Multimodal Invasive Carp Deterrent Study at Barkley Lock and Dam—Status Update through 2022

Open-File Report 2023–1051

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

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)

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

$$°F = (1.8 \times °C) + 32.$$

Supplemental Information

Frequency is given in kilohertz (kHz).

Abbreviations

FGS Fish Guidance Systems Ltd.

HTI Hydroacoustic Technology Inc.

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Abstract

Invasive carp (*Hypophthalmichthys nobilis* [Bighead Carp], *Mylopharyngodon piceus* [Black Carp], *Ctenopharyngodon idella* [Grass Carp], and *H. molitrix* [Silver Carp]) continue to spread in the United States and deterrents at river navigation locks are one emerging control strategy for slowing the spread. High-head navigation dams on large rivers serve as impediments to the upstream spread of these populations. One possible control technique is using a multimodal deterrent that utilizes a combination of lights, sound, and air bubbles to guide fish away from a location. Laboratory tests and small-scale field deployments of similar multi-stimuli deterrents have demonstrated potential for deterring invasive carp. These earlier studies led to the deployment and initiation of a field study of a multimodal deterrent in 2019 at the downstream lock approach at Barkley Lock and Dam on the Cumberland River near Grand Rivers, Kentucky. We are using two types of telemetry systems to evaluate how the multimodal deterrent affects movement and behavior of Silver Carp, Grass Carp, and four native species: *Aplodinotus grunniens* (Freshwater Drum), *Polyodon spathula* (Paddlefish), *Ictiobus bubalus* (Smallmouth Buffalo), and *Acipenser fulvescens* (Lake Sturgeon). We are evaluating fish movements in response to the multimodal deterrent by using a study design that cycles between 1 week with the multimodal deterrent on and 1 week with it off. This weekly cycling provides baseline comparisons across variable environmental conditions. When the multimodal deterrent is on, the number of Silver Carp completing upstream passage through Barkley Lock is reduced by about one-half. This study that began in 2019 can provide insights into the effectiveness of a multimodal deterrent for limiting upstream movement of invasive carp or effects on native fishes through strategic navigation locks on large rivers.

Introduction

Four species of invasive carp—*Hypophthalmichthys nobilis* (Richardson, 1845; Bighead Carp), *Mylopharyngodon piceus* (Richardson, 1846; Black Carp), *Ctenopharyngodon idella* (Valenciennes in Cuvier and Valenciennes, 1844; Grass Carp), and *H. molitrix* (Valenciennes in Cuvier and Valenciennes, 1844; Silver Carp)—are within the waters of the United States. The expansion of invasive carp populations in the Mississippi River (not shown) and its tributaries threatens the country's renowned aquatic biodiversity, outdoor economies, and way of life (Kolar and others, 2007). Federal, State, university, and industry partners have joined together to test a new and innovative deployment of a fish deterrent technology to slow the upstream push of the invasive carp. Laboratory tests and small-scale field deployments of similar multi-stimuli deterrents have demonstrated potential for deterring invasive carp (Taylor and others, 2005; Ruebush and others, 2012; Dennis and others, 2019). These earlier studies led to the deployment and initiation of a field study of a multimodal deterrent in 2019 at the downstream lock approach at Barkley Lock and Dam (fig. 1) on the Cumberland River near Grand Rivers, Kentucky (not shown). The multimodal deterrent uses an air-bubble curtain, along with light and sound, to deter invasive carp from moving across the bubble curtain. The data we are collecting can be used to evaluate how the number of Silver Carp, Grass Carp, and some native fish species (that is, *Aplodinotus grunniens* [Rafinesque, 1819; Freshwater Drum], *Polyodon spathula* [Walbaum, 1792; Paddlefish], *Ictiobus bubalus* [Rafinesque, 1818; Smallmouth Buffalo], and *Acipenser fulvescens* [Rafinesque, 1817; Lake Sturgeon]) moving into Lake Barkley changes when the multimodal deterrent system is on compared to when it is off. In addition, we are monitoring variables suspected to affect the efficacy of the multimodal deterrent including environmental conditions (for example, water temperature, tailwater elevation) and

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Figure 1. The multimodal deterrent system is installed in the downstream approach at Barkley Lock and Dam. The system, stretching across the width of the lock approach, consists of an air-bubble curtain, lights, and sound. Photograph by Andrea Fritts, U.S. Geological Survey.

vessel traffic in the area. What we learn with this experimental study can inform invasive carp management decisions in many locations, such as where to use deterrent technology and how it could be deployed most effectively.

This study began in 2019 and is being completed by a multiagency science team that consists of scientists from the U.S. Geological Survey, U.S. Fish and Wildlife Service, University of Minnesota, Fish Guidance Systems Ltd. (FGS), Hydroacoustic Technology Inc. (HTI), and the Kentucky Department of Fish and Wildlife Resources in partnership with the U.S. Army Corps of Engineers. A team of biologists, engineers, acoustic scientists, and resource managers was put together to complete the deployment and evaluation components of this project. This type of large-scale effort would not be possible without these strong partnerships. This report provides a status update of the study through October 2022.

Methods

We deployed a multimodal deterrent on the downstream side of Barkley Lock (fig. 1) on the Cumberland River near Grand Rivers, Kentucky, in 2019. The multimodal deterrent used in this experimental study is a BioAcoustic Fish Fence (commonly known as BAFF; FGS, Fareham, United Kingdom). We are evaluating fish movements in response to the multimodal deterrent by using a study design that cycles between 1 week with the multimodal deterrent on and 1 week with it off. This weekly cycling provides baseline comparison across variable environmental conditions. Cycling of the multimodal deterrent would not be a feature of a permanent deployment. We are using two types of telemetry systems to study fish movements; that is, VEMCO and HTI (Innovasea Systems Inc). The VEMCO system leverages ongoing telemetry studies in multiple basins (including the Cumberland River) to assess fish movement rates through locks and dams and is hereafter referred to as the 69-kilohertz (kHz) telemetry system. The HTI telemetry system (hereafter the 307-kHz telemetry system) was implemented specifically to track fine-scale (1–2 meter [m]) movements of fish in the vicinity of the multimodal deterrent. We installed a network of receivers for both telemetry systems around Barkley Lock, including areas downstream from the lock, in the lock, and upstream from the lock. Fish were implanted with telemetry transmitters that can be detected by corresponding receiver arrays. Silver Carp and native fish species that were tagged with 69-kHz transmitters were collected and tagged in the tailwaters of Barkley Dam or were tagged for other projects and moved into the vicinity of Barkley Dam on their own volition. Fish tagged with 69-kHz transmitters were captured during several events during 2017–2022, from several locations, according to the needs of the specific studies. Silver Carp tagged with 307-kHz transmitters were captured upstream from Barkley Dam, transported downstream, tagged, then released near the downstream lock approach. Evidence from Silver Carp movement in other waterbodies indicated translocated fish would be more likely to move upstream through a navigational lock, and thereby increase the number of Silver Carp encounters with the multimodal deterrent. Fish that received acoustic telemetry transmitters were captured in the fall and spring over the duration of our study when water temperatures were less than 20 degrees Celsius to maximize fish health and minimize the stress of surgery. All animal procedures were reviewed and approved by the U.S. Geological Survey Upper Midwest Environmental Sciences Center Institutional Animal Care and Use Committee, under IACUC protocol number ESB–19–BARKLEYBAFF–01. Transmitters used with both telemetry systems provide information on whether fish move through Barkley Lock and when this passage through the lock occurs, which allows us to identify whether the multimodal deterrent was off or on at that time. Fish with 307-kHz transmitters can be positioned within 1–2 m of accuracy, so it is possible to distinguish between fish moving upstream that have crossed the location of the multimodal deterrent but not made full passage into Lake Barkley and those that have crossed the location of the deterrent and then made full upstream passage into Lake Barkley (fig. 2). The spatial accuracy of the 69-kHz transmitters allows us to document zonal movements of fish as they progress through the downstream lock approach, lock chamber, and upstream lock approach, but it is not sufficient to determine with fine-scale resolution when and where fish move across the location of the multimodal deterrent. The multimodal deterrent and the 307-kHz telemetry systems were struck by lightning in early 2020 and were not able to be immediately repaired because of COVID-19 travel restrictions. Therefore, the period of full operation included in this report is October 2020–October 2022.

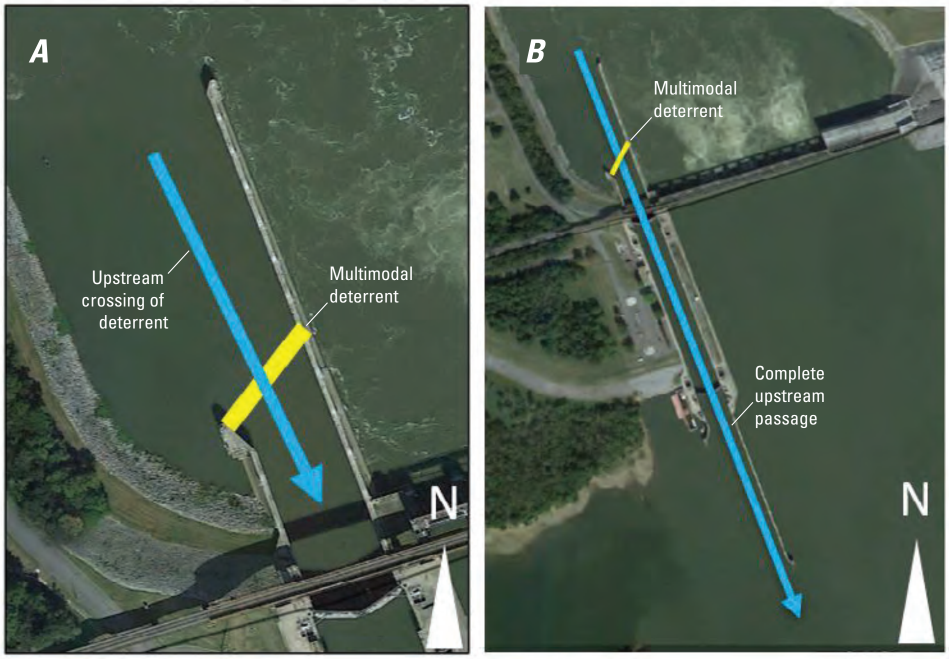

Figure 2. Depiction of (*A*) fish completing an upstream crossing of the location of the multimodal deterrent and (*B*) complete upstream passage into Lake Barkley. The multimodal deterrent is at an angle across the downstream lock approach and depicted with a yellow line.

Results of Fish Monitoring

Using data collected from October 2020 through October 2022, we provide a preliminary analysis of the first 2 years of this ongoing study. We plan to continue collecting data on tagged fish at Barkley Lock during 2023. More than 1,000 Silver Carp with 307-kHz transmitters have been detected with high spatial precision near Barkley Lock, and more than 500 Silver Carp with 69-kHz transmitters have provided additional information about how they respond to the multimodal deterrent.

Silver Carp passing through Barkley Lock into Lake Barkley show a distinct temporal pattern, with 80–90 percent of Silver Carp passing upstream from May through September (fig. 3). These periods also result in increased numbers of Silver Carp that cross the location of the multimodal deterrent during both operational states (table 1). When the multimodal deterrent is on, the number of Silver Carp completing upstream passage through Barkley Lock is reduced by about one-half. More than 300 Silver Carp with 307-kHz transmitters have been documented moving upstream through Barkley Lock since late 2020, and the number of Silver Carp making this movement when the multimodal deterrent is on is 50 percent lower than when it is off (table 2). For Silver Carp with 69-kHz transmitters, upstream passage is reduced by 56 percent when the multimodal deterrent is on (table 2). Data are available as a U.S. Geological Survey data release (Fritts and others, 2023).

We are also evaluating the effect of the multimodal deterrent on movement of Grass Carp and native fish species. During 2021–22, 30 Grass Carp crossed the location of the multimodal deterrent in an upstream direction while the system was off, whereas 19 Grass Carp crossed while the system was on. Preliminary analysis of full upstream passages through Barkley Lock does not seem to show a strong reduction in upstream passage when the multimodal deterrent is on for Grass Carp or any native species (table 3). Additional information is planned to be gathered for these species during the third year (2023) of the study.

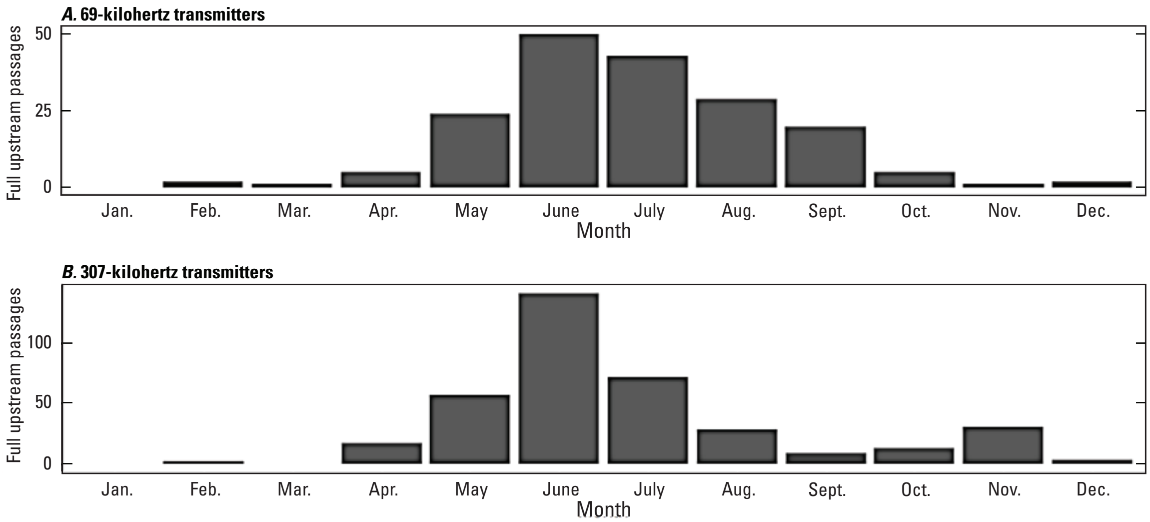

Figure 3. The monthly number of full upstream passages by *Hypophthalmichthys molitrix* (Silver Carp) through the Barkley Lock (2020–22). Upstream passages were documented with (*A*) 69-kilohertz transmitters and (*B*) 307-kilohertz transmitters. Counts include passages made during the off and on conditions of the multimodal deterrent.

Table 1. Counts of *Hypophthalmichthys molitrix* (Silver Carp) implanted with 307-kilohertz transmitters that crossed the location of the multimodal deterrent in an upstream direction during each operational state of the multimodal deterrent (on and off). Time frames are split by low passage periods (October–April) and high passage periods (May–September) based on data from figure 3.

Period	Counts	
	Off	On
November 2020–April 2021	97	8
May 2021–September 2021	147	82
October 2021–April 2022	140	43
May 2022–September 2022	118	59

Table 2. Counts of *Hypophthalmichthys molitrix* (Silver Carp) implanted with 69-kilohertz or 307-kilohertz transmitters that completed full upstream passage through Barkley Lock during each operational state of the multimodal deterrent (off and on). Ratio off:on is a standardized ratio—for every 100 Silver Carp that completed upstream passage when the multimodal deterrent was off, the associated number that completed upstream passage when it was on is provided.

[%, percent; kHz, kilohertz]

Tag type	Counts		Ratio off:on	Reduction when multimodal deterrent system is on (%)
	Off	On		
69-kHz transmitter	96	41	100:44	56
307-kHz transmitter	228	113	100:50	50

Table 3. Number of individuals implanted for each transmitter type (69 kilohertz or 307 kilohertz) and counts by species for full upstream passages through the Barkley Lock during each operational state (on and off) of the multimodal deterrent.

[kHz, kilohertz]

Transmitter type	Species	Number implanted	Counts	
			Off	On
307 kHz	*Ctenopharyngodon idella* (Grass Carp)	75	14	18
69 kHz	*Aplodinotus grunniens* (Freshwater Drum)	113	9	8
69 kHz	*Polyodon spathula* (Paddlefish)	78	14	9
69 kHz	*Ictiobus bubalus* (Smallmouth Buffalo)	110	0	2
69 kHz	*Acipenser fulvescens* (Lake Sturgeon)	6	0	1

Study Outlook

In addition to collecting information on fish passage through Barkley Lock, we are also using time-to-event analyses to develop statistical models to evaluate how deterrents, such as the multimodal deterrent, work under a variety of situations and environmental conditions. Time-to-event analysis is a method designed to identify how outcomes, such as a fish moving upstream across the location of the multimodal deterrent, are affected by potential explanatory factors, including not only the multimodal deterrent operation but also temperature, time of day, and other relevant factors. Furthermore, we plan to evaluate fine-scale movements in response to multimodal deterrent operation, environmental variables, and other factors that may affect fish movement using fish tagged with 307-kHz transmitters. These analyses may inform future optimizations to the deterrent system and may identify locations where invasive carp cross the 60-m-long multimodal deterrent. Tagging and monitoring Silver Carp, Grass Carp, and several native species is currently planned through at least October 2023.

Design, Installation, and Operational Considerations

Considerations for designing, installing, and operating a multimodal deterrent like the one used in this study are site specific and dependent on user specifications and needs. Although we provide considerations associated with the design, installation, and operation of the multimodal deterrent used for this Barkley Lock and Dam study, considerations for other locations may differ. Product costs associated with the multimodal deterrent system used in this study can be provided by FGS (https://fgs.world). We provide design and installation considerations (table 4) and operational considerations (table 5) for this research deployment, for which we leased a semiautomated multimodal deterrent system. Installation of the unit at this test location required creating a recess in bedrock to install the system below the level of the lock sill during high water conditions, conditions that may substantially differ at other locations. The following options are available for the multimodal deterrent system: (1) semiautomated multimodal deterrent system that was used in this study (as installed downstream from Barkley Lock), (2) a fully automated multimodal deterrent, and (3) a manual multimodal deterrent system (table 4). Deployments in other locations may differ substantially. The annual maintenance at this site was completed by contracted divers and FGS.

Planning and design included designing a concrete frame to protect the multimodal deterrent system components at this location, cargo containers to house the air compressor and controls and the multimodal deterrent system components, and a bedrock survey. Construction, equipment, and installation included purchase of necessary equipment, fabrication of the concrete housing and other components, grinding a recess in the bedrock to install the multimodal deterrent system, installation of the multimodal deterrent system, and installation of telemetry equipment used to study fish movement around the location of the multimodal deterrent system. We had additional costs that we could readily break out from the overall construction costs that we considered specific to this site. These costs are not included in the roughly $3.7 million estimate and included running a separate power line to the multimodal deterrent system and dealing with high water levels that outstripped the capacity of the equipment we had for grinding bedrock and shortened the time divers could spend in the water each day because of the increased depth and pressure (work must be scheduled 45 days in advance at this site and water levels can be unpredictable). The multimodal deterrent system included sound projectors, lights, and bubble lines and the cable, hoses, and controls to operate them. The specifications of the existing semiautomated system are listed in table 4 along with two additional options.

Table 4. Design and installation costs and considerations for the multimodal deterrent system used in this study and specifications for multimodal deterrent system options. Site specific considerations are included for the conditions encountered during this study. Costs exclude State or Federal salary, travel, and operational costs; telemetry equipment costs (only dive costs associated with telemetry installation); and inflation.

Design and installation considerations (associated costs)
Planning and design ($342,000) • Contracted design services to develop frame, buildings, cable routing, sound projector system, and complete bedrock survey.
Construction, equipment, and installation ($3,757,000) • Equipment and fabrication of concrete housing for the multimodal deterrent system, a recess excavated into bedrock, air compressor/dryer and lines to deterrent system, cargo container to house compressor equipment and deterrent system controls, installation of multimodal deterrent system and telemetry equipment, project oversight/management. o Site specific: new electrical line to location of the multimodal deterrent site (+$192,000). o Site specific: high water during install required different dredging equipment and shorter diver days (+$1,318,000).
Multimodal deterrent system options [control equipment, sound, lights, bubbles] • Semiautomated system [option used for Barkley Lock and Dam study]: automated operation and integrated feedback on condition of individual sound projector components to allow for remote monitoring and operation of the sound projector components (but not the air supply system). Composed of 30 high frequency sound projectors, 30 low frequency sound projectors, and active pressure compensation units. • Fully automated system: same as existing semiautomated system with the addition of automated controls for air supply system. • Manually operated system: provides passive air compensation, low frequency sound projectors only, no underwater communication hubs, no integrated control or feedback on system performance. System would need to be operated and monitored from the control equipment room onsite.

Annual system costs include electricity and fixed maintenance of components such as the air compressor and air conditioner (table 5). Annual maintenance event is a generalized trip based on our experience. FGS suggests an 18-month routine maintenance trip to clean and assess the system. Based on the multimodal deterrent system used in the Barkley Lock and Dam study, an annual trip may be needed for a deterrent deployed in a lock approach environment for routine maintenance and (or) to repair any sound projectors that are not performing properly. Specific to this site, we have had to address silt accumulation on each trip. We typically did just enough silt removal to access the sound projectors. In March 2023, we took a more aggressive approach using a suction dredge to remove silt from within and along the multimodal deterrent system housing to an area 15 to 30 m downstream to try and reduce sediment issues in the future. We expect silt to be less of an issue when the multimodal deterrent system is operated full time rather than 1 week on and 1 week off, and silt accumulation will vary based on deployment site. Also, specific to our installation, we are completing sound surveys and telemetry system repairs as part of maintenance events, which may not be a part of other future installations that are not studying deterrent effectiveness. An annual lease (noted as optional in table 5) was used for this study given it could be a temporary research deployment. Annual deterrent system monitoring (noted as optional in table 5) could be pursued if remote monitoring of deterrent system performance is desired.

Many factors can affect overall costs at a given location. Costs provided in this section are for informational purposes only and are specific to conditions and requirements for this research study at this location. Any information regarding the cost of installation and operation of a multimodal deterrent for projects at other locations is beyond the scope of this report but may be provided by FGS.

Table 5. Annual operation costs and considerations for the multimodal deterrent system used in this study. Lease costs would not be incurred if a deterrent system was purchased. Costs exclude State or Federal salary, travel, and operational costs; telemetry equipment and analysis costs (only dive costs associated with telemetry maintenance); parts and labor resulting from lightning strike damage and flooding to components; and inflation.

Annual operational considerations (associated cost)
Annual system costs ($96,000) • Electricity ($6,000/month) and fixed maintenance ($24,000/year for air conditioners, air compressor, closed-circuit television, and network maintenance).
Annual maintenance event ($437,000) • Includes removing and cleaning all sound projectors and other routine maintenance. Based on Barkley study, an annual maintenance trip is suggested. o Site specific: silt removal [5 days] (+$91,000). o Project specific: sound survey [4 days] (+$36,000). o Project specific: telemetry repairs [2 days] (+$30,000).
Annual lease [optional] ($654,000) • Rather than purchase, we leased the multimodal deterrent equipment for this research project at a current rate of $54,500/month, which includes remote monitoring of the system by FGS.
Annual deterrent system monitoring [optional] • Remote monitoring of deterrent system performance can be completed on either automated system in table 4.

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