Quantifying Lock and Dam Passage, Habitat Use, and Survival Rates of Asian Carp in the Ohio River

2019 Report

Geographic Location: The Ohio River from Cannelton pool near Leavenworth, IN, to 2.5 miles 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 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 exhibit high reproductive potential 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, ensures 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 biology could facilitate targeting susceptible life stages and 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 need exists to prevent the establishment of these species into the upper portions of the Ohio basin. This study reach focuses on the middle and upper reaches of the Ohio River.

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.
5. Estimate probability of survival.

Project Highlights:

An array of 121 stationary receivers was deployed during 2019 (Figure 1 and Table 1), which recorded over 3 million detections of 180 Silver and Bighead carp throughout five Ohio River pools. The data used in this report does not encompass all possible 2019 detections, as a number of final receiver downloads for the year occurred after the cut-off date to begin analysis. Therefore, total detections and number of unique detections will increase when all of the detections are incorporated in the final data set for 2019. This data will be incorporated into future reporting and analysis as in years past.

Tagging effort in fall of 2019 resulted in 30 Silver Carp and 1 Bighead Carp tagged within McAlpine pool of the Ohio River. Total carp with active tags in Cannelton, McAlpine, Markland, Meldahl and RC Byrd pools is 388 Silver Carp and 25 Bighead Carp. Average size of Silver Carp collected increases upstream between each pool, ranging from 826.5mm in Cannelton Pool to 966.0 mm in Meldahl pool. This data is summarized in Table 2.

Most of the fish tagged during the course of this study remained in the Ohio River pool where they were tagged (Table 3). Nearly all of the Bighead Carp and Silver Carp have made net movements of five miles or less (upstream and downstream) from first to last detection of 2019 (Table 4 and figures 2 and 3). This trend was also identified in 2017 and 2018.

Pool-to-pool transition probabilities for Silver Carp have been estimated and summarized (Table 3).

Annual survival for Silver Carp was estimated to be 65%. Bighead Carp survival rate will be provided following completion of the analysis.

Methods: Ultrasonic telemetry was used to track the movements of Asian carp and evaluate fishes ability to pass the lock and dam systems. A stationary array of VR2 receivers are strategically placed within the mainstem river of each pool of the study area, at the lower few miles of select tributaries within each pool and at each lock and dam. At each lock and dam, a collection of four VR2's are deployed to capture any pool to pool transitions that may occur using the lock chambers. Lock and dams within the study reach have one VR2 in each of the downstream and upstream approach walls and two VR2's in the lock chamber. This consistent spatial coverage across all lock and dams ensures detection capabilities are similar at each location and increases confidence in interpretation of detection data.

Ultrasonic Transmitter Tagging: Adult Bighead and Silver carp were surgically implanted with ultrasonic transmitters (Vemco, Model V16-6H; 69 kHz) which provide individual identification. The V16-6H coded transmitters are nominally programmed to transmit a signal every 40 seconds yielding a battery life of 1,825 days. Fish were collected via boat electrofishing and gill nets set to block or trap fish and tagged by agency personnel in Cannelton, McAlpine, Markland, and Capt. A. Meldahl pools. Efforts were concentrated in areas that are attractive to Asian carp such as side channels, backwaters, and tributary creeks and rivers. Prior to surgery, fish were measured for total length (mm) and weight (g), and visually or manually sexed (if possible). Previously, tagged fish were fitted with an external jaw tag applied around the dentary bone (lower jaw) (National Tag Co. #1242 F9). However, due to some evidence of these jaw tags negatively affecting the jaws of tagged fish, lock-on tags inserted posterior to the dorsal fin were used for all fish tagged in 2018 and 2019 (Floy Tag & Manufacturing, Inc. FT-4 Lock-on tag with clear over-tubing). Allocation of tagging effort is analyzed yearly to ensure the number of tagged fish in each pool of the study reach is maintained and meets the goals and needs of the partnering agencies. The number of tagged fish in each pool changes due to upstream or downstream movement among the pools, reported catches of tagged fish that were removed from the system, natural mortality and the largest factor, depletion of the tag's battery life. The number of expiring tags and partnership goals in each pool are the most important factors determining how tagging effort is allocated.

Ultrasonic receiver array: The receiver array extends from Cannelton Lock and Dam upstream to Willow Island Lock and Dam, including McAlpine, Meldahl, Greenup, R.C. Byrd, Racine, and Belleville Lock and Dams. Mainstem Ohio River VR2 receivers are removed from the river during the winter months to avoid loss of equipment to ice flows, high water and barge collisions. Most tributary and lock and dam VR2 receivers stay in the system and remain active in the river all year. In the spring months, the mainstem VR2 receiver array is re-deployed and the Lock and Dam and tributary locations are visited to download overwintering data and perform any needed maintenance to the receivers. The mainstem receiver locations are at regular intervals between lock and dams, utilizing a mix of navigation buoys and other structures to affix the VR2. Receiver data are downloaded monthly or as often as possible. The stationary receivers account for the vast majority of detections and provide the needed data to capture pool-to-pool transitions and movements made within pools. Mobile tracking is an option that has been used to pick up extra detections and locate fish in areas of interest.

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 2019). Because individuals were tagged throughout the duration of this study, not all individuals have a complete encounter history (maximum of 79 possible time periods). Encounter histories of tagged carp whose tag battery expired were censored and removed from the estimation procedures. Known harvested fish were coded as having transitioned into a "dead" state in which detection and survival probabilities were fixed at one and transition probabilities out of the "dead" state were fixed at zero (Coulter et al. 2018). 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 two was taken as evidence that a model outperformed a competing model, with smaller values being better.

Results and Discussion:

Receiver array and Placement - Receivers were generally concentrated from McAlpine pool upstream to R.C. Byrd pool in 2019 and associated tributaries within these pools. Many of the tributary locations have a VR2 placed near the mouth of the stream and a 2nd VR2 further upstream to interpret upstream or downstream entrance or exit of the tributary. Utilizing two VR2 receivers in a tributary enhances our interpretation of tributary use and timing throughout the year. Many of the tributary sets are deployed year-round and have low VR2 receiver loss. Total number of receivers in Belleville pool decreased due to limited data garnered from those sites due to lack of tagged individuals that far upstream. Those VR2 receivers were reallocated in downstream locations that are now providing better coverage in areas with tagged individuals. A concurrent catfish telemetry study being conducted by the Ohio Department of Natural Resources Division within Capt A Meldah pool and a similar study by West Virginia Division of Natural Resources in R.C. Byrd pool leverages the utility of this array; these concurrent efforts provide greater coverage than what could be achieved by individual studies.

Receivers were offloaded and/or removed in the winter of 2018 to avoid loss due to winter flooding, ice flows, and commercial barge strikes. Receivers that were removed in the winter of 2018 were re-deployed in the spring of 2019. All lock and dam receiver locations are in use year-round while many mainstem locations are removed prior to winter. Favorable river conditions within the mainstem and tributaries led to high receiver recovery and offload in 2019.

Fish Tagging Efforts– To date 571 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). Of the 571 tagged carp, three have been found deceased and 139 have tags that were set to expire during the fall of 2019. During 2019, 31 fish were tagged over two weeks of tagging effort within Markland pool collected with gill netting and boat DC electrofishing. This pool was targeted due to 115 tags scheduled to expire within McAlpine Pool. Future tagging efforts revolve around replacing expiring tags in the associated pools by species. See Table 2 for an in-depth breakdown of tag allocation for the Ohio Basin by pool and species along with information on tag expiration. Tags used in this study have a five-year life span. Future tagging efforts will be based on the number of expiring tags in each pool and meet the needs identified by participating agencies.

Fish Detections: Between 01 January 2019 and 12 December 2019 receivers recorded over 3 million individual Asian carp detections. Of the 413 active tags in this study, 164 (40%) were detected in 2019. The total number active tags includes 182 Silver Carp and 4 Bighead Carp tagged during 2016 and 2017 in the lower portion of Cannelton pool. This pool does not have extensive VR2 coverage compared to upstream pools (6 total VR2's in Cannelton) and likely accounts for the lower number of individual fish detected. Also, the number of active tags does not account for fish that have migrated downstream out of the current array (most likely downstream movement into and out of Cannelton Pool). This could reduce the detection percentage until more receivers are placed in the lower portion of Cannelton and other lower pools of the Ohio River or until the recently tagged fish move upstream into the receiver array. Plans are being made to increase the number of receivers in the lower Ohio River in order to quantify downstream movement and dam passage in the lower pools and connected basins to better inform management decisions.

Fish Movement: Movement within pools during 2019 for Asian Carps follow the same patterns seen in previous years. Seasonal movement for both species across all pools with sufficient data indicates an increase in movement in the month of April through May, June, and July. During 2019, the majority of tagged fish remained close to the area in which they were initially detected at the start of the year; this pattern was identified in 2017 and 2018 as well. Mean monthly movement distances by each species in each pool were calculated, showing peak movements between April and July. Figures 3, 4 and 5 summarizes this data by species, pool and time of year for the 2019 data.

Model Selection: Pool-to-pool transition probabilities, survival, and detection probabilities were estimated for Silver Carp using the same methods in Program MARK in previous years. The best model for Silver Carp survival was time and state invariant, probabilities that varied by state and time, and transition probabilities that varied between pools (Table 3). Bigheaded Carp results will be reported once further analysis is complete.

Tributary Use: At the time of release of this report, tributary use had not yet been analyzed and tributary use versus mainstem Ohio River use will be completed and released at a later date. Most tributaries are now outfitted with two VR2's, which is providing directionality to the detection data and will provide valuable insights into tributary use.

Dam Passage: Throughout this study, there have been 62 dam passage events (40 downstream and 22 upstream passage events) (Figure 2). The 22 upstream passage events (35%) were completed by two Bighead Carp (five total passage events) and 12 Silver Carp (17 total dam passage events). Due to the consistent layout of the VR2 array at each lock and dam and year-round deployment, we are confident in our ability to detect passage events made while utilizing the lock chambers at each dam. However, multiple passages have occurred that remained unassigned (i.e. through the lock chambers or through the gates) and more data is needed to verify successful passage. Obtaining acoustic telemetry data directly upstream and downstream of the gates where passage can occur during open water conditions or through gate openings presents safety and logistical challenges. Mobile tracking and site investigations to detect individual fish have assisted with confirming successful passage and location information of individual fish and can continue to be deployed to locate additional fish if deemed necessary. Figure 2 displays verified passages at each dam within the study area.

Preliminary pool-to-pool transition probabilities for Silver Carp between Cannelton, McAlpine, Markland and Meldahl pools of the Ohio River are summarized in Table 3. Over 90% of tagged Silver Carp remain in the pool in which they were initially tagged across the study reach, with likelihood of this observation increasing when fish are located in upstream pools. For Silver Carp analyzed in this study, staying within the same pool accounted for the most likely observation in any of the navigation pools along the Ohio River.

Survival: The annual survival estimates of tagged Asian carp were calculated in Program MARK using a multi-state livecapture model. Silver Carp survival was estimated to be 64.6% (95% C.I. = 61.4 – 67.6%) throughout all pools. Bighead Carp annual survival rate will be reported once further analysis is complete. Known harvest of Silver and Bighead carp has remained low in the study reach as less than 5 individuals were reported harvested. Given the low harvest numbers, we believe this is a robust estimate of natural mortality (e.g., 95% CI = 35.4% - 38.6% for Silver Carp)

Recommendations:

The current telemetry array established from McAlpine L&D upstream to Willow Island L&D, including the tributaries and mainstem array, is well established and proper site selection has led to less receiver loss over the last 2 years. Coverage gaps within the existing array are minimal for existing analytical work, but some needs do arise. Validating pool-to-pool transitions and how those occur (e.g. through the lock gates or through the lock chamber) could be refined with a more robust array near the gates of each lock and dam to better capture movement that occurs through the gates. This would enhance our knowledge of pool-to-pool transitions and we could investigate river conditions present at the time of such transitions. Additionally, removal of the mainstem array for the winter months does create a window of poor mainstem river coverage. Bridge pier mounts have been successfully utilized in other large rivers to establish year round coverage with minimal receiver loss and might be a valuable addition to existing coverage in the mainstem Ohio River.

Expansion of this array into pools downstream of McAlpine is recommended to increase the programs ability to detect tagged fish released in Cannelton pool: solidify detection probabilities, strengthen survival estimates and capture pool-to-pool movement that occurs in the lower Ohio River. Bigheaded carp densities are also much greater in the lower pools of the Ohio River system; understanding the level of pool-to-pool movement that occurs in higher density pools and the net gain or loss due to pool-to-pool movement will be important information to develop accurate management plans based on basin wide movement patterns. Detections of tagged Asian carp in Lake Barkley originating from Cannelton pools brings to light the need to understand the relationship between Kentucky Lake and Lake Barkley and how these systems influence population level metrics and ultimately, management decisions for the Ohio Basin. With the 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 Lock and Dam will help evaluate what effects these barriers will have on the upper pools of the Ohio River. Increasing receiver coverage in lower portion of Cannelton Pool and the Lower Ohio River will help to understand larger-scale movement patterns of Asian carp in the Ohio River Basin, as well as the importance of those downstream source populations to the upstream movement of Asian carp.

Data management will continue to be vital as the program adds to the existing data set. Plans are in place to increase the number of tagged Asian carp within the existing programs study area and include additional pools. Current analytical techniques and computing ability may not suffice as the data set grows yearly and if inclusion of additional pools to the analysis is desired. Front end data management and data processing capability will become increasingly important to analyze movement, survival and detections of Asian carp in the study reach of the Ohio River within Program MARK.

Literature Cited:

Burr, B.M., D.J. Eisenhour, K.M. Cook, C.A. Taylor, G.L. Seegert, R.W. Sauer, and E.R. Atwood. 1996. Nonnative fishes in Illinois waters: What do the records reveal? Transactions of the Illinois State Academy of Science 89(1/2):73-91.

Coulter, A. A., M. K. Brey, M. Lubejko, J. L. Kallis, D. P. Coulter, D. C. Glover, G. W. Whitledge, and J. E. Garvey. 2018. Multistate models of bigheaded carps in the Illinois River reveal spatial dynamics of invasive species. Biological Invasions 20(11):3255-3270.

DeGrandchamp, K. L. 2003. Habitat selection and movement of bighead carp and silver carp in the lower Illinois River. Master's Thesis. Southern Illinois University at Carbondale, Illinois. 47 pp.

DeGrandchamp, K.L., J.E. Garvey, and R.E. Colombo. 2008. Movement and Habitat Selection by Invasive Asian Carps in a Large River. Transactions of the American Fisheries Society 137:45-56

Freeze, M. and S. Henderson. 1982. Distribution and status of the bighead carp and silver carp in Arkansas. North American Journal of Fisheries Management 2:197-200.

Garvey, J.E., K.L. DeGrandchamp, and C.J. Williamson. 2006. Life History Attributes of Asian Carps in the Upper Mississippi River System. ERDC/TN ANSRP-06-__ November 2006.

Peters, L. M., M. A. Pegg, and U. G. Reinhardt. 2006. Movements of adult radio-tagged bighead carp in the Illinois River. Transactions of the American Fisheries Society 135:1205-1212.

Sparks, R.E., T.L. Barkley, S.M. Creque, J.M. Dettmers, and K.M. Stainbrook. 2011. Occurrence and predicted dispersal of bighead carp on the Mississippi River system: development of a heuristic tool. Pages 51-71 in D.C. Chapman and M.H. Hoff, editors. Invasive Asian Carps in North America. American Fisheries Society, Symposium 74, Bethesda, Maryland.

Tsehaye, I., M. Catalano, G. Sass, D. Glover, and B. Roth. 2013. Prospects for fishery-induced collapse of invasive Asian Carp in the Illinois River. Fisheries 38(10): 445-454.

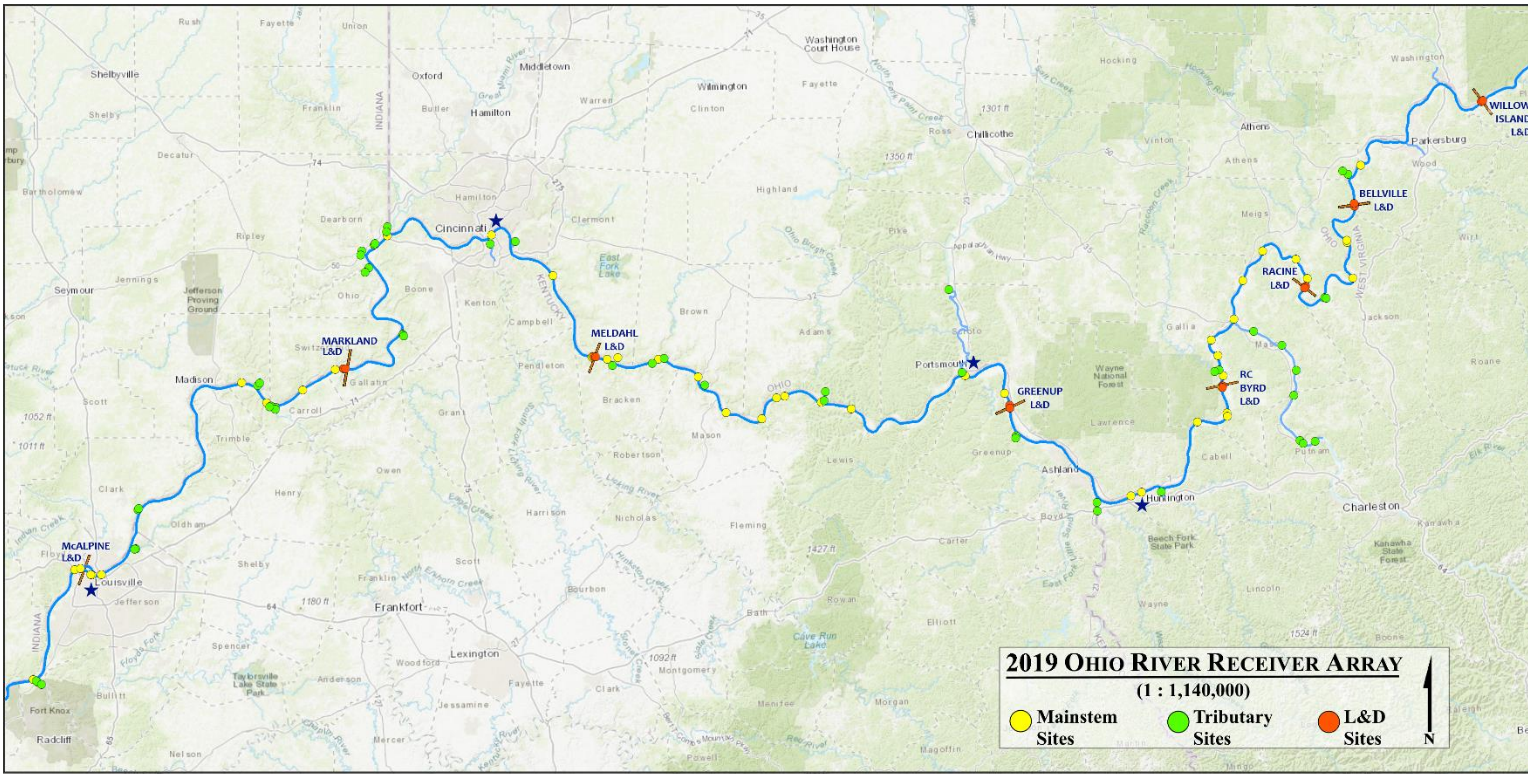

Figure 1:Map of the 2019 Ohio River Receiver Array depicting Mainstem, Tributary and Lock and Dam Sites.

Figure 2: Total count of upstream and downstream passage events at each Lock and Dam from 2013-2019.

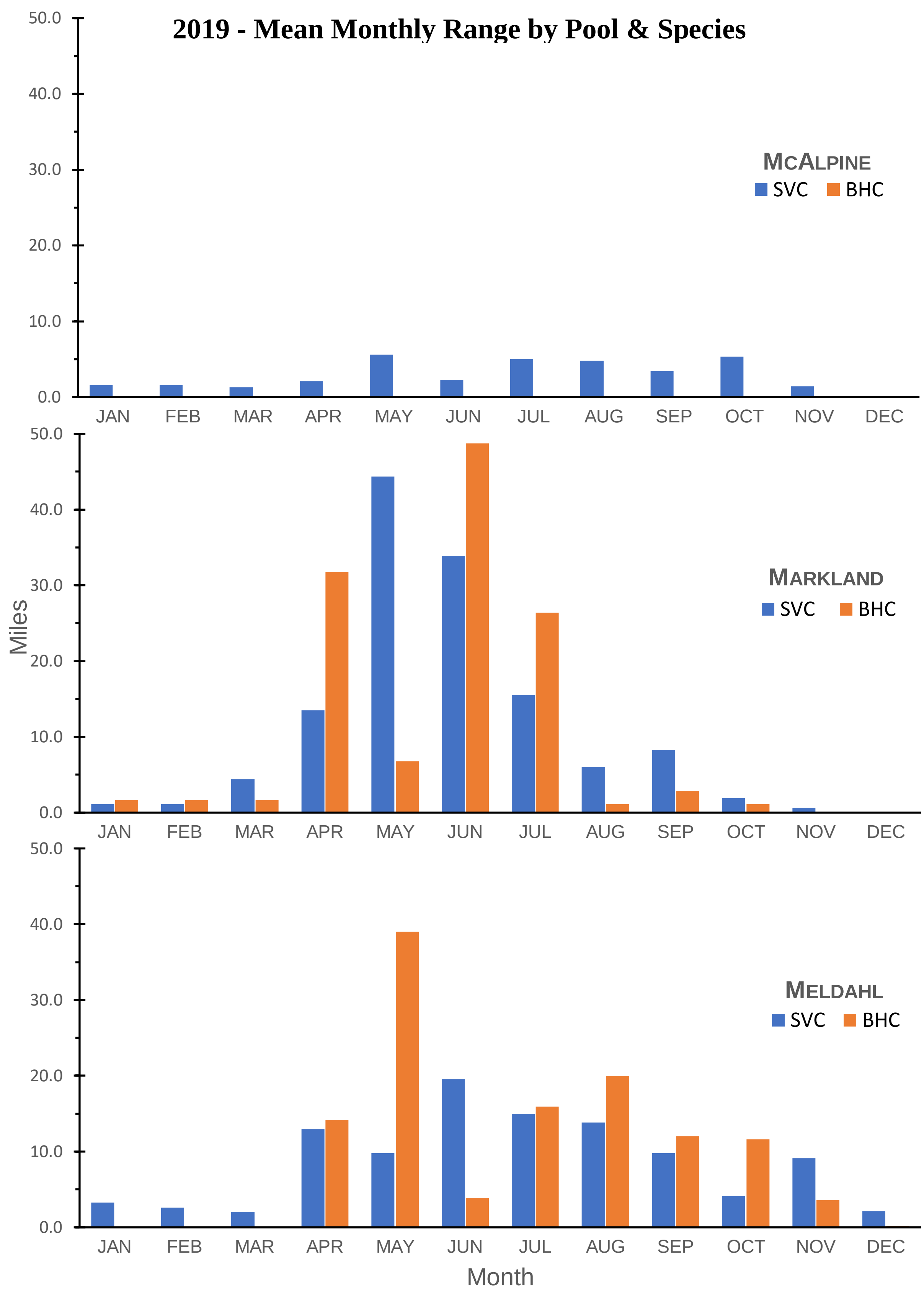

Figure 3. The mean monthly distances (in river miles) between the most upstream and downstream detections for tagged Bighead Carp and Silver Carp in the three most active pools of the telemetry project. Only tagged carp that were detected by 2 or more receivers during 2019 were included in the distance calculations. – Chris Hickey, KDFWR.

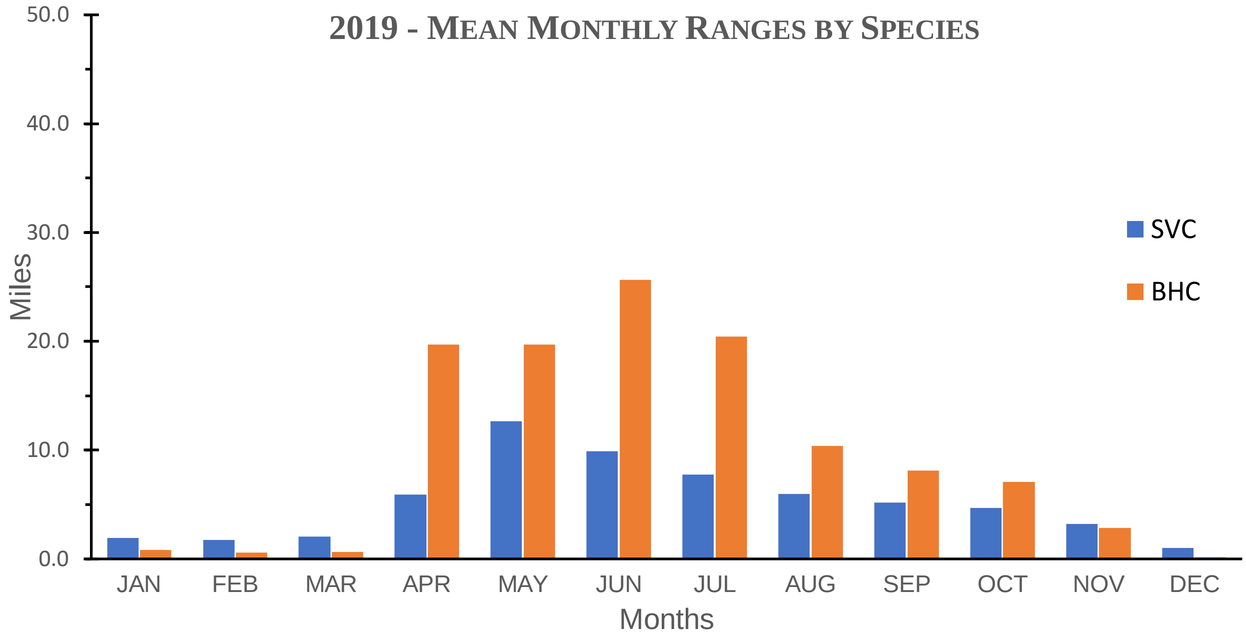

Figure 4: The mean monthly distances (in river miles) by species between the most upstream and downstream detections for all tagged Bighead Carp and Silver Carp that were detected by 2 or more receivers during 2019– Chris Hickey, KDFWR.

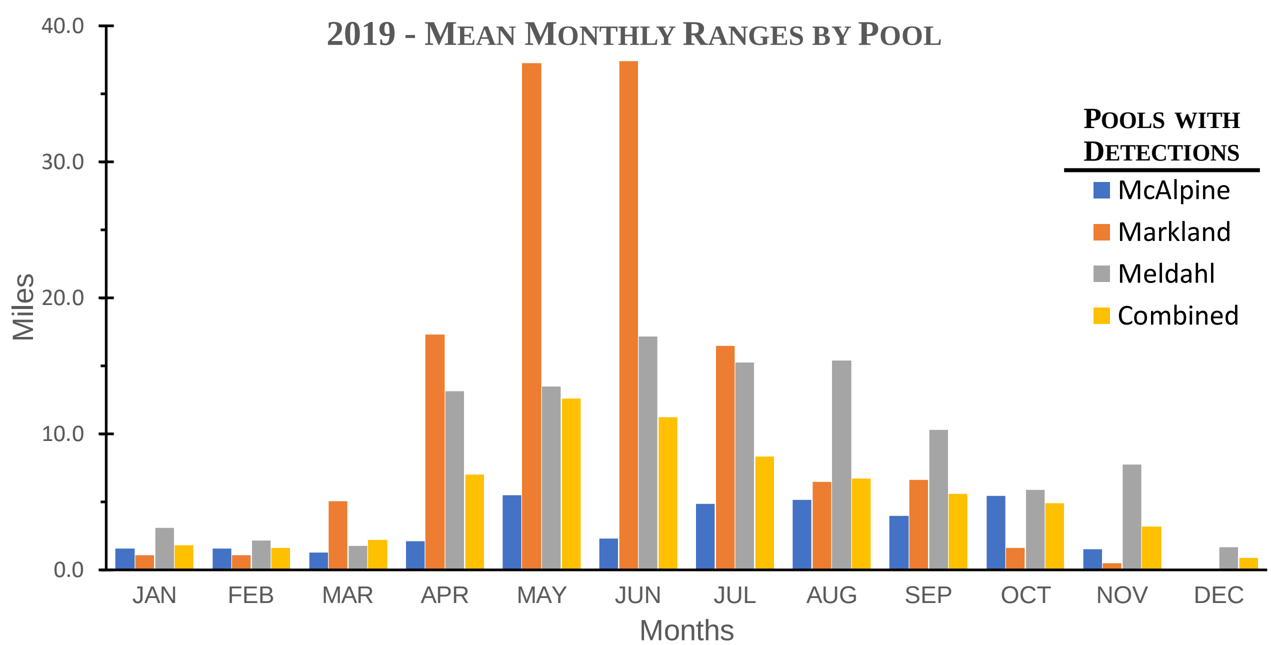

Figure 5: The mean monthly distances (in river miles) by pool between the most upstream and downstream detections for all tagged Bighead Carp and Silver Carp that were detected by 2 or more receivers during 2019– Chris Hickey, KDFWR.

OHR Pool	Length per pool (mi)	2018 Sites								2019 Sites							
		Mainstem		Tributary		L&D		Total # of Sites	% of All 2018 Sites	Mainstem		Tributary		L&D		Total # of Sites	% of All 2019 Sites
		N	% of Pool	N	% of Pool	N	% of Pool			N	% of Pool	N	% of Pool	N	% of Pool		
Willow Island	3.0	1	50.0	0	0.0	1	50.0	2	1.5	0	0.0	0	0.0	1	100.0	1	0.8
Belleville	42.2	7	41.2	6	35.3	4	23.5	17	13.0	1	14.3	2	28.6	4	57.1	7	5.8
Racine	33.6	3	33.3	2	22.2	4	44.4	9	6.9	1	14.3	2	28.6	4	57.1	7	5.8
RC Byrd	41.7	1	11.1	4	44.4	4	44.4	9	6.9	8	38.1	9	42.9	4	19.0	21	17.4
Greenup	61.8	6	37.5	6	37.5	4	25.0	16	12.2	5	35.7	5	35.7	4	28.6	14	11.6
Meldahl	95.2	15	55.6	7	25.9	5	18.5	27	20.6	12	50.0	8	33.3	4	16.7	24	19.8
Markland	95.3	9	36.0	12	48.0	4	16.0	25	19.1	5	23.8	12	57.1	4	19.0	21	17.4
McAlpine	75.3	8	38.1	10	47.6	3	14.3	21	16.0	7	35.0	10	50.0	3	15.0	20	16.5
Cannelton	24.0	3	60.0	2	40.0	0	0.0	5	3.8	3	50.0	3	50.0	0	0.0	6	5.0
Totals	472.1	53	40.5	49	37.4	29	22.1	**131**	100.0	42	34.7	51	42.1	28	23.1	**121**	100.0

Table 1: Total number and pool distribution of all mainstem (main), tributary (trib) and Lock and Dam (L&D) sites of the projects telemetry array in 2018 and 2019.

Tagging Year	Status after 2019	AC Species	OHR Pool						Total
			Cannelton	McAlpine	Markland	Meldahl	Greenup	RC Byrd	
2013	*Inactive*	*Silver Carp*	-	-	*0*	*6*	*0*	-	*6*
	Inactive	*Bighead Carp*	-	-	*0*	*13*	*0*	-	*13*
2014	*Inactive*	*Silver Carp*		*115*	*6*	*10*	*0*	-	*131*
	Inactive	*Bighead Carp*		*4*	*4*	*0*	*0*	-	*8*
2015	Active	Silver Carp	-	22	3	5	0	-	30
	Active	Bighead Carp	-	1	1	5	0	-	7
2016	Active	Silver Carp	92	94	6	0	-	0	192
	Active	Bighead Carp	4	1	4	2	-	3	14
2017	Active	Silver Carp	90	-	12	3	-	-	105
	Active	Bighead Carp	0	-	2	0	-	-	2
2018	Active	Silver Carp	-	-	21	10	-	-	31
	Active	Bighead Carp	-	-	0	1	-	-	1
2019	Active	Silver Carp	-	30	-	-	-	-	30
	Active	Bighead Carp	-	1	-	-	-	-	1
(2015-2019)	Active	Silver Carp	182	146	42	18	0	0	388
		Bighead Carp	4	3	7	8	0	3	25
		Overall	186	149	49	26	0	3	**413**
(2013-2014)	*Inactive*	*Silver Carp*	-	*115*	*6*	*16*	*0*	*0*	*137*
		Bighead Carp	-	*4*	*4*	*13*	*0*	*0*	*21*
		Overall	-	*119*	*10*	*29*	*0*	*0*	*158*
% Species Composition (2015-2019)	Active	Silver Carp	44.1	35.4	10.2	4.4	0.0	0.0	93.9
		Bighead Carp	1.0	0.7	1.7	1.9	0.0	0.7	6.1
		Overall	45.0	36.1	11.9	6.3	0.0	0.7	100
Mean Total Lengths (mm) (2013-2019)	Combined	Silver Carp	826.5	855.1	920.3	966.0	0.0	0.0	858.3
		Bighead Carp	1139.8	1146.3	1175.1	1153.6	0.0	1210.0	1160.1

** Transmitters implanted in 2014 were expected to reach the end of their 5-year battery life during 2019 and are now considered to be Inactive.*

Table 2: Total counts, species composition and mean total lengths (mm) of Asian Carp (AC) in five pools of the Ohio River (OHR) that have been surgically implanted with acoustic transmitters in 2013-2019.

Departure Pool	Destination Pool			
	Cannelton	McAlpine	Markland	Meldahl
Cannelton	0.926	0.072	0.000	0.001
McAlpine	0.062	0.938	0.000	0.000
Markland	0.000	0.021	0.979	0.000
Meldahl	0.005	0.000	0.005	0.990

Table 3. Pool-to-pool transition probabilities of Silver Carp in the Ohio River through acoustic telemetry – 2013 to 2019 (preliminary results). The best model for Silver Carp provided state and time invariant survival, 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 in Greenup Pool or above due to the lack of movement data within these reaches of the river. The majority of fish are staying in the same pool each month (92.6% to 99.0%).

Year	Pool	AC *Spp*	Monthly Ranges											
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2017	McAlpine	BHC	*0.0*	--	--	--	7.0	56.9	--	46.8	--	--	--	--
		SVC	*0.5*	*0.4*	*0.9*	9.4	12.5	12.1	5.4	4.6	3.8	3.2	1.7	*1.2*
	Markland	BHC	--	--	*0.0*	28.4	28.4	37.8	6.5	1.4	0.0	0.0	0.0	*0.0*
		SVC	--	--	--	68.2	0.8	9.1	0.0	0.0	0.0	0.0	0.0	*0.0*
	Meldahl	BHC	*0.4*	*0.5*	*0.1*	--	22.1	57.5	13.3	9.8	5.0	0.1	0.2	*0.0*
		SVC	*0.1*	*0.2*	*0.2*	32.4	11.8	10.0	12.9	18.2	6.8	1.6	0.2	*0.1*
	All Pools	BHC	*0.3*	*0.5*	*0.1*	28.4	18.0	42.5	7.2	7.6	1.9	0.0	0.1	*0.0*
		SVC	*0.4*	*0.4*	*0.8*	10.8	11.9	11.3	5.6	5.2	4.0	3.1	1.3	*1.0*
2018	McAlpine	BHC	--	--	--	--	--	--	--	--	--	--	--	--
		SVC	*1.4*	*0.5*	*0.6*	*0.5*	9.6	12.3	13.0	4.1	2.1	2.3	1.1	*0.7*
	Markland	BHC	*0.5*	*0.2*	*0.6*	*0.5*	60.0	45.7	42.1	0.6	0.6	0.5	0.5	*0.0*
		SVC	*0.3*	*0.4*	*0.6*	*0.6*	50.0	52.0	24.7	0.4	4.4	1.7	0.3	*0.8*
	Meldahl	BHC	*0.0*	*0.0*	*0.0*	*0.0*	38.2	13.1	23.3	5.0	0.3	0.3	0.0	--
		SVC	*0.0*	*0.0*	*0.0*	*0.0*	22.4	6.7	16.1	8.5	3.5	0.0	0.0	*6.6*
	All Pools	BHC	*0.2*	*0.2*	*0.3*	*0.1*	32.2	19.7	24.5	2.2	0.5	0.4	0.3	*0.0*
		SVC	*1.1*	*0.5*	*0.6*	*0.5*	11.3	12.3	12.0	3.8	2.5	2.1	1.0	*0.8*
2019	McAlpine	BHC	--	--	--	--	--	--	--	--	--	--	--	--
		SVC	*1.6*	*1.6*	*1.3*	2.1	5.6	2.2	5.0	4.8	3.4	5.3	1.4	*0.0*
	Markland	BHC	*1.7*	*1.7*	*1.7*	31.7	6.8	48.7	26.4	1.1	2.9	1.1	0.0	--
		SVC	*1.1*	*1.1*	*4.4*	13.5	44.4	33.9	15.5	6.0	8.2	2.0	0.7	*0.0*
	Meldahl	BHC	*0.0*	*0.0*	*0.0*	14.2	39.1	3.9	16.0	20.0	12.0	11.6	3.6	*0.2*
		SVC	*3.3*	*2.6*	*2.0*	13.0	9.8	19.6	15.0	13.8	9.8	4.1	9.1	*2.1*
	All Pools	BHC	*0.8*	*0.6*	*0.7*	19.7	19.7	25.7	20.4	10.4	8.1	7.1	2.9	*0.2*
		SVC	*2.0*	*1.8*	*2.1*	5.9	12.6	9.9	7.7	6.0	5.2	4.7	3.2	*1.0*

Table 4 . Average monthly ranges for the tagged Bighead (BHC) and Silver Carp (SVC) detected in 2017 - 2019. Range was calculated as the distance between the most upstream and downstream detections over a given time period. Hence, all tagged carp added to the analysis had to be detected by at least two receivers in 2017, 2018 and/or 2019. The green line indicates when the array was bolstered by the redeployment of mainstem receivers. However, the red line marks when the array was reduced by annual efforts to retrieve the mainstem receivers and move them to over-winter storage.