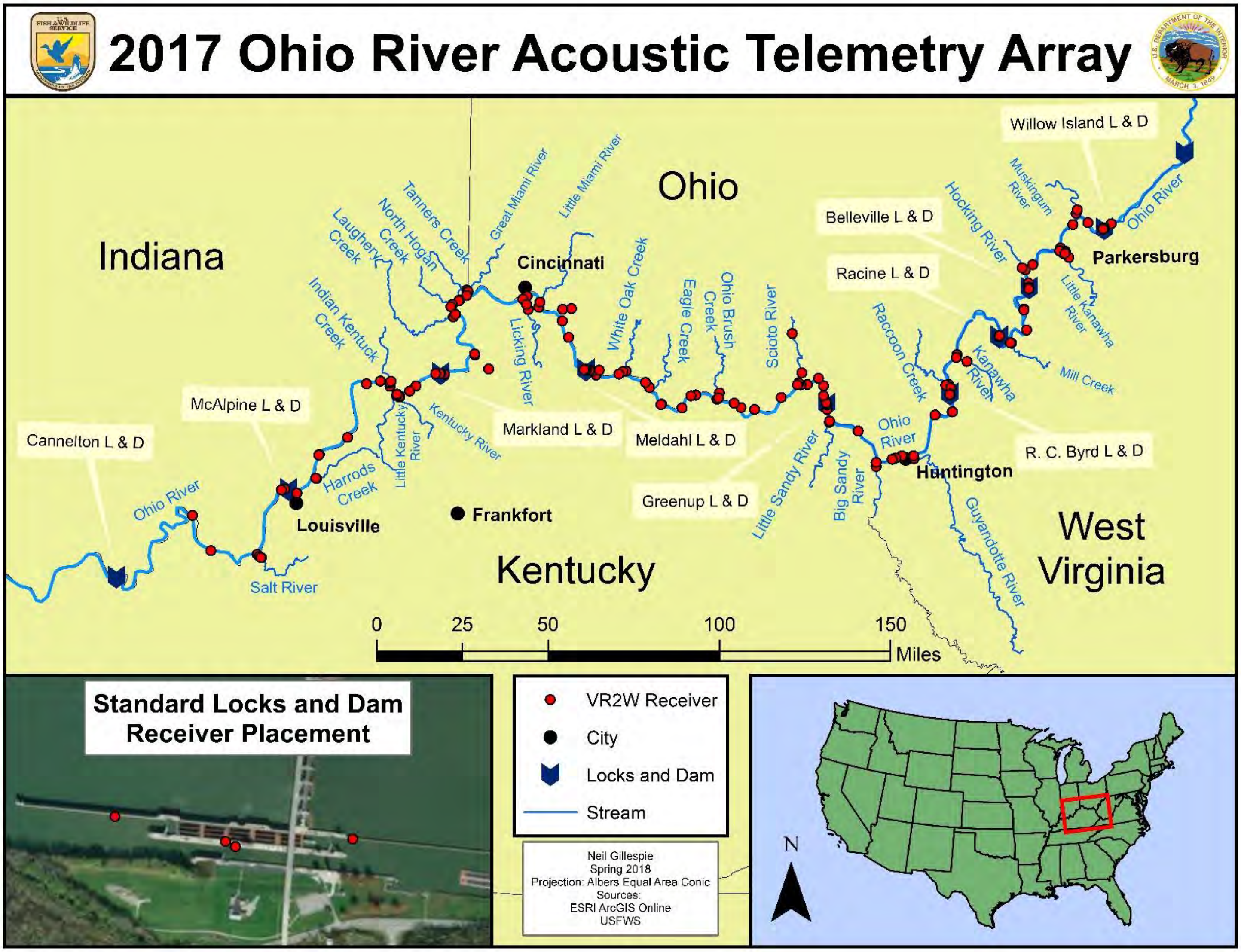

Figure 1. Locations of stationary VR2W and VR2AR receivers in 2017. Individual points may represent more than one receiver at this scale.

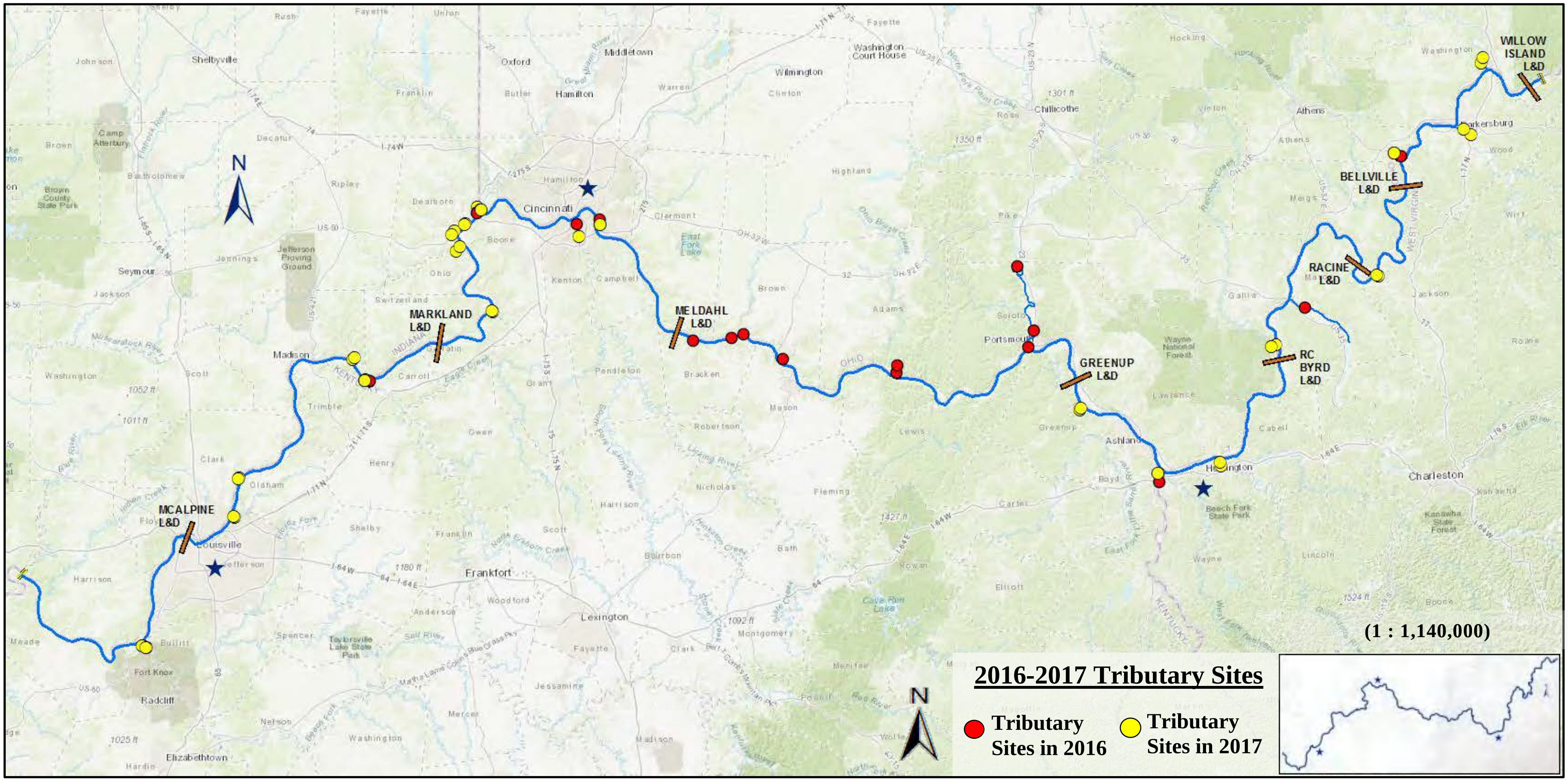

Figure 2. Distribution of the receiver stations that were located in tributaries during 2016 - 2017. The 2017 efforts to extend the project's receiver coverage of tributaries succeeded in establishing as many as two new stations in 15 previously unmonitored streams and small rivers, which was in addition to the 13 tributaries that already contained receiver sites by the end of 2016.

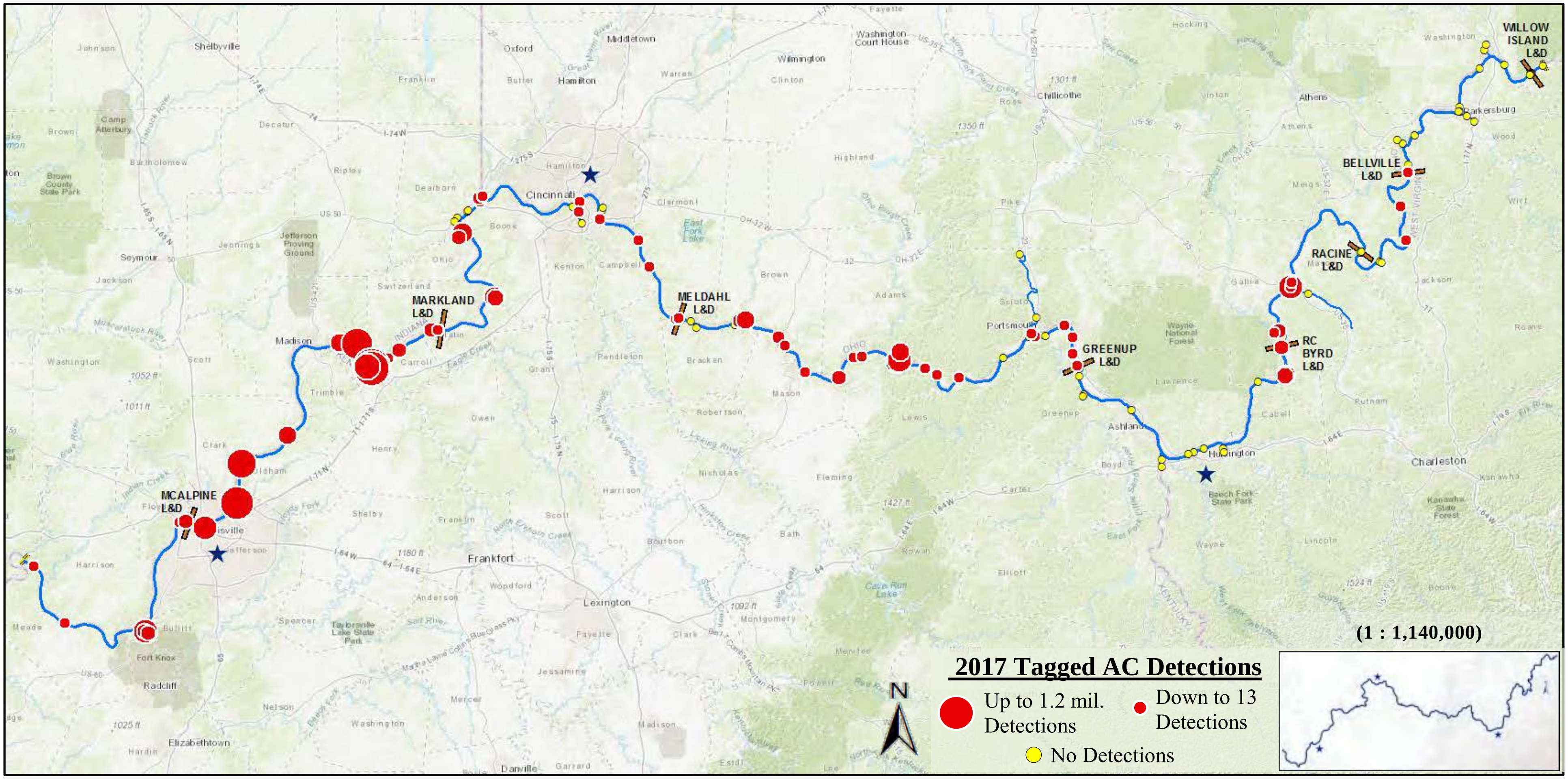

Figure 3. The distribution of the receiver stations that made at least one valid detection of a tagged Asian Carp in 2017. The diameter of each red circle on the map corresponds to the total amount of tagged carp detections that were made by the receiver that had been deployed to that location.

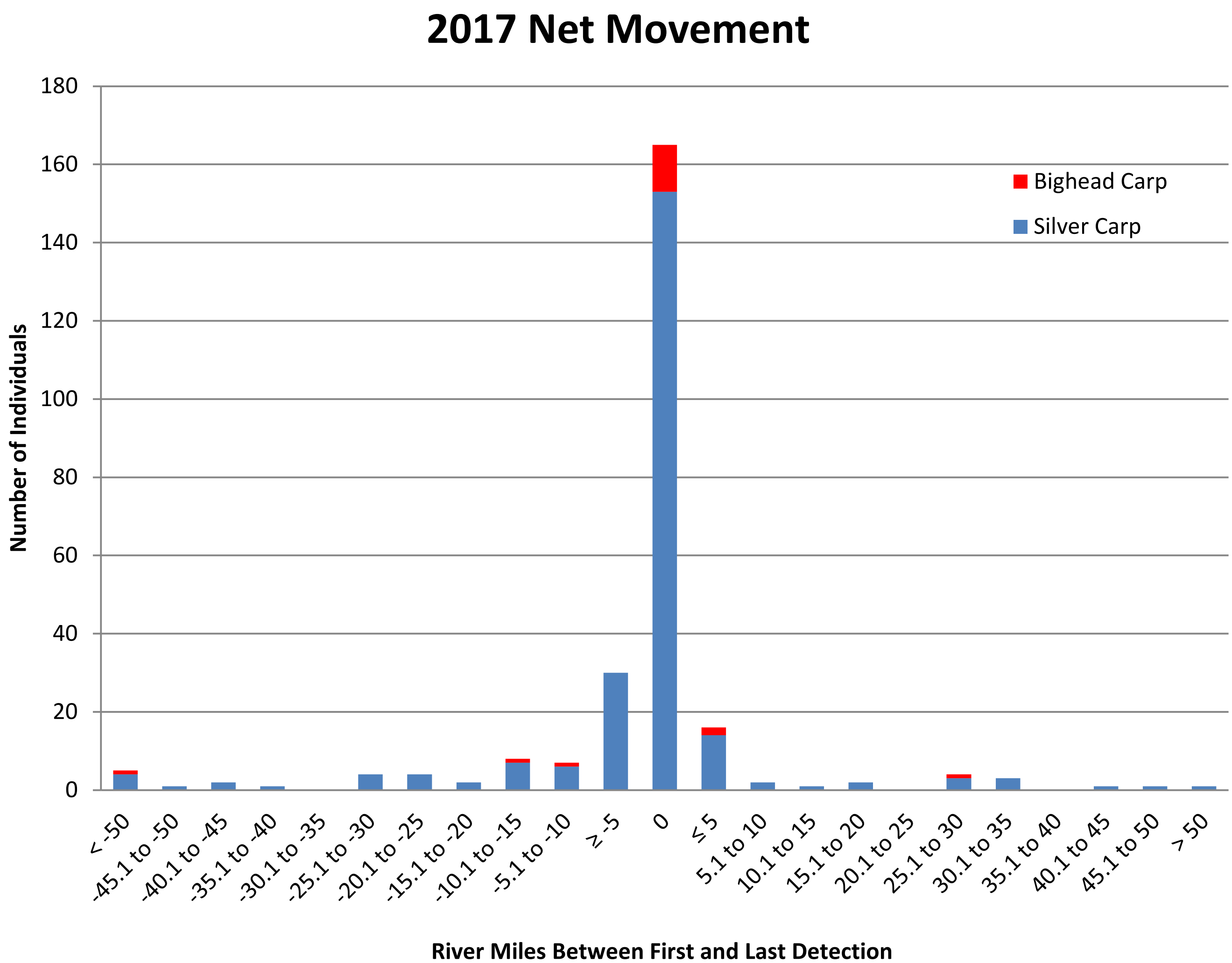

Figure 4. Net upstream and downstream movement of Asian carp in the Ohio River from first to last detection in 2017.

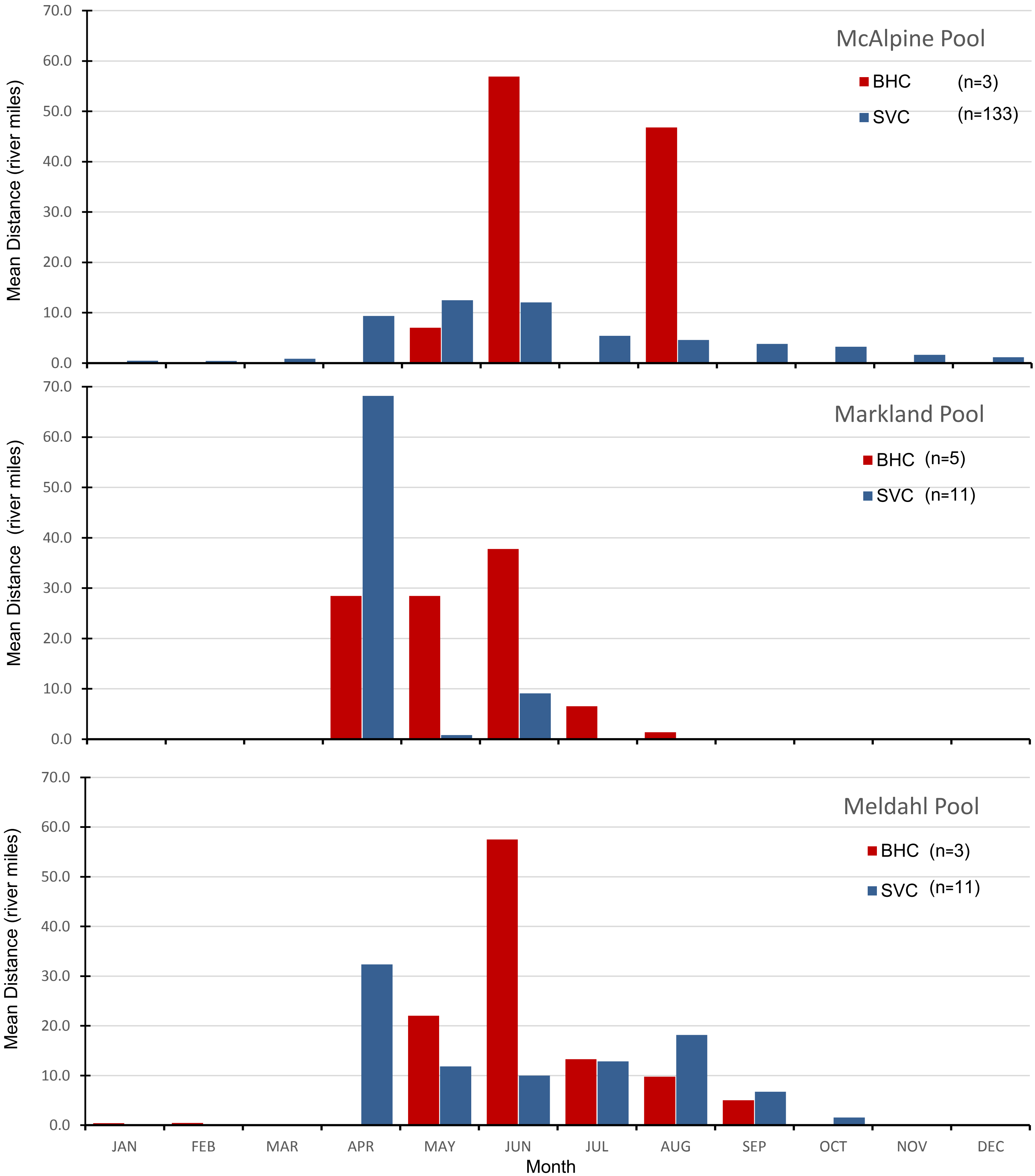

Figure 5. The mean monthly distances (in river miles) between the most upstream and downstream detections for tagged Bighead Carp and Silver Carp in the three most active pools of the telemetry project. Only tagged carp that were detected by 2 or more receivers during 2017 were included in the distance calculations.

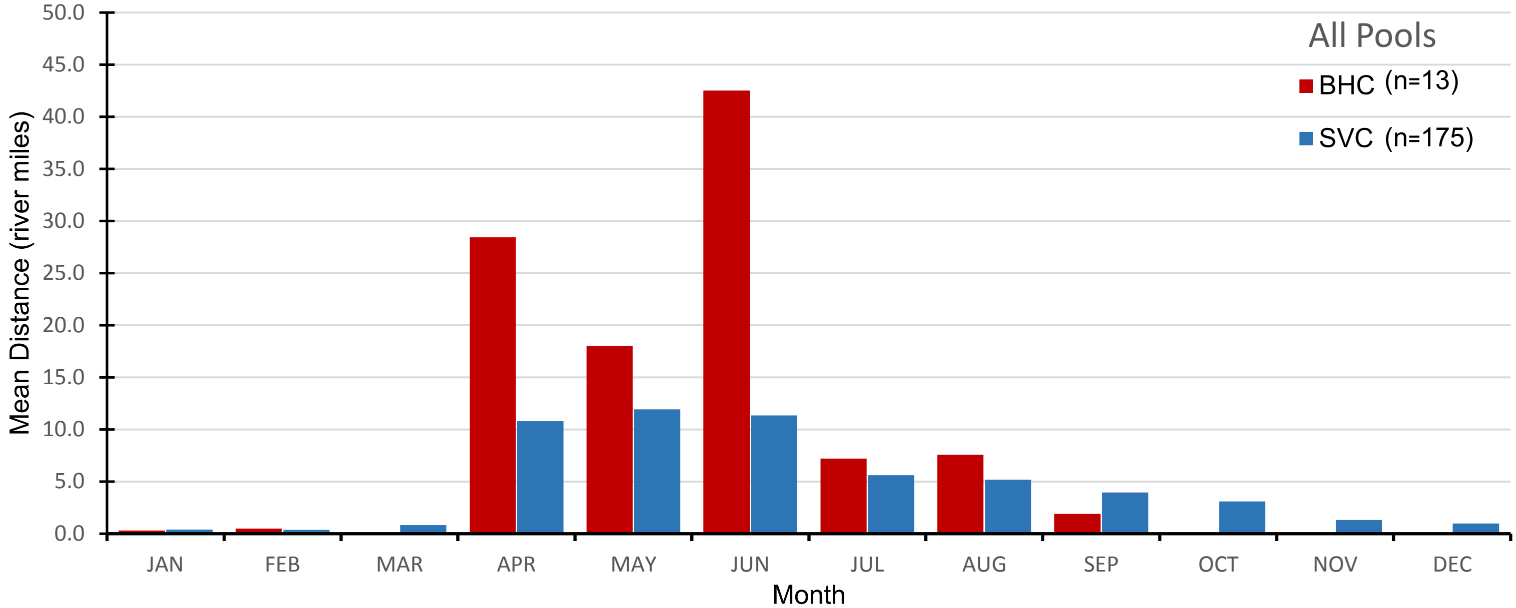

Figure 6. The mean monthly distances (in river miles) between the most upstream and downstream detections for all tagged Bighead Carp and Silver Carp that were detected by 2 or more receivers during 2017

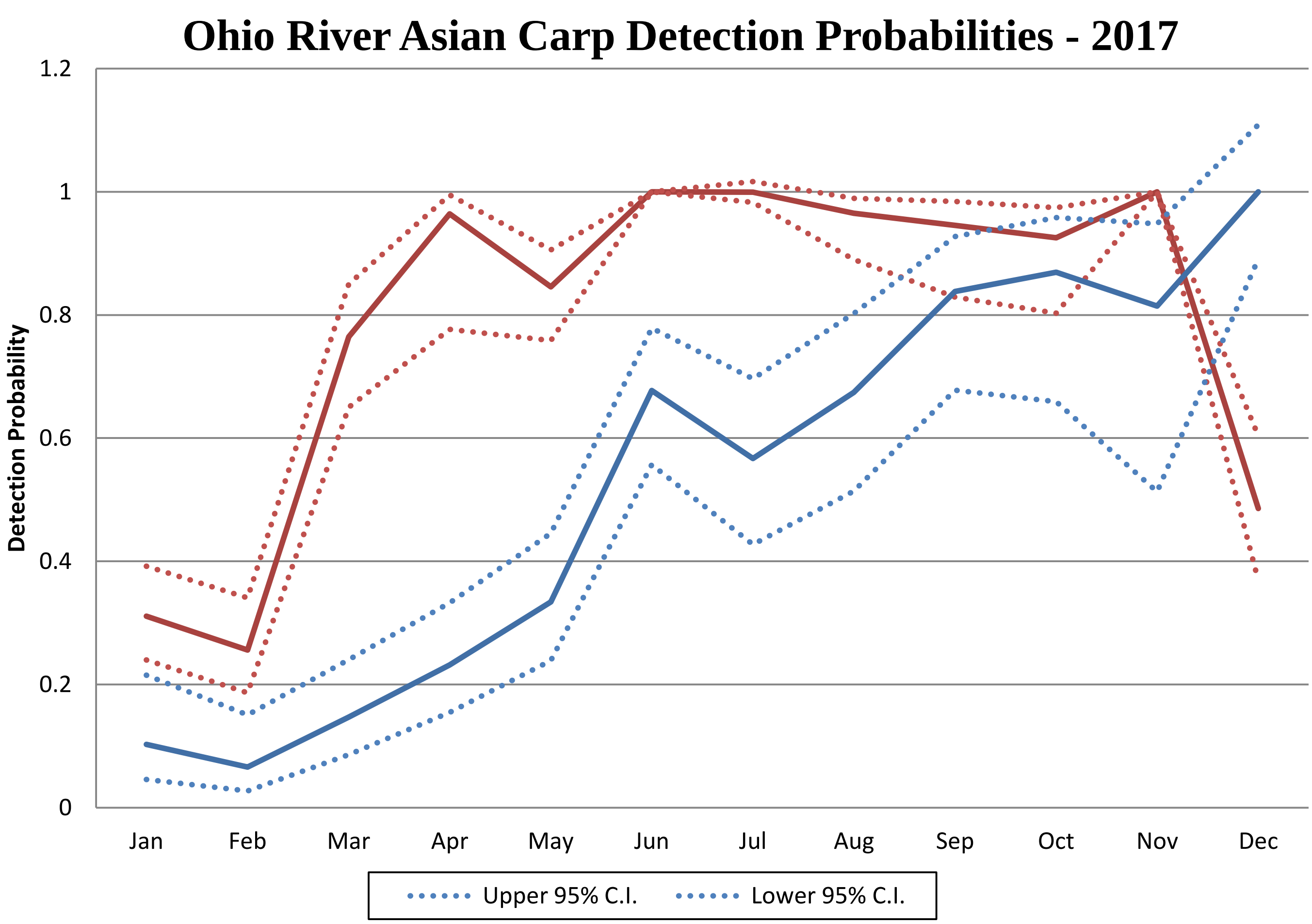

Figure 7. Detection probabilities with upper and lower 95% confidence intervals of telemetered Asian carp within the mainstem Ohio River and its tributaries during 2017.