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Lock 19 Underwater Acoustic Deterrent System Study—Interim Project Update, through 2022

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U.S. Department of the Interior
U.S. Geological Survey

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By Marybeth K. Brey, Christa M. Woodley, Jessica C. Stanton, Andrea K. Fritts, Matthew Sholtis, Theodore Castro-Santos, Jonathan M. Vallazza, and Janice L. Albers

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datums

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Frequency is given in kilohertz (kHz).

Abbreviations

DNR	Department of Natural Resources
ERDC	U.S. Army Engineer Research and Development Center
HTI	Hydroacoustic Technology Incorporated
UADS	underwater acoustic deterrent system
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Lock 19 Underwater Acoustic Deterrent System Study—Interim Project Update, through 2022

By Marybeth K. Brey,[1] Christa M. Woodley,[2] Jessica C. Stanton,[1] Andrea K. Fritts,[1] Matthew Sholtis,[1] Theodore Castro-Santos,[1] Jonathan M. Vallazza,[1] and Janice L. Albers[1]

Abstract

Invasive carp (*Hypophthalmichthys nobilis* [Richardson, 1845; Bighead Carp], *H. molitrix* [Valenciennes in Cuvier and Valenciennes, 1844; Silver Carp], *Ctenopharyngodon idella* [Valenciennes in Cuvier and Valenciennes, 1844; Grass Carp], and *Mylopharyngodon piceus* [Richardson, 1846; Black Carp]) expansion threatens the Laurentian Great Lakes and other major waterways. Numerous tools and techniques are being tested or developed to curtail the upstream expansion of invasive carps while minimizing the effect to native species. Underwater sound is one technology that has shown promise as a deterrent in the laboratory and ponds and is being considered for use at bottleneck locks and dams to reduce the risk of invasive carps moving to uninvaded areas. To test this technology at a management-relevant scale, an underwater acoustic deterrent system (UADS) was designed and installed at Lock 19 on the Mississippi River in 2021. The experimental UADS operates on a continuous schedule of 80 hours on and 80 hours off to allow for comparisons of fish behavior during varying environmental, operational, and navigation traffic conditions. Two telemetry systems, operating at 69 and 307 kilohertz, were deployed to evaluate how the UADS may affect movement and behavior of invasive carps and native fish species. During 2021–22, Silver Carp were twice as likely to pass over the UADS and into the lock when it was off compared to on; however, Bigmouth Buffalo, a native fish, were 1.2 times more likely to make upstream passage when the UADS was off compared to on.

Introduction

Hypophthalmichthys nobilis (Richardson, 1845; Bighead Carp), *H. molitrix* (Valenciennes in Cuvier and Valenciennes, 1844; Silver Carp), *Ctenopharyngodon idella* (Valenciennes in Cuvier and Valenciennes, 1844; Grass Carp), and *Mylopharyngodon piceus* (Richardson, 1846; Black Carp), herein, collectively referred to as "invasive carps," are invasive fish species established throughout the Mississippi River Basin. Invasive carp range expansion threatens the Laurentian Great Lakes (Hansen and Johnson, 2010; Ivan and others, 2020) and other major waterways (Kasprak and others, 2022). Previous studies and experience demonstrated that some locks and dams operate as bottlenecks for fish movement and invasive carp range expansion because of unique hydraulic conditions and operations at these pinch-point dams (Zigler and others, 2004; Anderson and others, 2019; Vallazza and others, 2021; Turney and others, 2022). Dams that are considered bottlenecks are those that restrict upstream fish passage to the lock chamber, resulting in limited (but not zero) upstream fish passage at most river stages (Wilcox, 1999; Tripp and others, 2014; Fritts and others, 2021).

Numerous tools and techniques are being tested or developed to curtail the upstream expansion of invasive carps while minimizing the impact to native species. Underwater sound is one technology being considered at locks of bottleneck dams to reduce the risk of invasive carps moving from the Mississippi River drainage basin to the Great Lakes (for example, Brandon Road Interbasin Project) and upstream into uninvaded areas of the Mississippi River Basin (for example, Jackson and Runstrom, 2018; strategy 2.2). As demonstrated in the laboratory (Vetter and others, 2015, 2017; Murchy and others, 2017), underwater acoustic deterrent systems (UADSs) may be more specific to invasive carps than other tools because these species have more sensitive hearing than many native species and acoustic signals have been specifically designed to target their sensitive frequency bands (Nissen, 2018; Vetter and others, 2018). In laboratory behavioral trials, Grass Carp and Silver Carp demonstrated a similar degree of negative phonotaxis to a broadband sound, similar to the sound used in a UADS (Murchy and others, 2022); however, Grass Carp response has not yet been evaluated in pond or field settings. Larger spatial and temporal evaluations of UADS deployments would be beneficial at navigation locks at dams with bottleneck characteristics but where invasive carp are at least moderately abundant and passage through the lock is known to occur with at least moderate frequency. Such field tests are important for evaluating the magnitude of deterrence that can be achieved for invasive carps, and the

[1]U.S. Geological Survey.

[2]U.S. Army Engineer Research and Development Center.

response of native fishes to the deterrent. The Invasive Carp Regional Coordinating Committee recognized this need to test deterrents at locks and dams as early as 2007 (see section 3.2.2.3 of the Management and Control Plan for Bighead, Black, Grass, and Silver Carps in the United States; Conover and others, 2007). The Invasive Carp Regional Coordinating Committee has provided supplemental funding through the Great Lakes Restoration Initiative to test deterrent technology at two movement bottleneck dams in the Mississippi and Ohio River Basins in recognition of the technology's applicability in the Upper Illinois River Waterway System to protect the Great Lakes.

Site selection for the experimental UADS deployment included four specific criteria based on numerous meetings with natural resource management agencies (including the U.S. Fish and Wildlife Service, Iowa Department of Natural Resources [DNR], Illinois DNR, Minnesota DNR, Wisconsin DNR, and the Missouri Department of Conservation), a workshop, and previous studies. After determining the site would be at a lock and dam, the following criteria were established:

1. Upstream passage of invasive carps and native species at the location should be mostly, if not completely, limited to the lock chamber (that is, at high-head dams that never or infrequently have "open river" conditions, thus generally limiting passage only through the lock).

2. A population of invasive carps should be above and below the dam with at least moderate upstream passage rates to increase the likelihood that test specimens are readily available to move through the deterrent for evaluation purposes.

3. Established populations of several important native migratory species should be on both sides of the dam with at least moderate upstream passage rates to increase the likelihood that native species test specimens are readily available to move through the deterrent.

4. Locations where telemetry monitoring systems already exist, or where background data regarding fish passage are available, should be prioritized.

Lock 19 on the Mississippi River near Keokuk, Iowa (lat 40°23'38.68″ N., long 91°22'32.10″ W., not shown), met all the criteria established for testing an experimental UADS. The dam associated with Lock 19 is a relatively high-head dam for the Mississippi River (mean hydraulic head [the difference in the tailwater elevation and the pool elevation] from 2017 to 2019 of 9.2 meters [m]; range of 4.7–11.4 m) for the Mississippi River Basin where upstream fish passage is limited to the lock chamber (that is, no upstream fish passage is possible through the main channel spillway gates). An abundant population of invasive carps and native migratory species above and below the lock are regularly collected and monitored by State and Federal agencies (Fritts and Knights, 2020; Sullivan and others, 2020; Fritts and others, 2021).

The study design for this project was devised and agreed upon by a multiagency science advisory team that consisted of scientists from the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers (USACE), U.S. Army Engineer Research and Development Center (ERDC), Iowa DNR, Illinois DNR, Minnesota DNR, Wisconsin DNR, and Missouri Department of Conservation. The USGS and ERDC, in partnership with the USACE, carry out the field evaluation and data analysis for the study. Additional field support is also provided by many of the previously mentioned State and Federal partner agencies.

Study Objectives

The study detailed in this report had the following objectives:

1. Design and install a UADS in the downstream lock approach channel.

2. Evaluate the effectiveness of the UADS to deter upstream passage of fish into the lock chamber (focus of this interim report).

3. Evaluate the behavior of invasive carps and native fishes relative to UADS operation and covariates.

4. Evaluate the UADS operational performance over the study duration.

To meet the timely needs of our partners by providing the best available science to inform management decisions, this report provides preliminary results from the first 2 years of this ongoing study. Here, we focus on a summary of available raw data (that is, data summarized and not incorporated into a statistical model). Over the duration of the study, we are monitoring the system operation to evaluate how environmental conditions, vessel traffic, and lock operations may affect the UADS operation. Operational data analyses can inform how design modifications may be implemented to make the experimental UADS a more effective deterrent. The information learned during the UADS evaluation at Lock 19 can be used to inform invasive carp management decisions, such as where to use and what acoustic deterrent technology or engineering modifications could be considered for more efficient and effective system operation.

Methods

The UADS was designed specifically for the Lock 19 site by a team of USACE, ERDC, and USGS engineers and biologists. A "soundbar," composed of 16 underwater transducers or speakers (LL–1424HP; Lubell Labs, Whitehall, Ohio) is mounted in an approximately 31.9-m steel weldment and was installed so that it sits recessed in a water discharge

trench (where the water discharges when the lock is draining) in the downstream lock approach channel (fig. 1). The UADS and associated monitoring equipment were installed in February 2021. This UADS operates using only acoustic playbacks developed by the Government, as opposed to other commercial deterrent systems that may use combinations of stimuli (for example, a multimodal deterrent system that uses sound, lights, and bubbles). The UADS engineering design and acoustic signals used during operation are patent pending (patent application number 18/126,415). We are evaluating fish movement in response to the UADS by using a study design that cycles between 80 hours of the sound stimulus on and 80 hours of it off. This goal of using a periodic cycling schedule is to provide comparisons of fish behavior across variable environmental conditions, vessel traffic, and lock operations.

The data being collected in this study can be used to evaluate changes in fish passage (upstream movement) through the lock chamber and fish behavioral changes in the lock approach channel when the UADS is on compared to when it is off. We are using two types of acoustic systems to study fish movements (Vemco [69 kilohertz (kHz)] and Hydroacoustic Technology Incorporated [HTI; 307 kHz]; Innovasea Systems Inc.). Multiple ongoing studies throughout the Mississippi River Basin use the 69-kHz system to evaluate long-distance fish movements or inform invasive carp commercial or contracted harvest. The number and spatial extent of these studies allow us to leverage additional information for the evaluation of the UADS by being able to observe fish that were implanted with 69-kHz transmitters in other parts of the river and are detected near the UADS and observe the longitudinal movements of fish tagged as part of this study. The 69-kHz system allows us to track broad fish movement by leveraging ongoing telemetry studies in the Mississippi River and an existing receiver network at Lock 19. However, the 69-kHz system does not allow for fine-scale two-dimensional positioning of fish, which is necessary for evaluating fish behavioral responses to the UADS. The 307-kHz system was implemented specifically to account for shortcomings of the 69-kHz system and generate fine-scale movements of fish in the lock approach channel, near the UADS, during more frequent intervals than the 69-kHz system can provide. We installed a network of receivers for both telemetry systems around Lock 19, including throughout the lock approach channel, on the tailwater side (that is, the area of flowing river below the dam) of the lock approach river wall, in the lock, and upstream from the lock.

Figure 1. The underwater acoustic deterrent system being installed in the downstream lock approach channel of Mississippi River Lock 19, Keokuk, Iowa, in February 2021. Photograph by Mark Cornish, U.S. Army Corps of Engineers.

Fish were surgically implanted with one of two types or both types of acoustic transmitters (herein, referred to as "tagged" or "tagging") to meet fish tagging targets. All fish handling and surgery procedures were reviewed and approved by the USGS Upper Midwest Environmental Sciences Center Institutional Animal Care and Use Committee (Institutional Animal Care and Use Committee protocol no. AEH–20–LD19ADS–01). Tag types included 307-kHz LY coded transmitters (also referred to as a "tag"; diameter = 16 millimeters [mm], length = 48 mm, weight in air = 11.9 grams [g], acoustic transmissions [ping rate] = 3–8 seconds) or 69-kHz V16P–4x (diameter = 16 g, length = 68 mm, weight in air = 24 g, random ping rate = 30–90 seconds) acoustic transmitters. Each year of the study, a subset of as many as 25 individuals of *Ictiobus cyprinellus* [Valenciennes in Cuvier and Valenciennes, 1844; Bigmouth Buffalo], *Pylodictis olivaris* [Rafinesque, 1818; Flathead Catfish], *Polyodon spathula* [Walbaum, 1792; American Paddlefish], and *Acipenser fulvescens* [Rafinesque, 1817; Lake Sturgeon] were dual tagged (that is, one 307 kHz tag and one 69 kHz tag in each fish). In 2022, as many as 100 Silver Carp and a variety of other native species were also targeted for dual tagging. In 2021, all invasive carps were collected from Pool 19 and released downstream from Lock 19 in Pool 20 (that is, translocated) to potentially increase the probability that they would challenge the deterrent and attempt upstream passage. In 2022, we added 100 additional Silver Carp that were captured and released in Pool 20 (tailwater). Actual numbers of fish tagged in 2021 and 2022 are listed in the "tagged 307 kHz" columns in table 1.

To increase the probability of fish attempting upstream passage and challenging the UADS, Silver Carp, Grass Carp, and Bigmouth Buffalo were captured in Pool 19, had transmitters implanted, then were released downstream in Pool 20. All other fish (*Cycleptus elongatus* [Lesueur, 1817; Blue Sucker], *Aplodinotus grunniens* [Rafinesque, 1819; Freshwater Drum], *Esox lucius* [Linnaeus, 1758; Northern Pike], *Morone chrysops* [Rafinesque, 1820; White Bass], *Sander canadensis* [Griffith and Smith, 1834; Sauger], *Sander vitreus* [Mitchill, 1818; Walleye], American Paddlefish, Lake Sturgeon, and Flathead Catfish) were captured in Pool 20, tagged, and released in Pool 20. Tagged fish were released at one of two locations in 2021 (40°23′26.18″ N., 91°22′1.93″ W. or 40°23′12.51″ N., 91°23′28.94″ W.) and at one location (40°23′12.51″ N., 91°23′28.94″ W.) in 2022, each approximately 1 kilometer from the lock approach channel. All fish

Table 1. Number of individual fish tagged with 307-kilohertz acoustic transmitters (tagged 307 kHz) in 2021 and 2022 and number (and percentage) of fish detected on any receiver after tagging, position triangulated in the lock approach channel (positioned), detected in the lock chamber (in lock), and identified making full passage (2021 and 2022 combined).

[Fish species in bold (that is, Silver Carp—translocated and Bigmouth Buffalo—translocated) are the two species for the study with higher tagging targets for a more robust analysis. kHz, kilohertz; %, percent; --, no data or not applicable]

Species	Tagged 307 kHz (dual tagged)[a]		Number of fish for 2021 and 2022 combined (percentage of tagged fish)			
	2021	2022	Detected	Positioned	In lock	Full passage
Invasive carps						
Silver Carp—translocated	251	249	208 (42%)	103 (21%)	37 (7%)	23 (5%)
Silver Carp—tailwater	--	100 (82)	47 (47%)	10 (10%)	--	--
Bighead Carp—translocated	50	50 (2)	77 (77%)	61 (61%)	27 (27%)	15 (15%)
Grass Carp—translocated	100 (50)	100	144 (71%)	72 (36%)	3 (2%)	1 (1%)
Native fishes						
Bigmouth Buffalo—translocated	100	100	181 (91%)	150 (75%)	72 (36%)	38 (19%)
Bigmouth Buffalo—tailwater	20 (19)	21 (16)	25 (61%)	19 (46%)	10 (24%)	9 (22%)
Blue Sucker	16	16 (6)	18 (56%)	3 (9%)	--	--
Flathead Catfish	25 (25)	24 (13)	30 (61%)	8 (16%)	1 (2%)	--
Freshwater Drum	16	16 (3)	19 (59%)	19 (59%)	12 (38%)	6 (19%)
Lake Sturgeon	5 (5)	18 (18)	21 (91%)	8 (35%)	--	--
Northern Pike	--	3	2 (67%)	1 (33%)	1 (33%)	1 (33%)
American Paddlefish	4 (4)	6 (6)	9 (90%)	7 (70%)	5 (50%)	1 (10%)
Sauger	--	2	2 (100%)	--	--	--
Walleye	7	3 (1)	6 (60%)	3 (30%)	--	--
White Bass	15	15	20 (67%)	17 (57%)	12 (40%)	6 (20%)

[a]Some fish were "dual tagged" with 69-kHz and 307-kHz transmitters (number included in parentheses), whereas others were tagged with only 307-kHz transmitters.

tagged in the spring of 2021 and 2022 were tagged before water temperatures reached 20 degrees Celsius (°C) to minimize stress on the fish.

Additional data are being collected on multiple environmental and operational parameters that may affect UADS operation or fish behavior. A water quality gage installed downstream from the lock approach channel measures water temperature, chlorophyll, dissolved oxygen, turbidity, nitrate and nitrite, pH, specific conductance, and turbidity (05474500; Mississippi River at Keokuk, Iowa; U.S. Geological Survey, 2023). An acoustic Doppler current profiler (Teledyne RDI Instruments, 1,200 kHz, Rio Grande) is installed in the up-looking orientation on the soundbar and provides a vertical water velocity (magnitude and direction) from near the soundbar to the water surface to measure the displacement and movement of water in the lock approach channel as vessels traverse the area. Lock operations data are acquired from the USACE through the Performance Logic Control system that continuously records the percentage openness (0–100 percent) of all lock gates and valves. Lock Queue Reports are acquired from the USACE Lock Performance Monitoring System, and include data associated with vessel traffic (that is, time of arrival, time of lock entry, and time of lock exit). Cabled hydrophones (Calibration Standard Hydrophone Type 8104; Brüel & Kjær, Nærum, Denmark) are installed throughout the lock approach, on the lock gates, and on the soundbar to continuously monitor noise in the lock approach channel. Finally, two closed-circuit television cameras are installed at the site to directly monitor water flow in the lock approach channel. The video footage of the water surface within the lock approach channel is planned to be analyzed using large-scale particle image velocimetry (Muste and others, 2008) methods to evaluate the surface movement of water as vessels move through the lock chamber.

Fish telemetry data from the 307-kHz and 69-kHz systems were summarized to evaluate upstream movement past the UADS in 2021 and 2022. Downstream passage was monitored in a similar manner but is not summarized in this report. Fish were considered to have made partial upstream passage if their position was confirmed by a minimum of three detections at receivers in the upstream half of the lock chamber or fish were positioned by the 307-kHz positioning array in the lock. Fish were confirmed to have made full upstream passage if their location was confirmed by at least three detections on two separate receivers upstream from the lock chamber. Individuals were only counted once per on or off treatment in each year (for a maximum of four possible counts per fish in the 2021–22 period, if a fish made passage during on and off conditions in both years). These interim and preliminary results used data collected from April 6, 2021, to October 27, 2021 (203 days), and April 3, 2022, to October 15, 2022 (195 days). This study is currently scheduled to continue through 2023.

Preliminary Passage Results

In the past 2 years, more than 1,300 fish from 13 species have been tagged for this study (table 1), and data for this study are available in a USGS data release (Brey and others, 2023). Tagged fish are present in the downstream lock approach channel telemetry array throughout the year; however, peak abundance of tagged Silver Carp tends to occur later (early to mid-June) than tagged native species (mid-May; fig. 2). Partial upstream passage (that is, movement past the UADS into the lock chamber) and complete upstream passage (that is, movement through the lock chamber into Pool 19) by Bighead Carp and Silver Carp occurred between June 6 (water temperature of about 26.7 °C) and September 9 (water temperature of 23.5 °C) in 2021 and between April 10 (water temperature of 7.6 °C) and August 14 (water temperature of 26.6 °C) in 2022 (U.S. Geological Survey, 2023). Most passages by invasive carps (79 percent in 2021 and 67 percent in 2022) occurred between June 1 and July 31 for both years.

When the UADS was on, the number of Silver Carp with 307 kHz transmitters that moved upstream past the UADS (either full passage or partial passage into the lock) was reduced by 50 percent compared to when the UADS was off (table 2). Full upstream passage by Silver Carp with 69 kHz transmitters only occurred when the UADS was off (number of individuals detected = 4), although the sample size of 69 kHz-tagged fish is low (table 3). The native Bigmouth Buffalo, tagged with 307 kHz transmitters, had an only slightly higher movement rate into the lock when the UADS was off (that is, 1.2 times more likely to pass when UADS was off versus on). For native species tagged with 69 kHz transmitters (2021 and 2022 data combined), preliminary observations to date indicate that upstream passage was not likely reduced by the operation of the UADS (8 when UADS was off and 12 when the UADS was on).

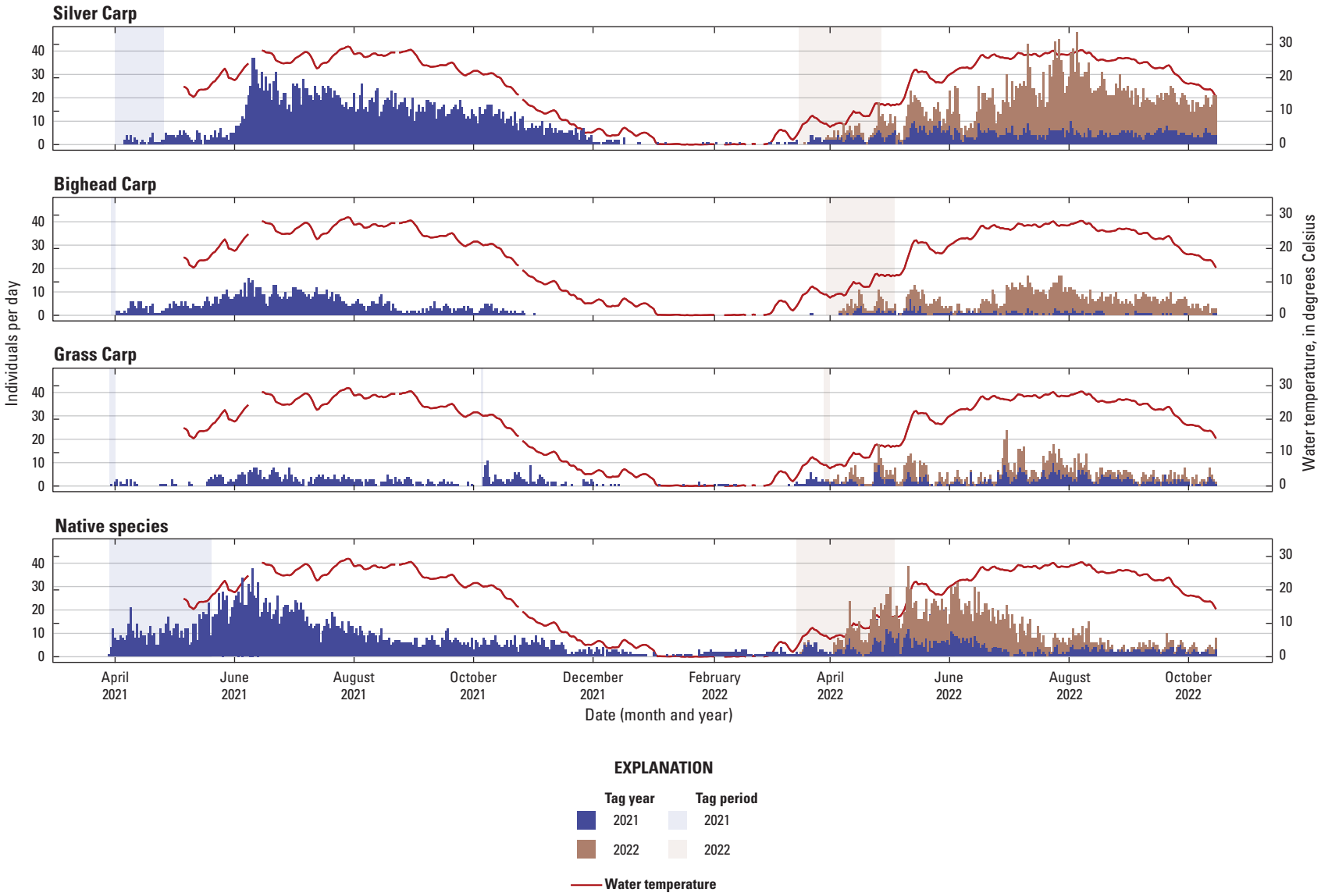

Figure 2. The count of unique fish detected at the 307-kilohertz telemetry array at Lock 19 per day that were tagged in 2021 and 2022, tagging periods in each year for each species (Silver Carp, Bighead Carp, and Grass Carp) or group of species (native species), and water temperature (in degrees Celsius; 05474500; Mississippi River at Keokuk, Iowa; U.S. Geological Survey, 2023).

Table 2. Counts of individual fish tagged with 307-kilohertz transmitters that passed the underwater acoustic deterrent system (made full or partial upstream passage into Pool 19) through Lock 19. Individuals were only counted once per on or off treatment in each year (for a maximum of four possible counts per fish in the 2021–22 column if a fish made passage during on and off conditions in both years).

[The off versus on column is a standardized ratio—for every one fish that completed upstream passage when the underwater acoustic deterrent system was on, the associated number completed upstream passage when it was off. --, no data or not applicable]

Species	2021		2022		2021–22
	Off	On	Off	On	Off versus on
Invasive carps	21	7	29	21	--
Silver Carp	12	6	18	9	2:1
Bighead Carp	8	1	11	12	--
Grass Carp	1	--	--	2	--
Native species	34	29	40	35	--
Bigmouth Buffalo	22	17	28	26	1.2:1
Flathead Catfish	--	--	--	1	--
Freshwater Drum	6	8	4	--	--
Northern Pike	--	--	--	1	--
Paddlefish	4	3	1	1	--
White Bass	2	1	7	6	--

Table 3. Counts of individual fish tagged with 69-kilohertz transmitters that completed full upstream passage (full passage) into Pool 19 through Lock 19 and the associated underwater acoustic deterrent system operational status during 2021 and 2022 combined.

Species	Full passage	Off	On
Invasive carps	8	6	2
Silver Carp	4	4	0
Bighead Carp	3	2	1
Grass Carp	1	0	1
Native species	20	8	12
Bigmouth Buffalo	14	5	9
Freshwater Drum	1	1	0
Northern Pike	1	0	1
Paddlefish	3	1	2
Striped Bass × White Bass	1	1	0

Project Outlook

In addition to assessing full upstream passage though Lock 19, a fine-scale behavioral analysis using the 307-kHz-tagged fish related to a variety of covariates including UADS operational status, lock gate operation, vessel presence/type, and environmental conditions is planned. A time-to-event analysis, which is a type of time-varying survival model (Castro-Santos and Haro, 2003; Castro-Santos and Perry, 2012; Goerig and Castro-Santos, 2017; Nyqvist and others, 2017), is the primary means for evaluating the effect of covariates of interest on fish behavior and passage. Other modeling or analyses to assess fine-scale fish movement related to UADS operation also are planned to be considered once the time-to-event analysis is underway. Additional data and statistical analyses can be used to help determine whether the observed differences in passage rates are meaningful in either a statistical or ecological sense.

Design, Installation, and Operation Costs and Considerations

Costs and considerations for designing, constructing, deploying, and operating a UADS are site specific and dependent upon user needs. Additional guidance can be given by contacting the USGS (Dr. Marybeth Brey) or ERDC (Dr. Christa Woodley). For the study at Lock 19, we provide cost estimates and considerations for the design, installation, and annual operations of the UADS (table 4). Additional site or project specific costs that were incurred during this study are listed below the main costs and indicated by a "+" sign. Deployments of a UADS at other locations may differ substantially. We provide the year the costs were incurred at the end of each item so that one can apply the appropriate rate of inflation (https://www.bls.gov/regions/mid-atlantic/data/consumerpriceindexhistorical_us_table.htm). Annual maintenance was completed by contracted divers; cost efficiencies may be

Table 4. Design, installation, and annual operation costs for the Lock 19 underwater acoustic deterrent system. Costs do not include State or Federal salary, travel, or operational costs (aside from electricity and trailer rental); telemetry and sound monitoring equipment or data analysis; monitoring/operating software development; or inflation. Costs are specific to this study and may differ if a deterrent is deployed at a different location.

[The year the costs were incurred is included at the end of each item so that one can apply the appropriate rate of inflation (https://www.bls.gov/regions/mid-atlantic/data/consumerpriceindexhistorical_us_table.htm). USACE, U.S. Army Corps of Engineers; ERDC, U.S. Army Engineer Research and Development Center; USGS, U.S. Geological Survey; +, indicates additional site or project specific cost; ~, about; mo, month; UADS, underwater acoustic deterrent system; yr, year; HVAC, heating, ventilation, and air conditioning; wk, week]

Components of the Lock 19 underwater acoustic deterrent system (associated cost)
Design and installation
Planning and design ($370,000) • Costs for the design, bathymetry (USGS), and acoustic survey (ERDC) [2020].
Construction, equipment, and installation ($1,530,000) • Firm fixed-price contract (metal fabrication of the soundbar and monitoring equipment mounts, all construction and installation costs); all operating equipment [2020]. o Site specific: required to bury or recess all cabling onsite [2021] (+$48,000). o Site specific: new transformer to access USACE power source [2020] (+$20,000).
Annual operations and maintenance
Annual operations ($6,000) • Electricity (~$400/mo for full time operation, internet/remote monitoring (~$120/mo) [2021]. • Project specific: trailer rental with HVAC for operating and scientific monitoring equipment (~$400/mo) [2021].
Annual maintenance event ($500,000) • Based on Lock 19 UADS 2022 maintenance: full soundbar removal, repair, and reinstallation; addition of 2 new telemetry hydrophones; replacement of 3 existing hydrophones [2022]. • Site/project specific: complete dive survey (~ 1 wk) [2022] (+$120,000). • Project specific: 8 new speakers and 5 speakers repaired [2022] (+$65,000).

possible if such maintenance was scheduled with concurrent USACE maintenance events. Costs do not include State or Federal salary, travel, or operational costs (aside from electricity and trailer rental); Government supplied telemetry and sound monitoring equipment or data analysis costs; or costs for development of UADS monitoring and operating software.

Planning and design included costs for preplanning meetings, site visits, and a 95-percent design of the custom weldment and mounting components for the UADS speaker array (also referred to as the "soundbar") by the USACE, USGS, and ERDC, plus the cost for the USGS contractor (Bailey Edward Design, Chicago, Illinois) to conduct all preplanning meetings and site visits and complete the design (to 100 percent) by adding the mounting components for the scientific monitoring equipment. Construction, equipment, and installation included purchase of necessary equipment by the Government (for example, speakers, amplifiers, and cabling) and a firm fixed-price contract for the Government contractor, Kaiyuh Services, covering all fabrication costs for the steel weldment and other mounting components (including all scientific monitoring components specific to this project), construction, and installation in January–February 2021. Site specific additions to these installation costs included recessing all cabling to be out of the way of navigation or lock operations and the purchase of a new transformer to use USACE power.

Annual costs include the electricity cost and remote monitoring capability (cellular modems). An additional consideration is that a full-time person would need to be available for regular maintenance and troubleshooting of the out of water electronics. The USGS and ERDC currently maintain all equipment for this experimental system. The additional cost for this specific site, because of the extensive amount of monitoring equipment, includes a monthly trailer rental. The annual maintenance event was a high-cost event that included removing the entire soundbar and cables with short notice to the contractor (J.F. Brennan Co.), replacing multiple speakers, and reinstalling the soundbar and cables. This type of maintenance may not be a regular occurrence for a system that was operating for the long term (that is, longer than a three-year study). With the most recent maintenance event, in 2023, we replaced all the speakers with ones that have wet-mateable connections (that is, the cables and speakers are able to be connected and disconnected while underwater). This should allow for divers to replace individual speakers if they are underperforming instead of removing the entire system. Completing a dive survey each year would be beneficial to remove any biofouling from equipment and to confirm there is no damage to the system from vessels or debris. The 2022 dive survey is broken out from the other maintenance event costs because it also included an underwater survey of all monitoring components specific to the research.

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For more information about this publication, contact:
Director, USGS Upper Midwest Environmental Sciences Center
2630 Fanta Reed Road
La Crosse, Wisconsin 54603

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