Range assessment and detection limitations of bridge-mounted hydroacoustic telemetry arrays in the Mississippi River

Fisheries Report 09-05

A Final Report Submitted To

Richard Kirk, Endangered Species Coordinator
Tennessee Wildlife Resources Agency

By

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August 2009

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ABSTRACT

The efficacy of bridge-mounted submersible ultrasonic receivers was tested on two Tennessee bridges crossing the Mississippi River. Two VEMCO VR 2W receivers on the I-55 Bridge in Memphis and up to five receivers on the I-155 Bridge outside Dyersburg, Tennessee, were tested at low and high river stages in 2007 and 2008. The ability of the receivers to detect the passage of tagged pallid sturgeon *Scaphirhynchus albus*, a federally endangered species, was evaluated by trolling pinger tags mounted to downrigger weights downriver past the receivers along multiple transects. Maximum tag detection distances for individual receivers at low and high river stages varied from as little as 51 m to as much as 335 m. Maximum tag detection areas for each receiver varied from 0.01 to 2.86 ha. Receiver detection ranges did not extend to the nearest bank at any of the bridge piers tested; therefore, total coverage of the river's width by receiver arrays mounted on either of those bridges is not possible with current ultrasonic tag and receiver technologies. Receiver performance in terms of number of receptions, detection area, and maximum detection distance was hampered when the receiver was close to the main channel (where currents were swifter) and at high river stages. The mechanism for degraded performance under both scenarios was likely acoustical interference associated with turbulence and air entrainment around bridge piers.

Movements and habitat use by pallid sturgeon *Scaphirhynchus albus* in the lower and middle Mississippi River (i.e., between the Gulf of Mexico and the mouth of the Missouri River at St. Louis) are poorly understood (Hurley et al. 2004; Colombo et al. 2007. To address this data gap, a multi-agency effort was undertaken in 2003 to implant pallid sturgeon with ultrasonic tags and track their movements using VEMCO[1] VR-2W submersible ultrasonic receivers. Submersible ultrasonic receivers manufactured by VEMCO and other manufacturers have been used extensively in marine and estuarine systems (e.g., Simpfendorfer et al. 2002; Clements et al. 2005; Heupel et al. 2006), but less frequently in freshwater systems.

A vexing problem faced by many researchers employing submersible receiver technology is how to deploy the receivers to simultaneously achieve good reception of transmitted signals and high receiver-retrieval rates. For instance, suspending receivers beneath buoys (which are prone to boat collisions) and anchoring receivers on shifting substrate resulted in low retrieval rates in several marine studies (Brakensiek and Coshow 2002; Comeau et al. 2002; Clements et al. 2005). Finding sites to deploy receivers in the Mississippi River is challenging given the large volume of barge traffic and the prevalence of loose, shifting substrates. Permanent structures such as bridges offer some advantages as receiver deployment sites; most importantly, receivers are protected from collisions. To this end, the Missouri Department of Conservation developed a mounting system for submersible receivers which consist of PVC conduit bolted to the downriver side of a bridge pier; the receiver is suspended within the conduit by a cable and the receiver’s hydrophone extends out the bottom of the conduit. This system allows researchers to retrieve the receiver at various river stages (to download data and replace batteries) and it protects the receiver from debris and vessel collisions; however, the receiver is "deaf" to transmissions from directly upstream. Another caveat of mounting receivers to bridges is that some of the most turbulent and acoustically noisy waters in a river are associated with instream structures such as bridge piers, and high levels of ambient noise degrade receiver performance. Finally, the spacing of receivers across a river cannot be adjusted when they are mounted to bridge piers; thus, the spacing cannot be adjusted to ensure bank-to-bank coverage.

Thousands of VEMCO submersible ultrasonic receivers have been deployed worldwide (Richard Valee; VEMCO Inc.; personal communication), and most of the literature on receiver detection range relates to marine deployments (Table 1). Determining the range and coverage of

[1] The use of trade, product, industry or firm names or products is for informative purposes only and does not constitute an endorsement by the U.S. Government or the US Geological Survey.

receiver arrays in the Mississippi River will provide insight into the likelihood of detecting the passage of tagged pallid sturgeon (and other species) among river reaches. Ideally, receivers should be spaced so that a tagged fish passing through the array will be detected by one or more receivers. However, the distance between receivers mounted on Mississippi River bridges is fixed by the spacing of bridge piers.

Huepel et al. (2006) suggested testing submersible ultrasonic receiver ranges by mooring tags at set distances from the receiver (or an array of receivers) overnight. However, that method is problematic in a highly trafficked river such as the Mississippi River. Mooring tags and testing receivers in or near the main channel would leave tags susceptible to collisions from barges, and temporarily anchoring buoys would be difficult in the lower Mississippi River, even for a few hours. Another method to test receiver range involves floating a tag along a series of transects past a moored receiver (Clements et al. 2005); the likelihood of tag loss is minimized because the tag is "supervised" and its position is known with certainty at all times.

The objective of the study described herein was to assess the range of VR-2W submersible ultrasonic receivers mounted to bridge piers in the Tennessee waters of the Mississippi River as a function of bridge site, proximity of each pier to the main channel, and river stage.

STUDY AREAS

Interstate 55 Bridge

The southern-most bridge over the Mississippi River in Tennessee is the I-55 Bridge in Memphis at MRkm 1,182. Constructed in 1949, this cantilever steel truss, four-lane highway bridge spans about 620 m of the Mississippi River at low stage. This bridge is supported by four evenly-spaced piers constructed of granite blocks. Directly upriver and within 100 m of this interstate highway bridge are two railroad bridges, also constructed in 1949. To facilitate vessel traffic on the river, the four piers of both railroad bridges have the same spacing as the I-55 Bridge.

Four piers support the I-55 Bridge and are numbered 1 to 4, with 1 being closest to the left descending bank. The westernmost piers (piers 2, 3, and 4) are spaced 175 m apart and piers 1 and 2 are 228 m apart. The center of the shipping channel (i.e., the thalweg) lies between pier

1 and 2 and is 52 m away from pier 2. The two inner piers (2 and 3) each have a protruding shelf approximately 0.2 m wide that is visible at river stage -0.6 m (measured at the Memphis gauge).

The outermost piers (1 and 4) are dewatered at low river stages; thus, those two piers are not suitable receiver attachment sites. Instead, receivers were mounted to piers 2 and 3 for testing. The receivers were anchored to the piers by suspending them inside PVC conduit bolted to each pier.

Interstate 155 Bridge

Spanning approximately 800 m over the Mississippi River, the I-155 Bridge is located near Dyersburg, Tennessee, and Caruthersville, Missouri, at MRkm 1,350. The I-155 Bridge has four highway lanes and is supported by seven concrete piers in varying degrees of contact with the river. The bridge is supported by steel trusses between piers 1, 2, and 3 and the remaining four piers support the bridge as a causeway. Unlike the I-55 Bridge in Memphis, there are no ledges visible on any piers. Pier 1 is dewatered at low river stages. Piers 3, 4, 5, 6, and 7 on the causeway portion of the bridge are equidistant and are spaced 67 m apart. Piers 1 and 2 are spaced widely apart (269 m) because they bracket the shipping channel; from pier 2 the main channel is 102 m away towards the left bank descending. Piers 2 and 3 are 151 m apart.

Conduits to hold receivers were permanently mounted to piers 2 and 3 in August 2007 by MDC biologists and were located 80 m and 239 m from the main channel, respectively. By June 2008, MDC biologists had subsequently mounted conduits (and receivers) on piers 5 and 7, located 381 m and 527 m from the main channel, respectively.

Interstate 40 Bridge

Also known as the Hernando de Soto Bridge, the I-40 Bridge in Memphis at rkm 1,185 is located 2.6 km upriver from the I-55 Bridge and spans more than 1 km over the Mississippi River at low stages. The I-40 Bridge carries vehicle traffic in six lanes and is considerably longer and wider than the I-55 Bridge. The distance between pier 1 (nearest the left bank descending) and pier 8 (nearest the right bank descending) is 1.2 km.

The eight piers are built of poured concrete and are in varying degrees of contact with the river; three piers are rarely submerged (Piers 1, 7, and 8); thus, they are not suitable candidates for receiver attachment. The main channel runs between Piers 1 and 2, which are spaced 269 m apart to facilitate traffic on the river; pier 3 is positioned 275 away from pier 2 towards the right-bank descending. Pier 2, the pier closest to the main channel with a base that is permanently submerged, has a 2-m wide ledge that is visible at river stage 0.2 m; that is, the pier consists of lower (wider) and upper (narrower) tiers. The presence of that wide ledge renders pier 2 unacceptable for a permanently mounted receiver because a conduit cannot be attached to that pier (which lies in the middle of a ~544 span of river) that would allow a receiver to listen for tagged fish at both low and high river stages. Although we conducted some preliminary investigations of receiver performance on piers 2 and 3 using temporary mounts (Casto-Yerty 2009), we do not present any of those data herein. Based on our assessment of pier placements and construction, the I-40 Bridge will never be a suitable site to deploy an array of submersible ultrasonic receivers.

METHODS

Simulated Fish Passage

The passage of a tagged pallid sturgeon was simulated by floating a tag suspended in the water column past piers with mounted receivers. Pallid sturgeon researchers in the lower and middle Mississippi River have been tagging fish with VEMCO model V16-6H-R64K coded ultrasonic tags with a 60-90 s randomized-delay transmissions. The tag used in fish passage simulations was also a model V16-6H-R64K pinger tag; however, the pinger tag had a fixed delay of 6 s between transmissions rather than a randomized delay. With a fixed-delay tag, the number of transmissions emitted over time was known. The tag was submerged in the lower third of the water column by means of a downrigger attached to the bow of the boat. The tag was strapped using cable ties into a channel carved into a 2.5 x 10 cm wood dowel. Electrical tape was wound around the transmitter and the dowel to further secure it. The 15-mm distal portion of the tag, which contained the transducer, overhung the dowel and was free of electrical tape or cable ties. The wooden dowel-and-tag-assembly was secured to a 3.6-kg trolling weight with two cable ties attached to loops mounted on either end of the trolling weight. The transducer pointed away from the downrigger weight. As the boat moved downstream, the tag's transducer faced upriver (i.e. in the direction of the bridge).

Tag transmissions are detected by VR-2W receivers using an omni-directional hydrophone and the receiver records the tag code and the time and date of detection to an internal flash drive. The bridge mounts for the receivers consisted of up to three 3.1-m long conduit pipes (10.2-cm diameter opening) bolted to the bridge piers. Access windows were cut into the conduits at various heights to allow access to each receiver at both high and low river stages.

Tags were trolled past receivers along transects approximately equidistant apart, beginning ~75 m upriver from each bridge pier. A boat-mounted Garmin GPSMAP™ model 188 Sounder GPS Unit was used to record GPS coordinates every 30 seconds using the reference coordinate system WGS 84. The time of each waypoint along each transect was manually recorded. The times of tag detections later retrieved from the receivers were compared with the known locations of each tag over time. Depth was noted along transects every 30 seconds and the tag was raised or lowered to keep it in the lower third of the water column. The boat moved downriver in reverse during all simulations (i.e., the bow pointed upriver). The 150-hp Mercury OptiMax two-stroke outboard motor was left on at idling speed and was used to keep the boat properly oriented. Transects extended at least 400 m downriver of each receiver at both high and low river stages. River stage was recorded at U.S. Army Corps of Engineers river gauges at Memphis, Tennessee (for the Interstate 55 Bridge tests) and at Caruthersville, Missouri (for the Interstate 155 Bridge tests).

Tests at the I-55 Bridge in Memphis were performed on 17-18 September 2007 and on 5 August 2008 during low and high river stages of -0.4 m and 4.8 m, respectively. During the low stage tests, the same receiver was mounted to piers 2 and 3 on two consecutive days. During the high stage test, separate receivers were attached to Piers 2 and 3 and range tests were performed simultaneously.

The low-stage test at the I-155 Bridge outside Dyersburg, Tennessee, was performed on 27-28 August 2007 when the river stage was 2.95 -3.20 m. The high-stage test was performed on 17 June 2008 and 18 July 2008 during river stages of 8.99 m and 6.64 m, respectively. Data were not retrieved from the receivers in June 2008 because the tops of the conduits were underwater, rendering the receivers inaccessible. After the July 2008 tests, data from the low and high river stage tests were retrieved from all of the receivers on that bridge.

Data Analysis

Upon retrieval, each receiver was connected to a laptop computer using a Bluetooth® wireless connectivity device and tag detections (if any) were downloaded. Tag detection times were subsequently compared to the times recorded at waypoints along each transect and the location of the tag during each transmission that was detected by the receiver was estimated via linear interpolation.

ArcMap 9.2 was used to display locations of the tag when its transmissions were detected by a receiver. Maximum possible reception area at both high and low river stage was estimated by creating a polygon from the detection points located farthest from the receiver and using the area measure tool in Arc GIS. The maximum coverage between banks provided by receivers at each river stage (i.e., the maximum distance across the channel at which tags could theoretically be detected) was measured parallel to each bridge using the linear measure tool in Arc GIS.

RESULTS

Interstate 55 Bridge

High water and the receiver's proximity to the swifter waters of the main channel degraded the performance of the receivers mounted to this bridge. The maximum detection areas for both the on-channel and off-channel receivers at low stage were at least twice as high as the maximum detection areas at high stage (Table 2). Maximum detection area for the off-channel receiver (pier 3) was ~ 4X greater than the on-channel receiver (pier 2) at both high and low stages. During low stage, cross-river coverage by the two receivers was 307 m, or about 50% of the river's width. Low-stage coverage was probably wider than 307 m because the receiver on pier 3 detected tags along the outer-most transects (Figure 1); however, most of the main channel was not covered by the two receivers. Cross-river coverage decreased to 236 m during high stage (Figure 2), or about 38% of the river's width. The degradation of receiver efficiency at high stage was also evidenced by the large number of close-in tag transmissions that were not detected, especially by the receiver on pier 3 (Figure 2).

Interstate 155 Bridge

The receiver mounted closest to the main channel (pier 2) provided excellent cross-river coverage of more than 280 m during low river stage (Table 2; Figure3), as did the receiver on pier 3 with 203-m wide coverage. Those two receivers alone provided coverage of 64% (383 m) of the river's width at low stage, which included some of the main channel. However, the pier 2 (on-channel) receiver could not detect any tag transmissions laterally at high river stage (Figure 4); thus, no transmissions in the main channel were detected at high stage. Although the on-channel receiver did not detect any lateral transmission at high stage, it detected several transmissions from nearly 200 m away directly downstream. No high-stage data were retrieved from the receiver mounted on pier 3 because its battery was dead when the receiver was retrieved. The two functioning off-channel receivers on piers 5 and 7 performed well at high stage in terms of lateral detections, number of detections, and maximum detection areas (Figure 4); however, the loss of data from pier 3 and the poor coverage of the pier 2 receiver resulted in cross-river coverage by all four receivers of only 326 m at high stage, or about 54% of the river's width.

DISCUSSION

Arrays of submersible acoustic receivers manufactured by VEMCO (and other manufacturers) are in wide use in marine and freshwater systems, but few studies have been published on the range of the VR-2W receiver in freshwater. Hildebrand (2008) used an array of VR-2W receivers attached to buoys to track white sturgeon (*Acipenser transmontanus*) in the Columbia River; tags suspended beneath buoys were detected by receivers up to 100 m upriver and 160 m downriver; however, the author noted that further studies needed to be conducted at high and low river stages. Whitty et al. (2008) reported that VR-2W receivers suspended beneath anchored buoys had an average maximum detection range of 246 m with a model V16 transmitter in the Fitzroy River, Australia. These detection ranges from other studies are roughly comparable to some of the maximum ranges observed in the present study, especially during low stages; however, VR-2W performance in the Mississippi River at high stage was severely compromised.

Clements et al. (2005) demonstrated that the mounting method strongly influences the ability of an receiver to detect tag transmissions. For best performance, receivers suspended from buoys had to be vertical (or near so) in the water column and the omnidirectional hydrophone had to be free of obstructions such as the buoy mooring rope or mounting bracket. In their study, Clements et al. (2005) reported ranges approaching 400 m for VR-2 receivers in the Columbia River estuary. Although those receivers in the Columbia River estuary operated where the current from outgoing tides sometimes exceeded 2 m/s, the receivers operated free of the turbulence and acoustical interference associated with instream structures such bridge piers. The difficulty receivers have in detecting transmissions when they are attached to bridge piers (especially piers near the main channel) is due to the entrainment of air bubbles as the rivers flows past the piers, which increases the ambient acoustic background (Leighton 1997).

Perhaps the most critical measurement of receiver performance for the purposes of detecting the passage of a tagged fish through an array is the coverage each receiver provides between banks (i.e., the proportion of the river's width covered by receivers). For both Tennessee bridges, cross-river coverage was greatest during low stages, but never exceeded 64% of the river's width. More importantly, the bridge-mounted receivers performed poorly in detecting transmissions from the main channel, where the swifter, deeper waters are thought to be habitat preferred by pallid sturgeon (Kallemyn 1983), or at the very least, used frequently by pallid sturgeon (Hurley et al. 2004).

In conclusion, no receiver near the main channel on the Mississippi River bridges we studied had good coverage that extended to the nearest bank; therefore, it is not possible to ensure that bridge-mounted VR-2W receiver arrays in Tennessee will detect the passage of tagged pallid sturgeon past the two bridges we tested, even at low river stages. Range testing at bridges in the middle and upper reaches of the Mississippi River are needed to confirm (or refute) our observations that bridge-mounted receiver arrays in North America's largest river offer incomplete coverage, even under ideal river conditions. It is important to note that pallid sturgeon have been tagged with transmitters with long randomized delays of up to 90 s (as opposed to the 6-s delay pinger tags used in our tests), which will further degrade the ability of bridge-mounted receivers to detect tagged fish. We offer this negative assessment despite the fact that one tagged pallid sturgeon was detected passing through the I-155 Bridge array during our study (D. Herzog; Missouri Department of Conservation; personal communication). Unfortunately, our results show that lack of receiver detections over time at a bridge does not mean a tagged fish did not pass by the bridge. New technological developments in receiver capabilities and ultrasonic signal characteristics will be required before the use of bridge-mounted receivers can be recommended to detect movements of tagged fish in the Mississippi River. In the meantime, some movement data on tagged pallid sturgeon in the middle Mississippi River are being acquired by receivers attached to buoys, although receiver losses are still problematic (D. Herzog; Missouri Department of Conservation; personal communication).

Acknowledgements

We would like to thank D. Herzog for mounting receivers to the Interstate 155 Bridge and for providing receiver data and exceptional technical advice on many facets of our research. We thank the U.S. Coast Guard (lower Mississippi River Sector), Tennessee Department of Transportation and the Memphis Harbor Patrol for permission to mount receivers to bridges and work around critical infrastructures. Funding for this research was provided by the Tennessee Cooperative Fisheries Research Unit (U.S. Geological Survey), the Tennessee Wildlife Resources Agency; and the Center for the Management, Utilization, and Protection of Water Resources. This final report benefited from comments made on earlier drafts by D. Buckmeier, J. M. Redding, S. Hayslette, and H. Mattingly. Finally, we thank R. Bisch and T. O'Brien for all of their assistance out on the water and in the computer lab.

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Table 1. Reported operational ranges for VEMCO submersible ultrasonic receivers listening for model V16 sonic tags, transmitter power output in decibels, and location of study.

Citation	Receiver Model	Transmitter Power (dB)	Operational Range (m)	Habitat (Country)
Bacheler 2008	VR 2	158	Up to 400	Neuse River Estuary and Adams Creek (USA)
Brooking et al. 2006	VR 2	n/a	Up to 500	Passamaquoddy Bay and Cobscook Bay (USA)
Carlisle 2006	VR 1	165	350 - 500	Elkhorn Slough (USA)
Dagorn et al. 2007	VR 2	158	600-1300	Pacific Ocean (USA)
Egli and Babcock 2004	VR 2	n/a	Up to 500	Pacific Ocean (New Zealand)
Finstad et al. 2005	VR 2	n/a	120-260	Fjords (Norway)
George 2007	VR 2	165	<400 - >1000	Barataria Bay (USA)
Humston et al. 2005	VR 2	158	230-750	Atlantic Ocean (USA)
Mitamura et al. 2008	VR 1, VR 2	n/a	200-400	Mekong River (Cambodia, Thailand, and Vietnam)
Simpson and Fox 2007	VR 2	n/a	Up to 500	Delaware River and estuary (USA)
Starr et al. 2007	VR 2	152, 165	750	Atlantic Ocean (Belize)
Stokesbury et al. 2005	VR 2	n/a	Up to 605	St. Lawrence River estuary (Canada)
Taquet et al. 2006	VR 2	165	Up to 200	Indian Ocean
Taquet et al. 2007	VR 2	158	595-715	Indian Ocean
Whitty et al. 2008	VR 2W	165	Up to 246	Fitzroy River (Australia)
Wright et al. 2007	VR 2	159	200 - 750	Alsea River, its estuary, and the Pacific Ocean (USA)

Table 2. Number of detections, maximum detection distance, maximum detection area polygon, maximum reception distance towards the left-bank-descending (LBD), maximum reception distance towards the right-bank-descending (RBD), and bank-to-bank coverage provided by VEMCO model VR2W submersible receivers attached to bridge piers at various distances from the sailing line on the Mississippi River in 2007 and 2008. Range tests were performed using VEMCO model V12 pinger tags with a 6-s transmission delay at low and high river stages. Refer to text and Figures 1-4 for location of piers. No detections were logged at Pier 3 of the I-155 Bridge during high stage because of receiver battery failure.

Interstate Bridge	Pier Number	Stage (m)	Distance (m) from sailing line[1]	Number of Detections	Maximum Distance (m) From Receiver	Detection Area (ha)	LBD Detection Distance (m)	RBD Detection Distance (m)
55	2	Low (-0.41)	52	15	93	0.62	61	54
55	3	Low (-0.41)	250	100	277	2.64	159	47
55	2	High (4.82)	52	6	88	0.31	25	86
55	3	High (4.82)	250	17	151	1.17	66	58
155	2	Low (3.08)	80	54	160	1.95	129	153
155	3	Low (3.08)	239	116	200	2.63	105	98
155	2	High (8.99)	80	4	191	< 0.01	0	0
155	3	High (8.99)	239	.	.	.	.	.
155	5	High (8.99)	381	44	229	1.84	162	118
155	7	High (8.99)	527	67	335	2.86	162	30

[1] US Army Corps of Engineers lower Mississippi River navigation charts 11 & 22 (2007).

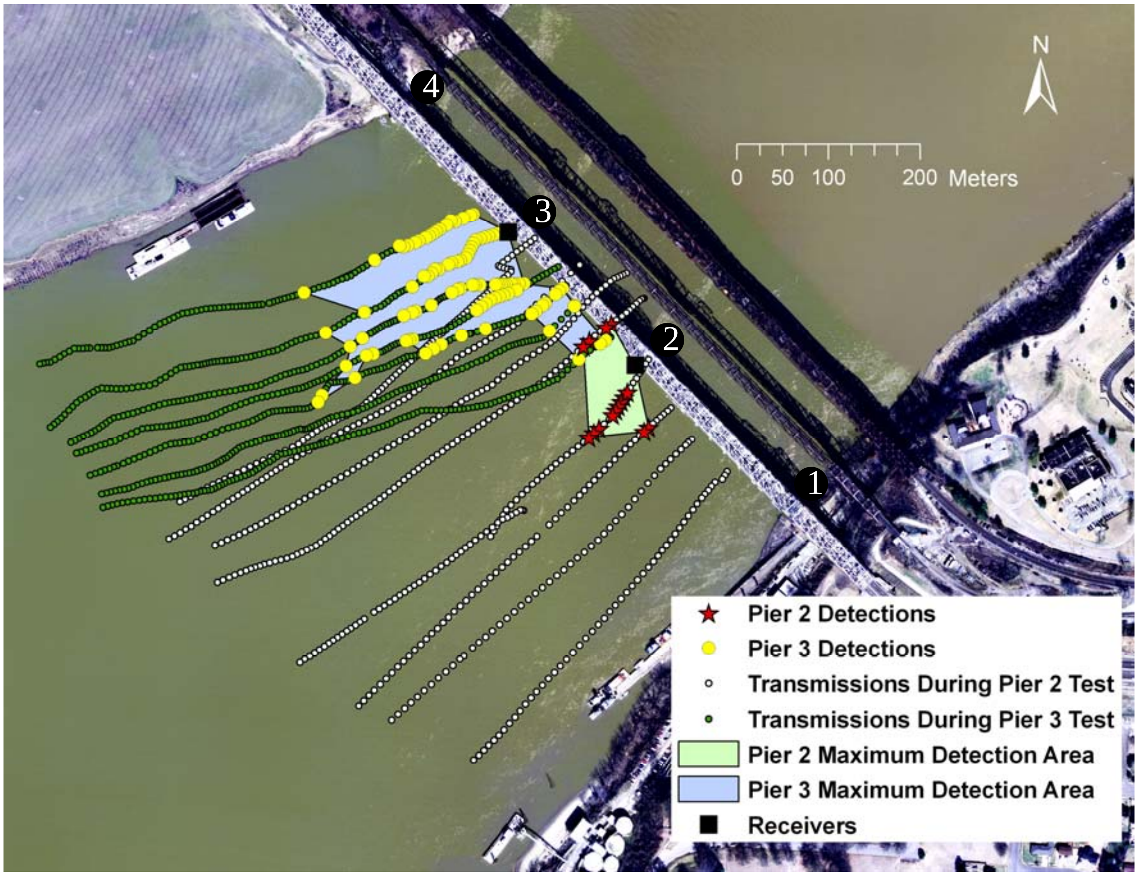

Figure 1. Locations of a submerged acoustic tag during transmissions, locations of the tag when two VR2W submersed ultrasonic receivers recorded a tag reception, and maximum reception area of each receiver during low river stage tests on 17-18 September 2008 at the Interstate 55 Bridge in Memphis, Tennessee. The main channel runs between piers 1 and 2. The spacing of bridge piers 1 through 4 is indicated. Photo taken at an unknown date at a high river stage.

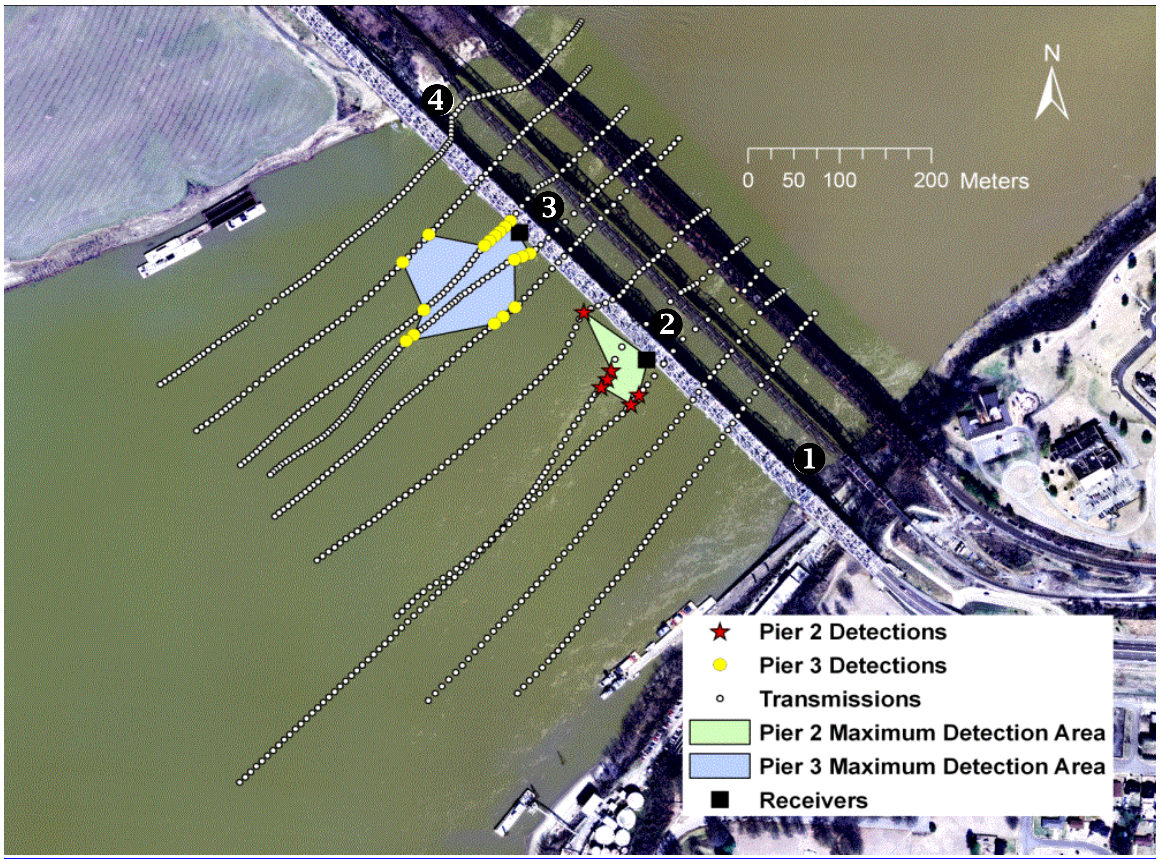

Figure 2. Locations of a submerged acoustic tag during transmissions, locations of the tag when two VR2W submersed ultrasonic receivers recorded a tag reception, and maximum reception area of each receiver during high river stage tests on 5 August 2008 at the Interstate 55 Bridge in Memphis, Tennessee. The spacing of bridge piers 1 through 4 is indicated. The main channel runs between piers 1 and 2. Photo taken at an unknown date at a high river stage.

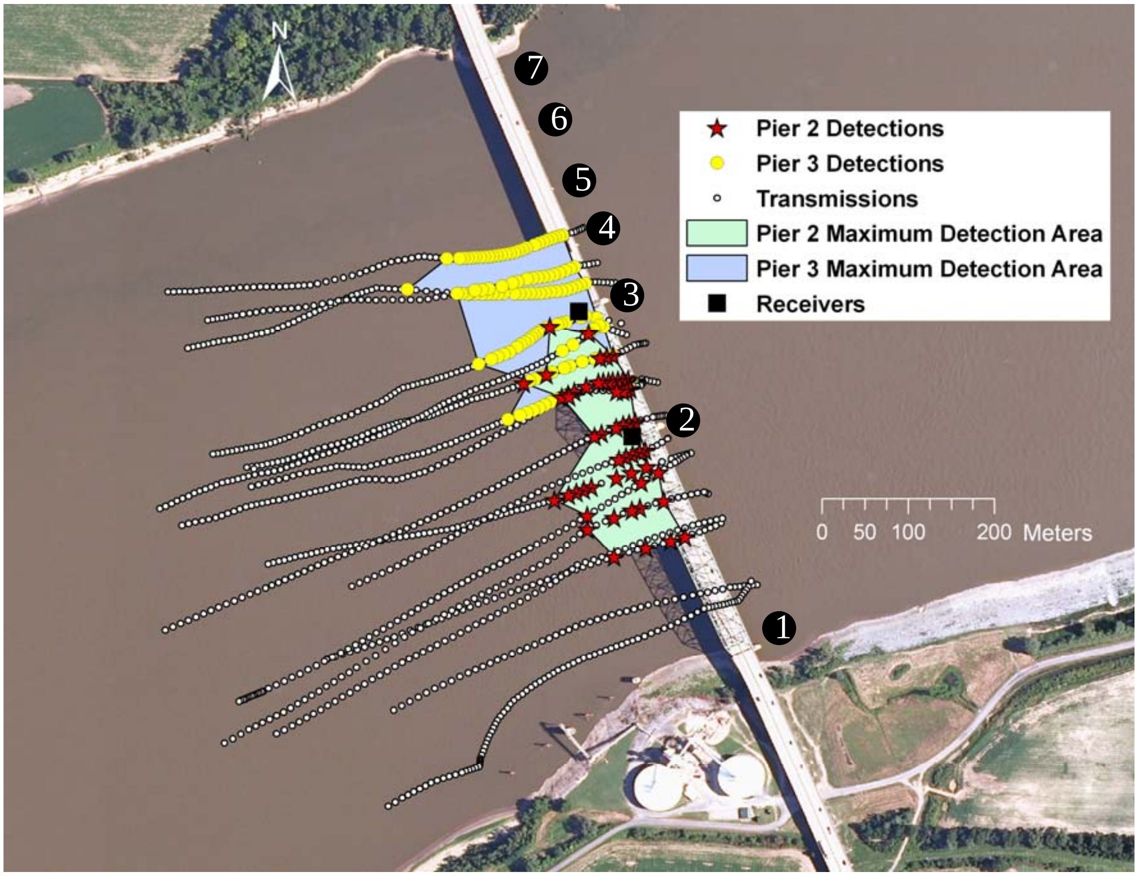

Figure 3. Locations of a submerged acoustic tag during transmissions, locations of the tag when VR2W submersed ultrasonic receivers recorded a tag reception, and maximum reception area of each receiver during low river stage tests on 27-28 August 2007 at the Interstate 155 Bridge outside Caruthersville, Missouri. The spacing of bridge piers 1 through 7 is indicated. The main channel runs between piers 1 and 2. Photo taken at an unknown date at a high river stage.

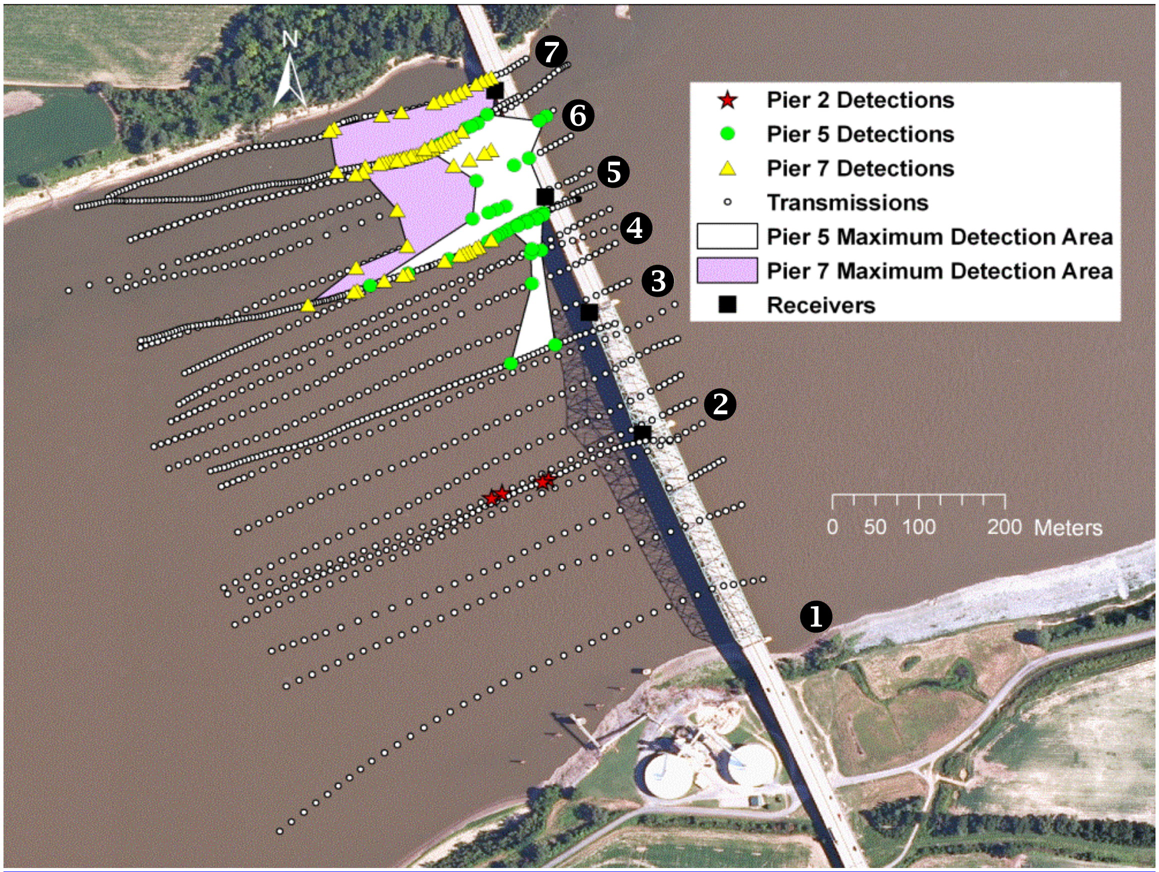

Figure 4. Locations of a submerged acoustic tag during transmissions, locations of the tag when VR2W submersed ultrasonic receivers recorded a tag reception, and maximum reception area of each receiver during high river stage tests on 17 June 2008 and 18 July 2008 at the Interstate 155 Bridge outside Caruthersville, Missouri. The spacing of bridge piers 1 through 7 is indicated. A receiver mounted to pier 3 did not log any detections due to battery failure. The main channel runs between piers 1 and 2. Photo taken at an unknown date at a high river stage.