Short Communication

Application of electricity and underwater acoustics to clear fish from a navigation lock during maintenance

Jose M. Rivera[1,*], Aaron R. Cupp[1], Josey L. Ridgway[2], Duane C. Chapman[2], Bethany E. Hoster[3], Matthew R. Acre[2], Robin D. Calfee[2], Jesse R. Fischer[2] and James J. Duncker[4]

[1]U.S. Geological Survey, Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Rd., La Crosse, WI 54603, USA
[2]U.S. Geological Survey, Columbia Environmental Research Center, 4200 New Haven Road, Columbia, MO 65201, USA
[3]U.S. Army Corps of Engineers, Rock Island District, 1500 Rock Island Dr, Rock Island, IL 61201, USA
[4]U.S. Geological Survey, Central Midwest Water Science Center, 405 N. Goodwin Ave., Urbana, IL 61801, USA

*Corresponding author
E-mail: jrivera@usgs.gov

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Abstract

The presence of fish within navigation locks can introduce an environmental challenge for construction crews when maintenance is required. This study examined the effectiveness of a dual-deterrent fish herding technique using electricity and acoustic stimuli to reduce the abundance of fish within a navigation lock before a scheduled dewatering for maintenance. Fixed-location multi-beam imaging sonar was used to evaluate fish per minute (FPM) detections near the lock entrance before, during, and after the herding effort. Standardized mobile side-scan sonar surveys were also conducted before and after the herding to examine fish presence throughout the entire lock. Collectively, a 73% reduction in fish targets detected by side-scan sonar and a 43% reduction in FPM detected by imaging sonar were observed following the herding technique. Post-fish herding, an 88% reduction in FPM > 400 mm and a 35% reduction in FPM < 400 mm were observed. Fish abundance within the lock chamber was reduced and did not result in construction delays, which was problematic and costly during previous dewatering events. Because data from this study are limited to a single lock dewatering and fish clearing event, caution is warranted with the extrapolation of these results. However, the applied methods show promise and may inform future fish clearing efforts to aid lock maintenance.

Key words: acoustic deterrent, electric deterrent, fish herding, hydroacoustics, invasive fish, Illinois River, lock dewatering

Introduction

Locks and dams are positioned throughout the United States, with 191 active lock sites and 237 lock chambers distributed within over 17,000 km of inland waterways (U.S. Army Corps of Engineers [USACE] 2000). Close to 630 million tons of cargo valued at over $73 billion annually are moved through the navigation locks within the inland waterways system (USACE 2000). Navigation locks and associated structures can also serve as a migratory passageway and habitat for fish, which presents a challenge when maintenance to the lock structure is required.

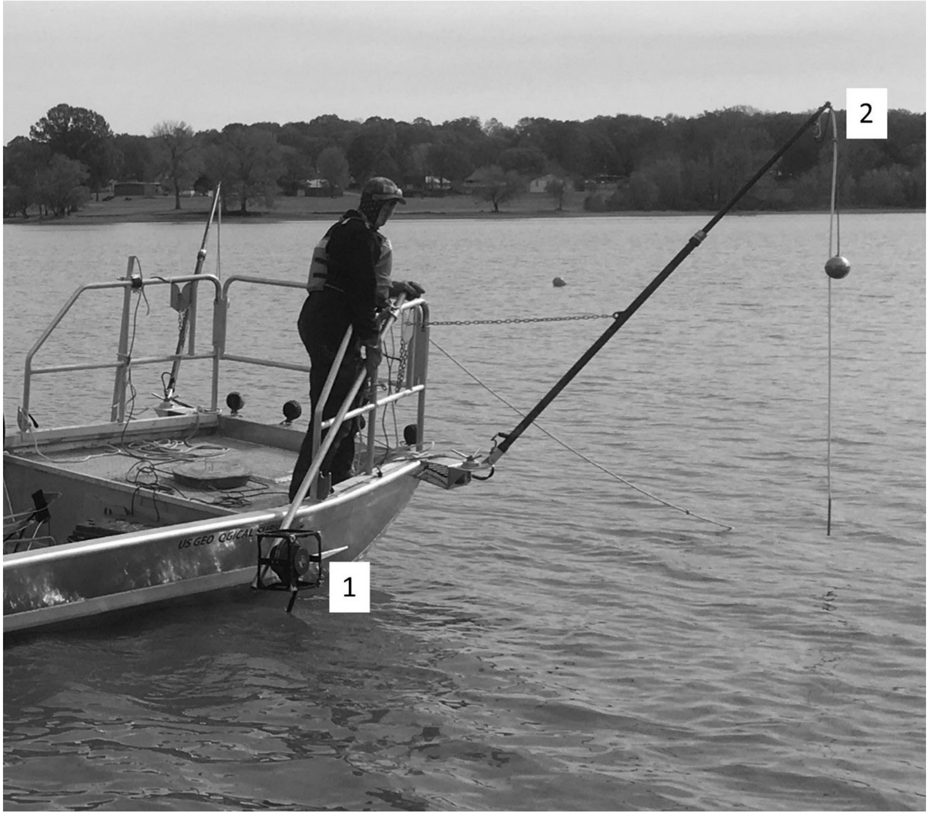

Figure 1. Drive boat used to deploy a dual-deterrent (acoustic deterrent and electricity) fish herding technique (method similar to Ridgway et al. 2021) to clear fish out of the navigation lock at Starved Rock Lock and Dam (Illinois River, LaSalle County, Illinois, USA; 41.324670°; −88.986316°). 1: The starboard speaker (LL916C, Lubell Labs, Columbus, Ohio, USA), 2: the starboard anode configuration composed of one stainless-steel sphere (6.4 cm diameter) and one stainless-steel cable (2.2 m length insulated cable with 20.3 cm uninsulated section at the end) (photo Josey Ridgway – U.S. Geological Survey, used with permission).

The U.S. Army Corps of Engineers is responsible for the operation and management of most locks in the inland waterways. Maintenance of these structures often requires considerable cost and manpower to execute (Riveros and Arredondo 2010). As part of a 2020 construction project at an Illinois River navigation lock (Starved Rock Lock and Dam; LaSalle County, Illinois; 41.324670°; −88.986316°, Figure 1), two lock chamber dewaterings were required to allow contractors to remove an existing set of miter gates and install replacements. During the first dewatering event, operation staff encountered large numbers of fish remaining within the lock, leading to work interruptions caused by the clearing of pumps clogged with fish and manual relocation of fish to outside of the lock chamber. The unexpected delays caused by the presence of large numbers of fish, including a high proportion of invasive silver carp *Hypophthalmichthys molitrix*, in the lock added costs to the repair project and increased the time the lock was out of service. The Illinois River has potentially the greatest abundance of invasive silver carp in the world (Sass et al. 2010). Silver carp commonly accumulate below dam structures (Cupp et al. 2021) and a specific need to clear fish from navigation locks prior to dewatering events was identified. A herding technique that can successfully clear fish from a navigation lock prior to dewatering could help to reduce the time a lock is out of service and reduce the costs associated with the manual clearance of fish. For the second dewatering, in September of 2020, the U.S. Geological Survey in coordination with the USACE implemented a dual-deterrent (underwater acoustics and electricity) fish herding technique to clear fish from the Starved Rock Lock chamber. Acoustic deterrents have been shown to affect movement behavior in fish, with implications for its use as a deterrent or herding tool (Vetter et al. 2015). Electricity emitted into water has similarly displayed the ability to deter fish (Noatch and Suski 2012) and affect fish movement behavior (Kim and Mandrak 2017). Furthermore, boat-mounted acoustics and electricity have been tested as a herding tool to clear fish from open reaches of river (Ridgway et al. 2023) and increase catch rates in entanglement nets (Butler et al. 2019).

The purpose of this study was to implement a dual-deterrent fish herding technique, consisting of underwater acoustics and electricity, to clear fish from Starved Rock Lock before USACE dewatered it for a second time to re-install miter gates. Conceptually, the intent was to use the combination of acoustics and electricity to herd fish from the lock chamber towards the downstream channel and block the entrance to the lock before bulkheads were set into place.

Methods

Study site

The Starved Rock Lock measures 34 m wide by 183 m length, with 12 m tall walls on the north and south and miter gates on the east and west ends of the lock. Water in the lock is approximately 5 m deep and is part of the Illinois River Waterway, designed to provide a navigable channel connecting the Great Lakes to the Mississippi River. At the time of this study, two barges (59.4 m × 10.7 m) were connected lengthwise and anchored at the center of the lock.

Fish herding

Three boats were used to strategically clear fish from the lock chamber. Two drive boats administered a herding stimulus composed of a combination of an acoustic deterrent and electricity described by Ridgway et al. (2023). A third boat (guide boat) used side-scan sonar (XM 9 20 MSI T; Humminbird, Racine, Wisconsin, USA) to continuously monitor the spatial distribution of fish in real time and direct the progression of the two drive boats through the lock downstream. The acoustic deterrent, a metal percussion sound recording (broadband; 35.5-second playback loop) of hammer strikes to a steel box (acoustic output: ~ 164 Db re 1 μPa directly in front of boat; electrical output: 22 peak amps), was emitted from pistonic piezoelectric underwater speakers (LL916C, Lubell Labs, Columbus, Ohio, USA). The acoustic deterrent was transmitted to the speakers using an MP3

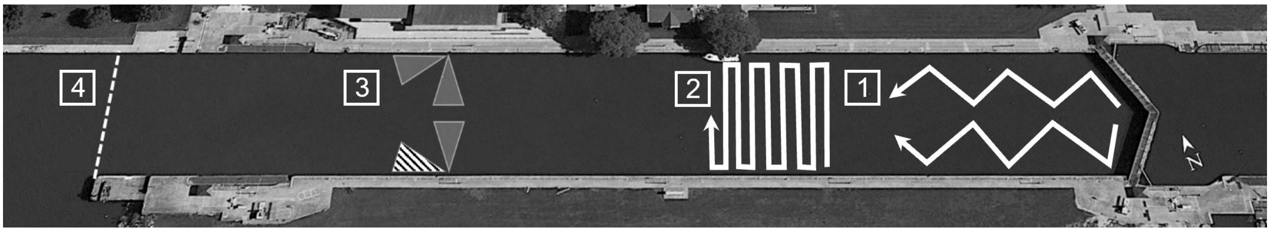

Figure 2. Approximate deployment locations of multi-beam imaging sonars used to monitor fish activity within the navigation lock at Starved Rock Lock and Dam (Illinois River, LaSalle County, Illinois, USA; 41.324670°; −88.986316°) for the deployment of a dual-deterrent (acoustic deterrent and electricity) fish herding technique. A conceptual representation of the two drive boats and the guide boat equipped with side-scan sonar progressing through the lock chamber during herding is also illustrated. 1: Progression path of the two drive boats, 2: Progression path of the side-scan sonar boat through the lock chamber, directing the drive boats, 3: Multi-beam imaging sonars, 4: Placement of net to keep fish from re-entering the lock chamber post-fish herding. The striped cone represents the sonar that was excluded from analysis due to equipment malfunction.

player (NWE393 Walkman; Sony, Minato City, Tokyo, Japan) and an amplifier (TOA CA160R; Lubell Labs). Each drive boat was outfitted with two underwater speakers, submerged to a depth of 0.15 m, mounted to the port and starboard sections of the bow rail. Electricity was delivered to the water using electrofishing control boxes (The Infinity Box, Midwest Lake Management, Polo, Missouri, USA; Apex Control box, Smith-Root, Vancouver, Washington, USA) and an anode configuration composed of one stainless-steel sphere (6.4 cm diameter) and one stainless-steel cable (2.2 m length insulated cable with 20.3 cm uninsulated section at the end) suspended from each of two electrofishing booms per boat (Figure 1). Electrical output was 80 Hz and 40% duty cycle. The power goal (Miranda 2009) threshold was 22 peak amps to achieve avoidance responses in fish rather than immobilization (Ridgway et al. 2023).

The overall goal was to clear fish from the lock chamber by herding fish downstream through the open downstream (west) miter gate. Boats started at the closed upstream (east) miter gate before proceeding downstream towards the west miter gate. Prior to herding the lock chamber at full stimuli thresholds, each drive boat made two passes along the east miter gate while independently administering ~ 75% of the power goal (16 peak amps), as well as trimming up the outboard engine to eject a plume of water (< 3 m) and striking the boat hull with a wood paddle (similar to practices by commercial fishers when herding Silver Carp [Ridgway et al. 2023]). Next, the drive boats positioned separately along the north and south lock walls near the east miter gate (bow facing downstream). While stationary, the drive boats incrementally increased the electrical and acoustic outputs until reaching full stimuli thresholds. Subsequently, the drive boats slowly motored downstream as directed by the guide boat until exiting the lock chamber (Figure 2). This synchronous progression down the lock chamber was incremental and instructed by the guide boat observing fish movements on side-scan sonar (Figure 2). Immediately after the herding boats exited the lock chamber, a series of surface-to-bottom block nets (i.e., one 9.1 m × 152.4 m and two 4.6 m x 15.2 m, each 2.5 cm bar mesh) were deployed across the channel just downstream from the west lock entrance (Figure 2)

Table 1. Duration of multi-beam imaging sonar sampling periods within the navigation lock at Starved Rock Lock and Dam (Illinois River, LaSalle County, Illinois; 41.324670°; −88.986316°) before, during, and after deployment of a dual-deterrent (acoustic deterrent and electricity) fish herding technique, and the number of fish targets detected (by 100 mm size class).

		Fish Length (mm)								
	Duration	≤ 100	101–200	201–300	301–400	401–500	501–600	601–700	701–800	801–900
Before	01:59:00	186	1,136	2,933	911	333	390	190	32	1
During	01:02:00	24	516	1,310	358	56	14	5	6	0
After	00:24:00	8	175	402	89	13	2	0	0	0

to keep fish from re-entering. Minor deviations to the herding scheme survey monitoring routes were implemented to avoid areas obstructed by the barges in the lock.

Sonar data collection

Fish were monitored in the lock chamber using a combination of fixed-location multi-beam imaging sonars and a single mobile (boat mounted) side-scan sonar to determine the effectiveness of the herding technique. Mobile side-scan sonar surveys, consisting of a two transects (along each wall), of the navigational lock chamber were conducted before and after the fish herding to examine the changes in lock-wide abundance of large fish (> 400 mm). A Humminbird side-scan sonar transducer (XM 9 20 MSI T; Humminbird, Eufaula, Alabama, USA), operating at 1.2-MHz frequency, was deployed from the bow of the guide boat. Fixed-location multi-beam imaging sonars were used to examine changes in fish length distribution and abundance before, during, and after fish herding. Four ARIS Explorer sonars (two 3000 models set to 1.8-MHz frequency, and two 1800 models set to 1.1-MHz frequency; Sound Metrics, Bellevue, Washington, USA) were deployed inside the lock chamber (approximately 50 m from the downstream entrance), mounted to a metal pole strapped to a ladder recessed in the lock wall. Two sonars were deployed from the northern wall, with one sonar aimed across the lock chamber and the other aimed downstream parallel to the lock wall. This redundant deployment scheme was replicated on the southern wall (Figure 2). However, due to an equipment malfunction, data collected from one of the sonars on the southern side was excluded from processing and analyses. All multi-beam sonars' ranges were from 1.5 to 14 m, with the focus set to 9 m. Multi-beam imaging sonar data were collected using ARIScope (Version 2.8; Sound Metrics), and collected for 119 minutes before, 62 minutes during, and 24 minutes after the fish herding (Table 1).

Data Processing

Multi-beam imaging sonar data were processed using Echoview (Version 11.1; Echoview Software, Hobart, Tasmania, Australia), with which multibeam targets were converted to single targets. A two-dimensional fish tracking algorithm was applied to single target echograms to detect fish tracks and quantify fish targets. The size distribution of fish targets was estimated using ARISFish (Version 2.8; Sound Metrics).

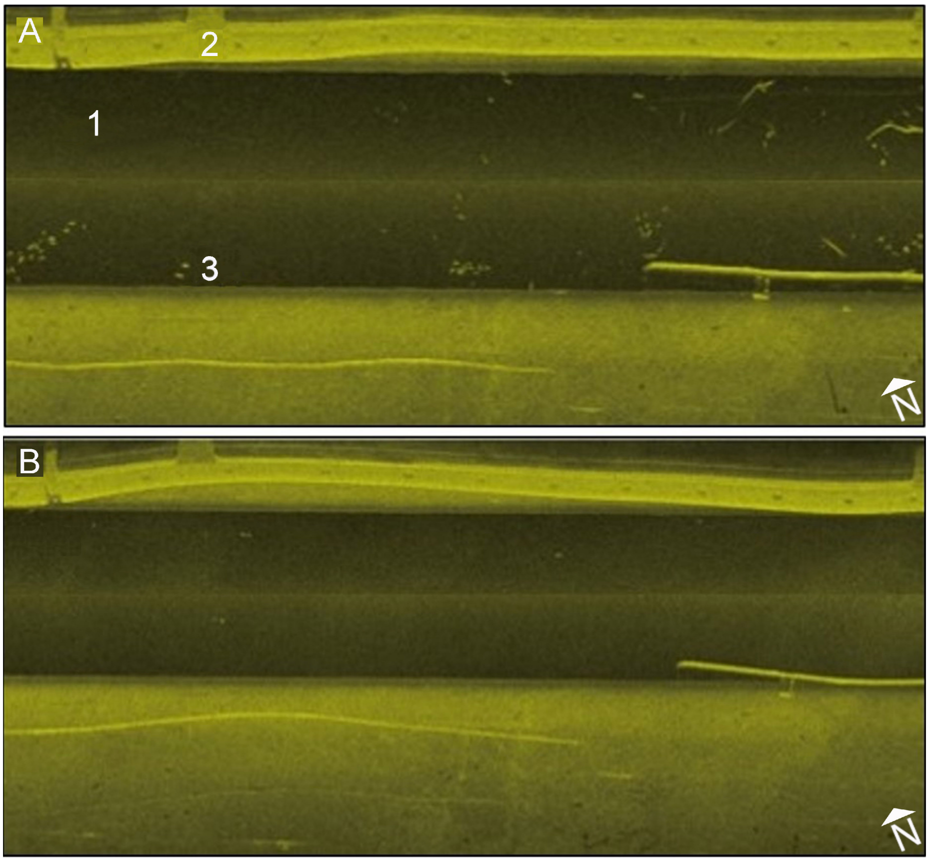

Figure 3. Side-scan mosaic snippets of a similar section within the navigation lock at Starved Rock Lock and Dam (Illinois River, LaSalle County, Illinois, USA; 41.324670°; −88.986316°) before (A) and after (B) deployment of a dual-deterrent (acoustic deterrent and electricity) fish herding technique. 1: Water column within lock chamber, 2: North lock wall, 3: Fish targets.

Side-scan sonar data were processed into georeferenced mosaic images using SonarTRX Pro (Version 20.1; Leraand Engineering Inc., Honolulu, Hawaii, USA). Google Earth Pro (Version 7.3; Google, Mountain View, California, USA) and ImageJ (Rasband, U.S. National Institutes of Health, Bethesda, Maryland, USA) were then used for further processing. Spatial overlaps in survey data were edited to avoid counting fish targets in duplicate. The pixel to length (mm) image scale was determined (i.e., 0.02 m/pixel) with the known cross-track distance. Fish targets (i.e., fusiform returns distinguishable from the immediate background) greater than 400 mm (20 pixels) were marked and quantified. Fish species were not identified using sonar. Fish species were visually confirmed by USACE during removal.

Data for this study are available at https://doi.org/10.5066/P94TS236 (Rivera et al. 2021).

Results and discussion

The dual-deterrent fish herding technique with acoustics and electricity reduced the number of fish detected by sonar in the navigation lock. There were 73% fewer fish targets detected using side-scan sonar after the fish herding (53), compared to before (195). A comparison of side-scan mosaic snippets of a similar section in the lock, from before and after the fish herding (Figure 3), showed a decrease in fish targets. The total fish per minute

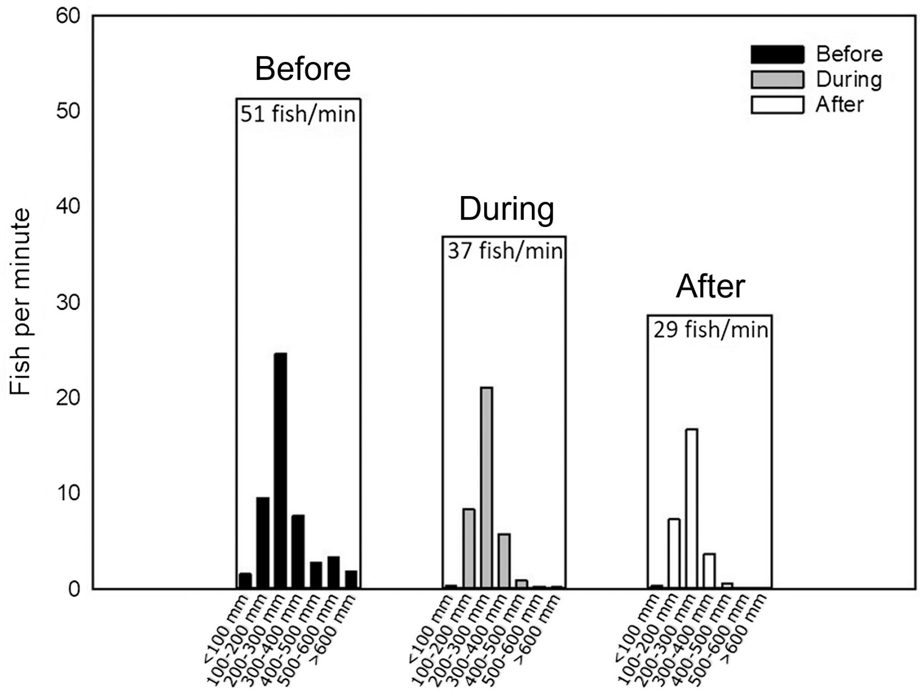

Figure 4. Fish per minute detected by multi-beam imaging sonars within the navigation lock at Starved Rock Lock and Dam (Illinois River, LaSalle County, Illinois, USA; 41.324670°; −88.986316°) before, during, and after deployment of a dual-deterrent (i.e., acoustic deterrent and electricity) fish herding technique. The three larger bars represent the total fish detected per minute; the smaller interior bars represent the length frequency distribution of fish detected per minute.

(FPM) detected in the navigation lock, using multi-beam sonars, decreased by 43% after the dual-deterrent fish herding technique was applied (Figure 4).

Fish targets, detected using multi-beam sonars, greater than 400 mm decreased by 88% (pre-fish herding: 8 FPM, post-fish herding: 1 FPM), compared to fish targets smaller than 400 mm, which decreased by 35% (pre-fish herding: 43 FPM, post-fish herding: 28 FPM). A visual comparison of the fish length frequency distribution observed during and after the fish herding (Figure 4) show a more positive skew (relative to the distribution of fish lengths before the fish herding), indicating a decrease in larger fish detected during those two periods when compared to before the fish herding. A comparison of the fish length frequency distribution (Figure 4) indicates a decrease in larger fish during and after the fish clearing effort when compared to before. These results are consistent with the positive relationship between fish size and swimming performance (Domenici 2001), where small-sized fish may be less susceptible to herding, having higher metabolism rates and greater risk of fatigue compared to large-bodied fish. These results also align with reported swim performance metrics, where sub-adult bighead carp and silver carp have 93% and 66.2%, respectively, faster burst swim speeds than larger juvenile bighead and silver carp (Hoover et al. 2012). Opposed to swimming linearly downstream and out of the lock, some fish species may be more inclined to maneuver in short, accelerated bursts in lateral or vertical (e.g., greater depths) directions to escape high stimuli gradients, similar to predator-prey interactions where

Table 2. Counts of fish species removed from within the navigation lock at Starved Rock Lock and Dam (Illinois River, LaSalle County, Illinois; 41.324670°; −88.986316°) after the deployment of a dual-deterrent (acoustic deterrent and electricity) fish herding technique used to clear fish prior to dewatering. Species marked with an asterisk are nonnative to the Illinois River.

Fish species	Count
Gizzard Shad *Dorosoma cepedianum*	291
Channel Catfish *Ictalurus punctatus*	188
White Crappie *Pomoxis annularis*	45
Common Carp *Cyprinus carpio**	25
Freshwater Drum *Aplodinotus grunniens*	25
Bluegill *Lepomis macrochirus*	22
Smallmouth Buffalo *Ictiobus bubalus*	21
Black Crappie *Pomoxis nigromaculatus*	12
River Carpsucker *Carpiodes carpio*	11
Walleye *Sander vitreus*	10
Sauger *Sander canadensis*	9
Striped bass *Morone saxatilis**	8
Flathead Catfish *Pylodictis olivaris*	6
Grass Carp *Ctenopharyngodon idella**	5
White Bass *Morone chrysops*	5
Bigmouth Buffalo *Ictiobus cyprinellus*	3
Goldeye *Hiodon alosoides*	3
Northern Pike *Esox lucius*	3
Skipjack Herring *Alosa chrysochloris*	3
Shortnose Gar *Lepisosteus platostomus*	2
Silver Carp *Hypophthalmichthys molitrix**	2
Goldfish *Carassius auratus**	1
Mooneye *Hiodon tergisus*	1
Smallmouth Bass *Micropterus dolomieu*	1

prey can maneuver in sharp turns when escaping predators (Domenici 2001). In addition, small-bodied fish are less susceptible to electricity. It is important to note that excessive acoustic or electricity energy could negatively affect fish physiology and herding efficacy as high voltage gradients can stun or injure fish (Reynolds et al. 2012) and high sound gradients can deafen fish. It is unlikely fish in the present study were adversely affected as the power goal was below immobilization thresholds. Fish could be deafened at sound pressure levels used in the present study when exposed over longer periods (12-h) but are known to fully recover hearing thresholds in a matter of days (Amoser and Ladich 2003).

Indications from sonar data that the fish clearing effort reduced total fish numbers and larger sized fish were supported by physical enumeration after the lock was dewatered. During the first lock dewater event in July 2020, without the aid of fish clearing, operation staff reported several thousand fish within the lock chamber after the water was removed, with the biomass composed primarily of invasive silver carp *Hypophthalmichthys molitrix* (USACE, written communication 2020). Exact counts during that event were not possible due to the high numbers of fish present. In contrast, with the implementation of fish clearing, USACE reported two silver carp present. A full list of species collected after dewatering is reported in Table 2.

Although it is unlikely that an identical fish species distribution was present within the lock during each of the dewatering events, the reduction in fish targets from sonar data and lack of fish collected in the end indicates fish clearing helped to avoid potential delays (and incurred costs) to USACE maintenance crews relative to when the lock was previously dewatered. The reduction of silver carp between the lock dewatering with and without the use of fish clearing indicates that the dual-deterrent fish herding technique may be particularly effective for this invasive species. The reduction of silver carp is also consistent with Ridgway et al. (2023) using this method to clear high densities of silver carp from reaches of open river (i.e., > 1 km; 40 m wetted width, 4 m depth).

Data from this study were collected as observations within a single fish clearing event. Therefore, replication and inferential comparisons were not possible. However, standardized data collection throughout the event allowed us to summarize sonar data using descriptive measures for fish targets per unit time and fish size to provide a general indication on fish clearing success with the intent that observations might inform future fish clearing events. Further research could ascertain herding performance across various fish lengths and species. A better understanding of these relationships could serve broader management uses of the dual-deterrent fish herding technique.

In summary, the dual-deterrent fish herding technique shows promise in reducing the number of fish present in a river navigation lock, particularly when clearing large fish is desired. Although the study design was limited due to dewatering protocols from USACE (e.g., data collection schedule), the results are intended to have applied observations and implications for future lock dewatering events. The implementation of the fish herding technique could be considered by lock managers during dewatering events, allowing for a quicker return to being operational and decreasing the economic impact of the lock being out of service.

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Author's contribution

All authors provided written contributions to various sections throughout the manuscript, reviewed multiple drafts, and approve the final version for publication.

Disclaimer

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