

M.L. 2014 Project Abstract

For the Period Ending June 30, 2018

PROJECT TITLE: Bioacoustics to Detect, Deter, and eliminate Silver Carp

PROJECT MANAGER: Allen F. Mensinger

AFFILIATION: University of Minnesota Duluth

MAILING ADDRESS: Biology Department, 1035 Kirby Dr

CITY/STATE/ZIP: Duluth, MN 55812

PHONE: 218 726 7259

E-MAIL: amensing@d.umn.edu

WEBSITE: www.d.umn.edu/biology

FUNDING SOURCE: Environment and Natural Resources Trust Fund

LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 04b

APPROPRIATION AMOUNT: \$262,000

AMOUNT SPENT: \$259,692

AMOUNT REMAINING: \$ 2,308

Overall Project Outcome and Results

The project examined various emerging technologies to detect and deter the upstream migration of invasive bigheaded carp into Minnesota. Both silver and bighead carp were found to have an aversion to broad band sound and the project focused on how to exploit this weakness. An early detection buoy was developed that stimulates silver carp jumping with sound to allow managers to locate fish. The hearing sensitivities of the fishes were examined and found to have higher frequency hearing than previously reported. Broadband sound was successful in deterring fish and also preventing them from entering a small channel. Fish were successfully herded by broadband sound in the wild, suggesting that sound could be used to increase capture rates. We have also noted that long sound exposure may cause transient hearing losses in fishes so the sound deterrence must be balanced against potential hearing loss. In summary, broadband sound induces aversive behavior in silver and bighead carp however further study is needed to address the duration of its effectiveness.

Project Results Use and Dissemination

Presentations have been made at state, regional and national scientific meeting to disseminate the data and five publications were produced.



Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan Final Report

Date of Report: 8/16/2018
Final Report
Date of Work Plan Approval: 6/4/2014
Project Completion Date: 6/30/2018

PROJECT TITLE: Bioacoustics to Detect, Deter, and eliminate Silver Carp

Project Manager: Allen F. Mensinger
Organization: University of Minnesota Duluth
Mailing Address: Biology Department, 1035 Kirby Drive
City/State/Zip Code: Duluth, MN 55812
Telephone Number: (218) 726-7259
Email Address: amensing@d.umn.edu
Web Address: www.d.umn.edu/biology

Location: Statewide

Total ENRTF Project Budget:	ENRTF Appropriation:	\$262,000
	Amount Spent:	\$259,692
	Balance:	\$2,308

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 04b; *appropriation extended to June 30, 2018 in M.L. 2017 Ch. 96, Sec. 2 Subd. 18(a)(2),*

Appropriation Language:

\$262,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota-Duluth to develop bioacoustic technology for detection and early warning systems, capture and elimination methods, and deterrent systems for silver carp. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

Carryforward; Extension (a) The availability of the appropriations for the following projects are extended to June 30, 2018: (2) Laws 2014, chapter 226, section 2, subdivision 4, paragraph (b), Bioacoustics to Detect, Deter, and Eliminate Silver Carp

I. PROJECT TITLE: Bioacoustics to detect, deter and eliminate flying carp

II. PROJECT STATEMENT:

The Asian silver carp, one of four invasive carp species, is migrating north via the Mississippi River and threatening native fish in Minnesota rivers and lakes by outcompeting them for food supplies. Additionally, its unique jumping ability places recreational boaters in danger of being injured during collisions with airborne fish. However, this jumping ability is a weakness that can be exploited to detect, manage and control fish populations. The goals of this project are:

- 1) use the sound that stimulates jumping to develop early warning and detection systems**
- 2) develop management techniques using sound to exhaust the fish on the surface or to herd the fish into shallow waters for capture and removal**
- 3) use sound to deter or repel fish from moving through strategic waterways**

In the previous year, we have made two significant findings: 1) determined the sound that initiates jumping in wild silver carp in the Illinois River; 2) successfully used this sound to repel carp in experimental outdoor ponds at the USGS Upper Midwest Environmental Science Center (UMESC) in LaCrosse, Wisconsin. This proposal would allow us to develop bioacoustic (sound) technology to combat the silver carp. The most effective sound that influences carp behavior is of relatively high frequency and is outside the hearing range of most native and game fishes. Our first goal is to develop remotely operated buoys with underwater speakers and above water video cameras to stimulate carp jumping to ascertain if an early detection or identification system can be developed. Our second goal is to develop a mobile sound system to stimulate continuous jumping for exhausting the fish on the surface and/or use sound to herd the fish into shallow water or nets for easy capture. Finally, we will test the efficacy of using sound to repel carp from specific areas. All the proposed studies will take place in large, secured (caged) outdoor experimental ponds at the USGS UMESC in LaCrosse, Wisconsin or on populations of wild carp in the Illinois River near Havana, IL. Both sites provide access to fish in outdoor locations where they behave naturally, allow large scale trials that cannot be replicated in indoor facilities and pose no danger of silver carp being released in MN waters.

III. PROJECT STATUS UPDATES:

Project Status as of 1/15/2015:

An early warning and detection buoy was fabricated and tested both in tanks and on the Illinois River. The buoy was remotely operated and equipped with an underwater speaker. Preliminary trials indicated that the buoy was effective in dispersing carp from an approximately 25 to 50 m radius both up and downstream. This was verified by electrofishing following acoustic testing. In several incidents, the carp was stimulated to jump however this behavior was inconsistently noted. The speaker was affixed to a boat to determine if fish could be "herded" up or down stream. The boat allowed a larger amplifier to be used and consistent movement away from the speaker as well as jumping was noted. Fish dispersion was approximately 50 meters up and down stream.

Barrier trials were attempted in both small outdoor tanks and a large outdoor pond at the USGS facility. Sound was effective in inhibiting both silver and bighead carp movement through a small opening in a barrier. This was confirmed by video analysis. Sound tests were also conducted on telemetry tagged fish in the large pond and are currently being analyzed.

Project Status as of 7/15/2015:

Activity 1: Due to spring flooding on the Illinois river, spring trials were not conducted with the buoy. A larger amplifier and speaker were acquired and the buoy modified for Fall trials pending lower water levels in Havana, IL

Activity 2: We have made significant progress on assessing the reaction of bighead carp and native fish to sound. Bighead carp were shown to be as responsive as silver carp to being moved across the ponds with sound. We determined the optimal sound pressure levels that resulted in repulsion. Native fish including walleye and sunfish were not responsive to the sound indicating the sound used as a carp deterrent at the current decibels, while not effect native species. Trials with bigmouth buffalo however were very mixed and fish behavior was not the same as with the silver and big head carp indicating that these fish would be a poor surrogate to test acoustic behavior. We also examined the effect of temperature on silver and bighead behavior and saw significant increase in deterrents with increased behavior which may allow us to model when acoustic deterrents will be most effective.

Activity 3: We continued to concurrently examine acoustic deterrents under controlled conditions at the UMESC facility in LaCrosse WI and in the field in the Illinois River. At UMESC, outdoor concrete ponds were partitioned in half and speakers placed near the small channel in the barrier. Complex sound was very effective in deterring fish from swimming through the channel. The number of crossing with bighead, silver and mixed schools was significantly decreased when sound was broadcast.

Project Status as of 1/15/2016:

We continue to make excellent progress towards all three activity goals. We continue to be the only laboratory in Minnesota combining controlled, large outdoor pond experiments with field studies in areas containing invasive carp. We have been working on a wide range of fish sizes, from 3 cm to 1 meter long fish. We continue to learn more about the effects on sound on both bighead and silver carp as well as native fishes. Our field studies have shown that sound can be an effective tool in dispersing carp from a given area as well as herding them both up and down stream. Our results are being disseminated in the literature and reports to government agencies including the Army Core of Engineers, the USGS, the US Fish and Wildlife, regional agencies and various state DNRs.

Activity 1: Based on situ sound recordings and behavioral observations, it appears the buoy will be more effective with a larger amplifier and speaker. The work is ongoing to modify the hardware on the buoy to optimize its performance. This involves concurrent modification of the battery and charge storage devices to augment the solar panels. Nick Frohnauer of Minnesota Department of Natural Resources was given a tour of the lab and expressed interest in the buoy's development and application

Activity 2: We continued examining the effect of sound on bigheaded carp and native fish. Additionally, we examined the effects of temperature on fish behavior. We established a new collaboration with the USGS in Columbia Missouri and they hosted us for a week in Missouri. They were anxious to try herding fish and we conducted trial runs on a small tributary of the Missouri River. This was done at no cost to the current grant. They also joined us on the Spoon River in Havana Illinois and provided sonar equipment to allow us to track the underwater movement of the fish with above water jumping. Preliminary analysis indicates that sound will cause the majority of carp to leave the area with subsequent passes causing many of the remaining carp to also leave. The sonar indicated that the remaining carp seek woody debris as refuge and targeting these areas would result in greater removal. However, on straight stretches of the river within debris, which would more closely mimic a lock and dam chamber, the sound was much more effective in moving fish as there was little refuge. This data is important for trying to herd the carp out of the area.

Activity 3. The acoustic deterrent work in the small concrete ponds continued will be providing the foundation for summer 2016 studies especially to further investigate habituation to sound. Broadband sound continued to be an excellent deterrent to bigheaded carps while having little effect on native fishes with approximately 10 species of native tested with plans for several more. A large scale field study was conducted with the USGS in Morris, IL in a backwater of the river. Large fish were captured, immediately tagged and placed in a large netted

enclosure with a narrow channel separating the two halves of the enclosure. Despite non optimal conditions, sound proved effective at both discouraging crossing and concentrating fish into small areas.

Amendment approved by LCCMR 2-10-2016

We respectfully request the transfer of the Professional/Technical/Service Contracts funds that were originally targeted for boat rental and fuel expenses from the Illinois Natural History Survey (INHS) to be moved to equipment to support activity 2 and 3. The INHS has been very supportive of the project and has decided that they prefer to provide boats and personnel as in-kind service.

The funds will be transferred to activity 2 and 3 to support the acquisition of additional acoustical hardware such as hydrophones and speakers. Our recent results have indicated two important pieces of information. The first is that we can drive the fish much further than anticipated and need additional hydrophones so we can understand the sound field at these longer distances. Secondly, we have noticed gaps in our sound field coverage that can be remedied by additional speakers.

The Professional/Technical/Service Contracts were for \$9000 and equally divided between activities 1,2, and 3. We request permission to move these funds into the Equipment/Tools/Supplies divided evenly between activity 2 outcome 3 and activity 3 outcome 3.

We also request to change the location in activity 3 outcome 3 from the Sand pit to Sand/pit open waters trials. This has no impact on the science being proposed however due to flooding issues, the USGS may not return to the Morris sandpit in 2016 and is investigating other potential sites such as the Brandon Road or Starved Rocks dam. This change will simply provide flexibility to conduct the trials at a slightly different location when it is finally chosen.

Project Status as of 7/15/2016:

We continue to make excellent progress towards all three activity goals. We continue to be the only laboratory in Minnesota combining controlled, large outdoor pond experiments with field studies in areas containing invasive carp. Our results continue to be disseminated in the literature and reports to government agencies including the Army Core of Engineers, the USGS, the US Fish and Wildlife, regional agencies and various state DNRs. We are encouraged by the reaction of the fish to sound stimulus in controlled tank conditions, large outdoor ponds and in the field. Spring weather and river conditions precluded many of the experiments so efforts were focused on building large barrier/channels in 1/10 and ½ acre ponds at the USGS facility in LaCrosse. Previous barrier trials had been conducted in small outdoor concrete tanks and these new ponds will provide a more realistic aspect of carp behavior.

The PI and his students presented at multiple meetings and submitted or had published several manuscripts on the bioacoustics and sound. The PI also entered into a new collaboration with the Nature Conservancy at the Emiquon field station just North of the Havana IL field site that will allow testing of the technology in large culverts with no additional cost to the grant. The laboratory presented their results at a sound deterrent workshop hosted by the USGS in LaCrosse, WI and received interest from a number of management agencies.

Project Status as of 1/15/2017:

We continue to make excellent progress towards all three activity goals. We continue to be the only laboratory in Minnesota combining controlled, large outdoor pond experiments with field studies in areas containing invasive carp. Our results continue to be disseminated in the literature and reports to government agencies including the Army Core of Engineers, the USGS, the US Fish and Wildlife, regional agencies and various state DNRs. We attempted to concentrate on habituation to sound and field trials during the summer and fall. We

established 3 1/10 acre ponds with barriers and attempted to determine how long the sound will be effective without fish habituating. Unfortunately, this cooperative effort with the USGS was beset by technical problems with the acoustic tags and it is uncertain if the data can be extracted from the study or the experiments need to be repeated this summer. Spring, summer and fall river water levels were at very high levels that precluded many of experiments. Two late fall experiments were conducted. An acoustic barrier was established at Emiquon and achieved operational status. Its efficacy will be assessed this spring. Herding trials continued in the Spoon river and an additional small outreach of the Illinois river. Herding/driving the fish was very effective however many of the silver jumped over the nets and eluded capture. These trials will be conducted again in the spring with nets designed to decrease the jumping. Many publications were submitted or published this fall to disseminate the results.

Project Status 7/15/2017

Habituation trails were restarted at the USGS in LaCrosse, WI to determine the duration that the sound deterrent is effective. Three 1/10 acre ponds and four smaller outdoor tanks were established and sound was played for extensive periods of time to determine how long the sound was effective. Fish were tagged with acoustic telemetry tags and fish position was continuously monitored. The 2016 issues with the tags were resolved with the manufacturer and all tags appeared to work throughout the summer. Data is currently being processed and the results will be reported during the next update.

We continue to participate in herding/driving fish. We were invited to join a USGS and other researchers to use the Unified Method to capture carp. This involved commercial fisherman, electroshocking boats and our sound boats to drive fish in Morris, IL to shallow waters for capture. This was a five day effort and results are still being analyzed.

We also started to evaluate the hearing ability of the silver and bighead carp to sound stimulus using Auditory Evoked Potentials in the laboratory.

Project Status 3/1/2018

We continue to work with our collaborators to examine carp hearing sensitivity and possible damage caused by refine to allow us to refine the optimal sound that will repel the fish without causing hearing damage. A collaborative agreement with the USGS has allowed us to use Auditory Evoked Potentials (AEPs) to examine carp hearing. This is a non invasive technique equivalent to an EKG that measures the electrical activities of the brain and inner ear when the fish is exposed to sound. It has allowed us to determine that carp hearing can detect higher frequencies sound than previously reported and that prolonged sound can damage carp hearing structures making acoustic deterrents less effective. These experiments are key to refining the sound in activities 2 and 3 to make sound deterrent optimal.

We also have been examining the underwater propagation of sound from our underwater speakers and will be modeling the sound patterns to better understand how speakers should be situated. Preliminary data shows that structures associated with the buoy or speakers may deflect some of the sound and we are investigating better ways of deploying/attaching to speakers to maximize sound output.

Presentations were made at several meetings and a manuscript is under final review at PlosOne that reports on the current activities.

Overall Project Outcomes and Results:

The project examined various emerging technologies to detect and deter the upstream migration of invasive bigheaded carp into Minnesota. Both silver and bighead carp were found to have an aversion to broad band

sound and the project focused on how to exploit this weakness. An early detection buoy was developed that stimulates silver carp jumping with sound to allow managers to locate fish. The hearing sensitivities of the fishes were examined and found to have higher frequency hearing than previously reported. Broadband sound was successful in deterring fish and also preventing them from entering a small channel. Fish were successfully herded by broadband sound in the wild, suggesting that sound could be used to increase capture rates. We have also noted that long sound exposure may cause transient hearing losses in fishes so the sound deterrence must be balanced against potential hearing loss. In summary, broadband sound induces aversive behavior in silver and bighead carp however further study is needed to address the duration of its effectiveness.

IV. PROJECT ACTIVITIES AND OUTCOMES:

Activity 1: Early warning and detection system development

Description:

One of the challenges in assessing the silver carp invasion is to accurately census the population and to identify the vanguard of new invasion fronts. Carp have been documented to avoid traps and nets which make using traditional fisheries census techniques challenging. Although environmental DNA analysis can confirm the presence of carp DNA at low concentrations in the water, it cannot pinpoint the source of the DNA (ie live carp vs bird fecal material) or the number and age of the carp. The silver's carp unique jumping ability could be used to develop early warning systems by stimulating the carp to jump and determine the number and composition of the population in the area. Preliminary trials have indicated that individual carp can be stimulated to jump and they do not have to occur in high densities to exhibit this behavior. Therefore, detection systems could be used both to census established populations as well as early warning systems when small numbers of carp first enter an area.

Silver carp of different size and age classes will be maintained in large, secured outdoor tanks at the UMESC facility in Lacrosse, WI which has a captive silver carp population. The carp are viewed remotely with overhead cameras to monitor their normal swimming patterns and their response to sound and/or vibrational stimulus. Underwater speakers will be mounted throughout the tanks and the carp response to complex sound, primarily underwater recordings of boat motor sound will be played through the speakers. The swimming and jumping behavior of the carp will be observed in response to sound stimulus. Preliminary trials have shown that silver carp will rapidly swim away from this type of sound. Other fish behavior such as jumping and schooling will be noted. Various sound frequencies and intensities will be tested to determine the optimal sound that causes the fish to move away from the sound source. As fish behavior is related to age (size), density and temperature, the sound will be tested on both juvenile and adult fish at different temperatures and densities.

We will develop a remotely operated, early warning buoy equipped with video cameras, underwater speakers, vibrational stimulus and hydrophones for the field deployment. This buoy will be designed to stimulate carp jumping behavior in the field. It will be programmed or remotely operated to play sound stimulus at random times during the day and the number of fish jumping will be recorded by the video cameras.

To test the buoy, prior to field deployment, trials will be conducted in a ½ acre pond to create more natural conditions and determine the stimulus range. The pond is equipped with fish tracking systems and underwater cameras which will allow us to monitor fish position and behavior underwater. We will use the optimal stimulus that was developed in the smaller tanks to stimulate carp jumping which will be recorded by the video cameras on the buoy. The number of carp jumping and the range of the stimulus will be determined.

We will then travel to Havana, IL to test the system on wild populations of carp in the Illinois River. The buoy will be floated into areas of varying carp concentrations and remotely operated to trigger various stimuli to detect the carp. Prior to or after buoy deployment, we will determine the carp concentration in the area by passing through with motor boats and/or electrofishing boats. We will compare its effectiveness in areas of high and low carp concentration to determine its effectiveness as a detection system.

Summary Budget Information for Activity 1:

ENRTF Budget: \$93,334
Amount Spent: \$92,448
Balance: \$846

Activity Completion Date: 6/30/2017

Outcome	Completion Date	Budget
1. optimal stimulus, small outdoor tank trials	12/31/14	\$32,334
2. buoy construction, ½ pond trials	12/31/15	\$32,000
3. buoy testing, Illinois River	12/31/16	\$29,000

Activity Status as of 1/15/2015

The buoy was purchased and modified during the summer of 2014. The buoy was equipped with solar panels to power a 20 W amp. Two battery operated Go-Pro cameras were mounted on the buoy to record above water fish activity. An underwater speaker was mounted below the water line. A MP3 player that continuously looped complex sound stimuli was used as the sound stimulus. All equipment was remotely operated so the buoy could be deployed by boat and allowed to drift downstream.

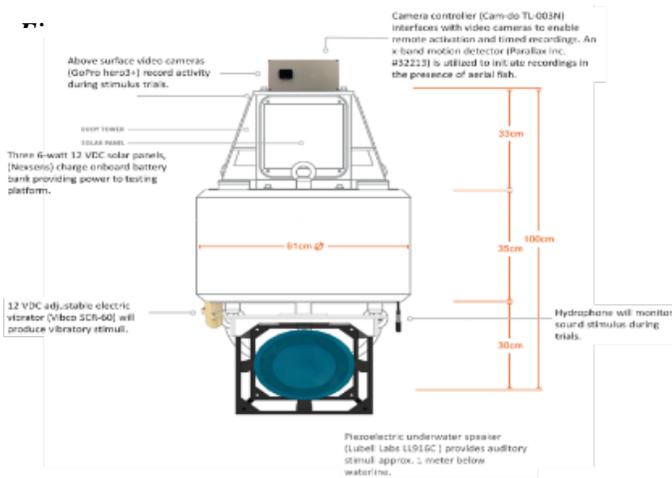


Figure 1. Schematic of buoy



Figure 2. Buoy being readied for preliminary trials on Illinois River



Figure 3. Buoy deployed in Illinois River

Preliminary trials were conducted on the Illinois River. The buoy was deployed and allowed to drift downstream from the boat. The sound stimulus was initiated for approximately one minute and then the boat approached the area and conducted electrofishing to determine the presence or absence of fish.

Jumping was not observed in the main channel however the area within 25 to 50 m of the buoy was devoid of carp. Electrofishing verified that carp had moved both up and downstream. The buoy was then relocated to a side channel that was approximately 30 m wide. The buoy appeared more effective in the narrower channel as carp was displaced at least 50 m up and downstream.

The buoy seems an effective tool to move carp both down and upstream away from a selected area. Jumping was rare however only a small amplifier was used. Please see activity 2 for information on using larger amplifier. Several adjustments will be made to the buoy including a counterweight to help balance the float and incorporating a vibrating probe to determine the effects of vibration without sound.

Activity Status as of 7/15/2015

Due to spring flooding on the Illinois river, spring trials were not conducted with the buoy. A larger amplifier and speaker were acquired and the buoy modified for Fall trials pending lower water levels in Havana, IL

Activity Status as of 1/15/2016

The spring and summer flooding precluded additional buoy field trials as efforts were concentrated on activities 2 and 3 due to the compressed season. The larger speaker was fitted to the buoy but power output delivered by the solar panels remained below the levels for sustained deployment. Efforts are underway this winter to add additional battery capacity to the buoy. These batteries combined with the solar input will allow longer deployments during the next deployment window. The information obtained from sound mapping activities in activity 2 and 3 also allowed better understanding of the sound created by the speakers. There are some gaps in the original sound field that fish can exploit and the buoy will be further modified to reduce these problems

Activity Status as of 7/15/2016

Modifications continue to be done with the buoy to stabilize its position. The three point anchor system is being developed to stabilize the buoy. The larger speaker caused unanticipated rotation either due to the physical

stimulus or creating more drag in the current. A mooring/anchor has been develop to maintain the position of the buoy in the stream as rotation confounds sound directionality. Spring flood conditions again prevented deployment so field trials are postponed to fall.

Activity Status as of 1/15/2017

Fall water conditions and woody debris precluded the use of the buoy. If water conditions continue to challenge its deployment, then ½ acre pond trials will be attempted to be conducted this spring/summer.

Activity Status as of 7/15/2017

River conditions continued to be inconsistent with either high flow or low water conditions. Additional evaluations of the overall technology suggests that the buoy can be highly effective in near shore or banks heavy debris. For channel blockage, multiple buoys will need to be deploy to increase acoustic deterrence.

Activity Status as of 3/1/2018. We are currently collaborating with the MN DNR to evaluate Lock and Dam 5 as potential site for acoustic deterrents. We have been given permission from the Army Core of Engineers to access the site and deployed hydrophones in the lock and dam in late fall to record sounds. The site provides a more accessible environment than the rivers we had been working in and should not be impacted as much by flooding. If the opportunity presents itself in the spring (water levels and river conditions) we plan to test the buoy downstream from the channel to see how it operates in larger river environments.

Additionally, we are testing the directional sound component of the speakers (which is also related to Activity 2) and preliminary finding has found some asymmetries in the sound propagation of the speakers that may either be related to the speakers, supporting structures or the buoy. We are testing a new speaker harness that will help us isolate any issue and allow optimal sound projection.

Final Report Summary:

The buoy proved effective in eliciting silver carp to jump and could certainly be further developed as an early warning system. Based on deployment experience and data from the other experiments in this report, the buoy would be more effective if two, larger underwater speakers were mounted perpendicular to each other underneath the buoy. This would allow a more uniform sound distribution and high intensity sound which would increase the effective area of the underwater sound field and significantly increase the probability that any silver carp in the area will jump.

ACTIVITY 2: Bioacoustical movement of carp

Description: We have determined that carp will swim away from complex sounds such as underwater recordings of outboard boat motors. Commercial fishermen already use crude sound stimulus (banging on the sides of their boats) to concentrate fish and herd them into nets. It is anticipated that multiple arrays of underwater speakers could herd and/or concentrate the fish into shallow water for capture. We will develop underwater speaker arrays drive and/or herd fish into specific areas of the tanks or use the speakers in the field to drive the fish into nets. As both species of carp exhibit sound aversion, we will employ this technology on both silver and bighead carp. The goal is reduce or eliminate already established populations by concentrating the fish for easy capture and removal

Additional, we plan to take advantage of the silver carp's unique jumping ability and use this behavior against the fish. Aerial jumps are energetically expensive for fish, and even salmon that migrate hundreds of miles upstream, need to rest before jumping successive water falls. If carp are stimulated to jump repeatedly, it may be possible to exhaust them to the point where they will float on the surface and can be easily netted and removed.

The initial trials will be conducted in large, outdoor concrete ponds on the campus of the USGS facility in LaCrosse, WI. Silver carp of different size and age classes will be maintained in large, secured outdoor tanks at the UMESC facility in Lacrosse, WI which has a captive silver carp population. The carp will be viewed remotely with overhead cameras to monitor their normal swimming patterns and their response to sound and/or vibrational stimulus. Underwater speakers will be mounted throughout the tanks and the carp response to complex sound, primarily underwater recordings of boat motor sound will be played through the speakers.

The swimming behavior of the carp will be observed in response to sound stimulus. Preliminary trials have shown that silver carp will rapidly swim away from this type of sound. Different sound frequencies, vibrations and intensities will be tested with the underwater speakers. Preliminary trails indicated playbacks of underwater boat noise is an effective stimulus to displace and move carp. In contrast to Activity 1, multiple speakers (4 to 5) will be placed strategically in the tank to herd the fish into designated areas. As the fish will be viewed remotely with the overhead cameras, different speakers or combinations of speaker can be activated to drive the carp into designated areas of the tank or stimulate jumping to the point of exhaustion.

Trials will move then to the ½ acre pond described in activity 1 to create more natural conditions. Speaker arrays consisting of multiple speakers will be suspended from boats and used to herd the carp into specific areas of the tank. To concentrate them in one area, it is anticipated that two or three arrays will be operating simultaneously. Fish position will be monitored either by jumping or underwater cameras. Trials will be conducted with 25 to 50 fish and the accuracy to technique evaluated based on the number of fish that can concentrated into the designated areas. Small boats with outboard motors may also be used in the pond to move or herd carp into designated areas.

Once the methodology has been optimized, field trials will be conducted on the Illinois River. The field trials will use underwater speakers and/or motor boats to drive the carp into nets or shallow water for capture. All trials may be augmented by electroshocking as electric current has been noted to produce herding behavior similar to sound in field trials. Additionally, before and after carp movement and capture, electroshocking can used to census the river population to test the efficacy of the procedures.

Summary Budget Information for Activity 2:

ENRTF Budget: \$ 88,083
Amount Spent: \$ 88,083
Balance: \$ 0

Activity Completion Date: 6/30/2017

Outcome	Completion Date	Budget
1. Bioacoustic movement, outdoor tank trials	12/31/14	\$ 29,583
2. develop speaker array, bioacoustic outdoor pond trials	12/31/15	\$ 29,000
3. Field trials, Illinois River	06/30/17	\$ 31,500

Activity Status as of 1/15/2015

The sensory biology and phonotaxic response of silver carp were investigated using controlled experiments in outdoor concrete ponds (10 x 4.9 x 1.2 m). Pure tones (500-2000 Hz) and complex tones (field recordings of

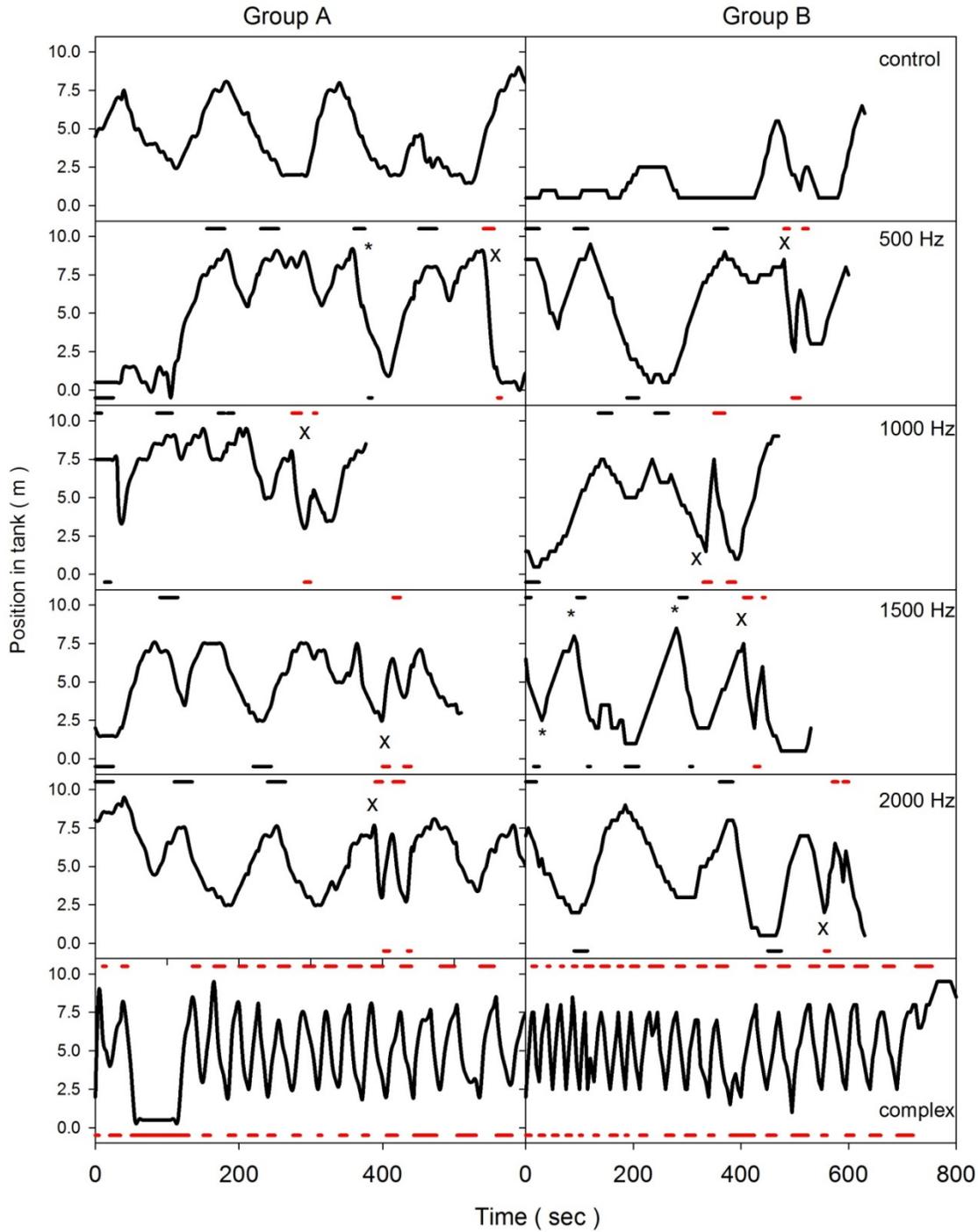


Figure 4. Silver carp movement in response to pure tones and complex sound

outboard motors) were broadcast using underwater speakers. Silver carp exhibited consistent negative phonotaxis to outboard motor sounds, however they habituated quickly to pure tones (after 1-2 trials). By alternating active speakers, silver carp movement was regularly directed away from the sound source to the opposite end of the pond. This research suggests that sound can be used to alter the behavior of silver carp with implications for deterrent barriers or potential control measures (e.g., herding fish into nets).

Trials were also conducted on bighead carp and native fish. The bighead head also were more responsive to complex sound stimulus although the fish did display greater sensitivity to higher frequency pure tones than silver carp. None of the native species tested exhibited response to the sound. Both of these data sets are currently being analyzed and will be available for the next progress report.

Preliminary tests were conducted on telemetry tagged silver and bighead carp in the large outdoor pond. The telemetry system allowed fish position to be continuously tracked. Two large speakers were suspended from floating platforms and complex sound broadcast. The large data sets are currently being analyzed by the USGS. The first trial was inconclusive due to heavy algal fouling of the pond. A follow up trial was more effective. Preliminary analysis indicates that the width of the pond will need at least a third speaker and/or offset speaker pairs to provide better coverage.



Figure 5. Position of the floating platforms that suspended the speakers in the 1/2 acre pond

The underwater speaker was transferred from the buoy to the electrofishing boat and used to drive fish away from designated areas. Fish were monitored using electroshock before and after sound stimulus. A 60 w amplifier was used instead of the 20 W amplifier. Sound was very effective in “herding” or moving fish away from areas. There were several occasions where all the fish in the immediate area jumped. As this did not transpire with the buoy, we believe that this behavior is driven by sound intensity. This is the first example where sound alone was sufficient to elicit jumping behavior. As only the single speaker was available, it is anticipated that using speaker pairs that can be directed could help focus the sound and herd the fish into specific spots.

Activity Status as of 7/15/2015

The sensory biology and phonotaxis response of bigheadcarp and native fishes were investigated using controlled experiments in outdoor concrete ponds (10 x 4.9 x 1.2 m). Pure tones (500-2000 Hz) and complex tones (field recordings of outboard motors) were broadcast using underwater speakers. Bighead carp exhibited consistent negative phonotaxis to outboard motor sounds (figure 6), however they habituated quickly to pure tones (after 1-3 trials) (Figure 7). By alternating active speakers, bighead carp movement was regularly directed away from the sound source to the opposite end of the pond. This research suggests that sound can be used to alter the behavior of silver carp with implications for deterrent barriers or potential control measures (e.g., herding fish into nets).

Native fish including walleye and sunfish show no reaction to the sound. Bigmouth buffalo behavior was quite different than the invasive carp and very inconsistent when exposed to sound, alternating between going away from the speakers and going towards them. The use of bigmouth buffalo as a surrogate to investigate invasive carp is not recommended, under at least these conditions.

The sound pressure levels were relatively modest which encourages as large speakers that broadcast high amplitude sound will more than likely harm both carp and native fish. Native fish were not affected by the sound used to drive the bighead and silver carp and therefore use of this sound in the field should not affect native fish.

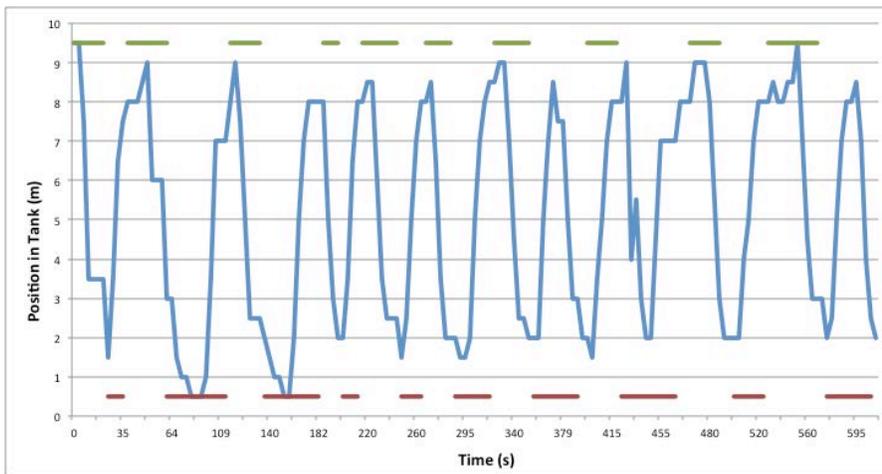


Figure 6. Movement of bighead carp in response to complex sound. The longitudinal position (m) of the center of the school is plotted versus time (s) with fish position mapped every 5 seconds. Solid lines above and below each fish position trace indicate the location and duration of the sound stimulus.

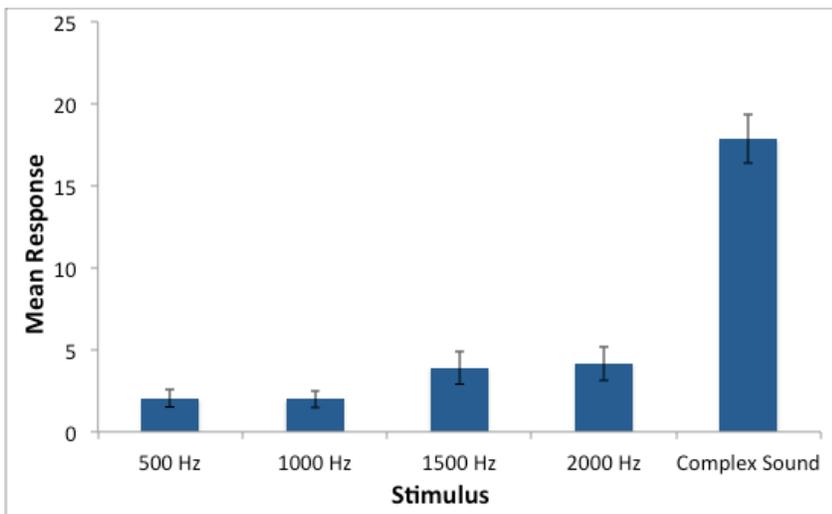


Figure 7 Bighead carp response to pure tones and complex sound. The number of consecutive movements is plotted for each sound.

Activity Status as of 1/15/2016

We continue to receive inquires on the effect of the sound on native fishes. Therefore we repeated the previous experiments on native fishes as well as two additional species on carp.

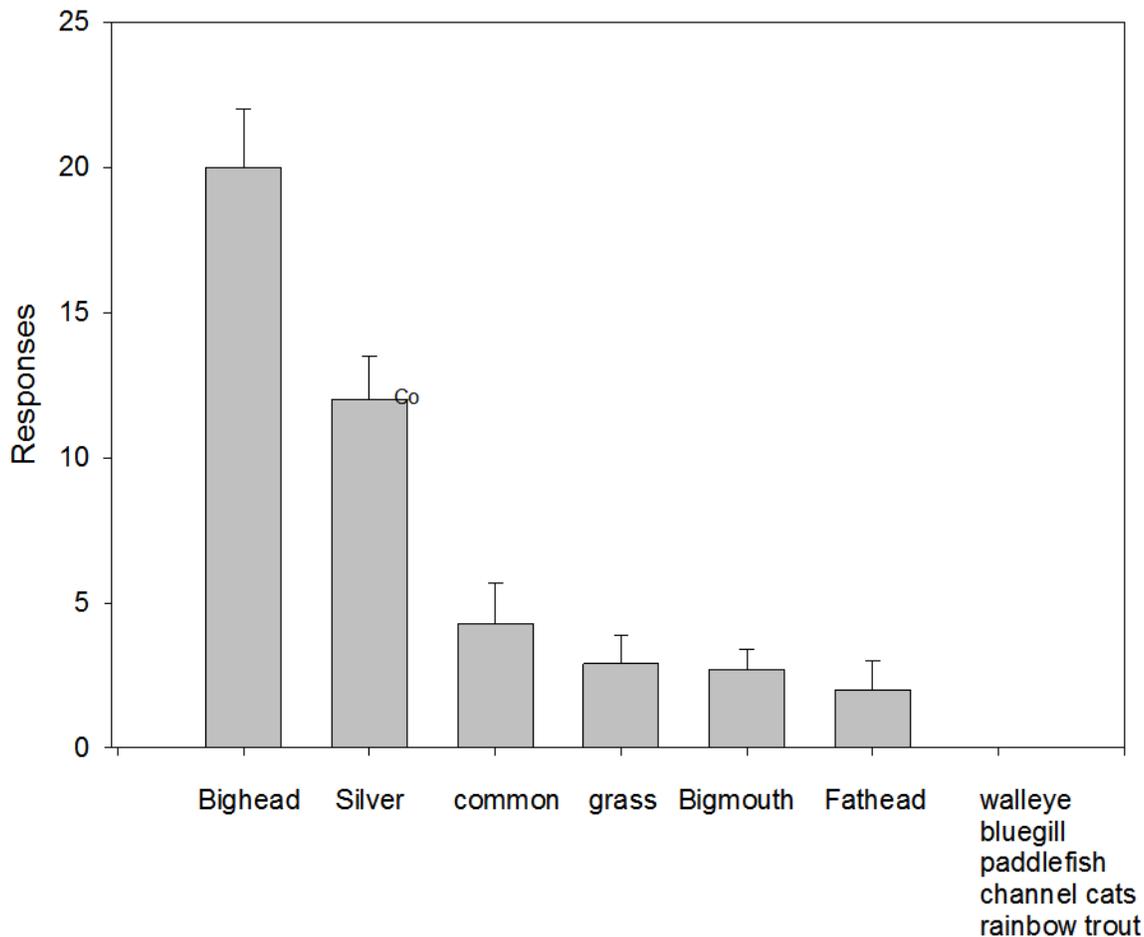


Figure 8. The average number of consecutive responses to broadband sound is plotted versus fish species

The above figure showed that broadband sound is extremely effective in changing the behavior of bighead and silver carp with most schools still responsive to sound after 10 minutes of sound presentation. Any habituation prior to this time period appears to be directly due to swimming fatigue and non habituation. Two other invasive carp species, common carp and grass carp, despite having similar hearing structures, were much less responsive to the sound. Native species such as bigmouth buffalo and fathead minnows showed mixed reactions with most schools non responsive. Other native fish such as walleye, bluegill, paddlefish, channel catfish and rainbow trout displayed no reaction to the sound. This confirms our preliminary hypothesis that silver and bighead would be most responsive to the sound and that other closely related species such as common carp and bigmouth buffalo are not suitable models for acoustic deterrents. Also, most native fishes tested have little or no response to the frequencies and stimuli deployed.

Our outdoor observations noted that the bigheaded carp behavior was influenced by water temperature. To understand the role of water temperature on sound sensitivity, we initiated indoor experiments under controlled water temperature conditions ranging from 12°C to 32°C to study the effect of temperature on bighead and silver carp behavior. Bighead carp displayed high negative phonotaxis at the warmer temperatures but activity was reduced at 12°C. However, swimming speed and overall activity was also reduced at these

temperatures. Therefore it is uncertain if the lower temperatures would reduce the effectiveness of the acoustic deterrent as the carp may not have the motivation to challenge the sound.

Herding studies were initiated on the Spoon River in Havana IL and on a tributary of the Missouri in Columbia, MO. The experiments were enhanced by underwater sonar provided by the USGS CERC office. In the Illinois study, a single boat with equipped with two underwater speakers slowly transited 200 m stretches of the river while broadband sound was broadcast. Controls consisted of boat movement with the speakers silent. Initial passes often stimulated > 100 fish to jump with subsequent passes detecting fewer jumpers. Boat movement when the speakers were silent rarely stimulated the carp to jump indicating that sound was the primary stimulus. Underwater sonar confirmed that most carp left the area with the remaining carp "hiding" in woody debris. These areas were targeted on subsequent passes and were successful in decreasing the number of fish remaining. This suggests that the sound will be most effective if areas, such as entry channels to locks are cleared regularly of debris. Sonar analysis is ongoing and will be correlated with the video that has been analyzed. This will allow us to assess the distribution of bighead carps also as they do not jump and therefore their behavior is not observable from the boat.

Two boats were used to herd fish towards nets placed across the tributary of the Missouri river. Sonar confirmed that fish were concentrated in front of the boats for long stretches of water however as fish neared the net, they reversed course and bisected the two boats where there was a gap in the sound field. It is hypothesized that an additional boat or speakers placed on booms on the existing boats would have created a more uniform sound field and drove the fish into the nets. Although the herding concept was proven successful, further refinement will be needed to increase capture.

Mensingher also spent a day with a commercial fisherman that was targeting carp. He observed how the fisherman optimizes catch by using sound and will attempt to incorporate this information in the next herding experiment.

Activity Status as of 7/15/2016

The field studies conducted in the Spoon River were analyzed and the results reported at the Aquatic Invasive Species and the Effects of Noise on Aquatic Animals conference.

We have learned that carp can be induced to jump by both boat movement and sound alone. The jumping patterns are very distinct at least in relation to the boat. During jumping in response to moving watercraft, almost all the fish jump after the boat has passed in very specific arcs defined by water movements associated with the water displacement. The behavior of wild silver carp responding to moving (16, 24, 32, and 40 km/hr) 6 m aluminum boats equipped with 4-stroke outboard motors (100 or 150 hp) was quantified. Experiments were conducted at three sites on the Illinois River near Havana, IL and most boat (57.9%) transits stimulated five or more fish to jump. The frequency of jumping (fish/min) was independent of speed and motor type and the vast majority of fish (> 90.0%) jumped after the boat had passed their position but avoided the area directly astern (< 4.0 m). Furthermore, 79.8% of fish vectored away from the moving watercraft. The results suggest that jumping direction is not random and fish can localize the stimulus source. The "delayed" jumping until after the boat had transited the area indicates that the trigger may be turbulence and/or higher sound pressure levels.

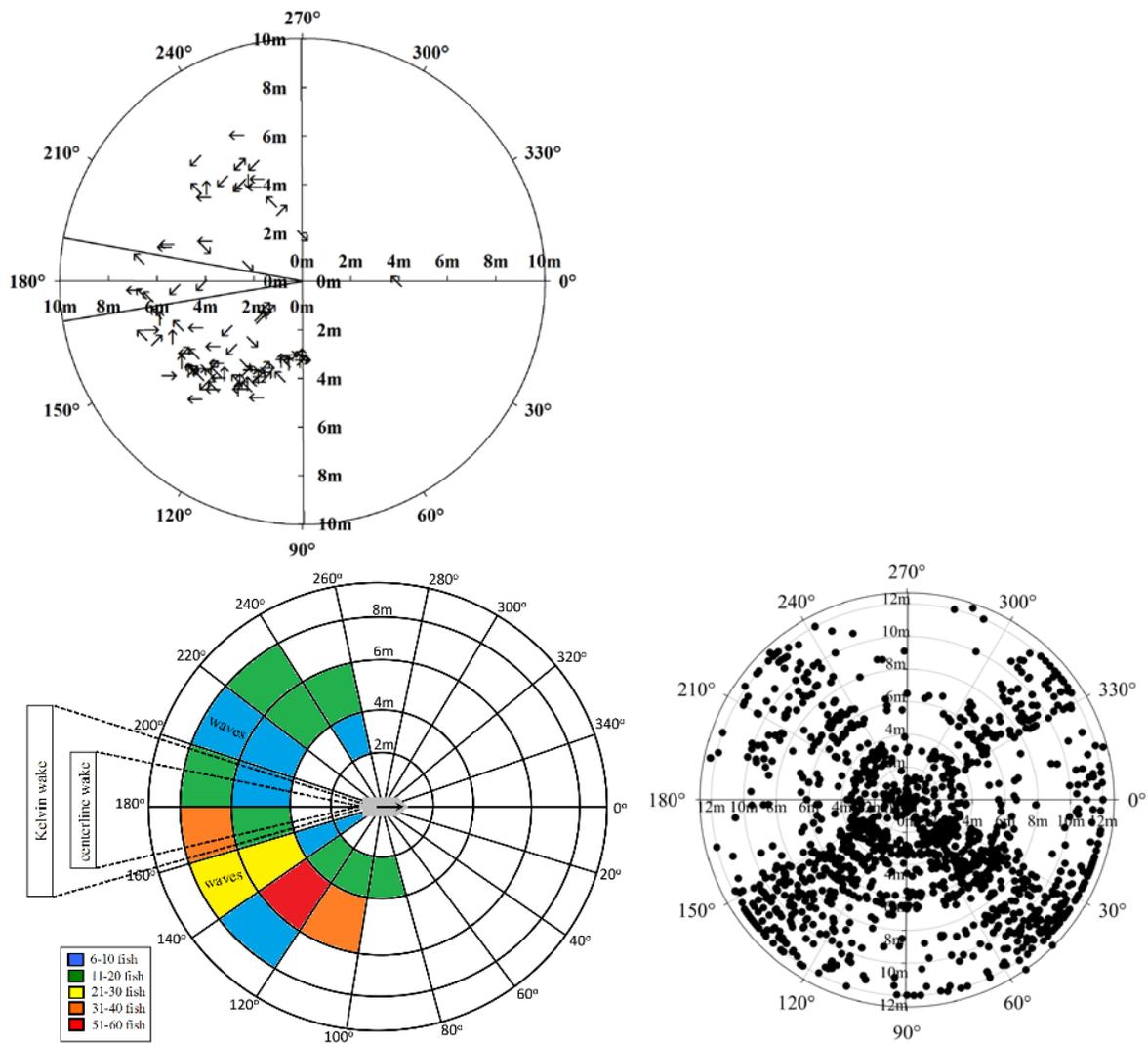


Figure 9. Jumping origin and vector in silver carp responding to fast moving boats (16 – 40 km/hr) equipped with a 100 or 150 hp. A) Arrows indicate individual carp jump origin and direction. B) Jumping number by quadrant. Jumping was not randomly distributed, with the majority of jumps occurring after the boat passed the fish and most jumps were away from the boat. C) Two speakers at front of boat were activated and polar plots show jumping origin and pattern. (Rao's $P < 0.05$).

We also demonstrated that sound alone in the absence of moving watercraft can cause carp to jump at much greater range. Additionally, the jumping pattern is strikingly different with fish jumping all around the boat compared to the fish jumping behind the boat in response to the moving watercraft. This indicates that static or boat mounted speakers can effectively cause carp to jump or perhaps herd them in the absence of boat movement. We are currently modeling the jumping to determine if we can predict the origin and end of the jumps in order to increase capture methods.

Activity Status as of 1/15/2017

Herding activities were conducted in conjunction with the USGS and the Illinois Natural History Survey in Havana IL in the Fall.

The first trials strung a net across the spoon River and herded the fish with two speakers submerged from motor boat. The sonar indicated high success in getting the fish to move in front of the boat and to the net. However,

many fish either jumped over the net or moved into the woody debris lining the river banks and moved upstream past the boat. The water levels were not optimal for this herding however, it was the first week that it they were low enough to even attempt the experiments. Lower water levels would reduce the amount of debris submerged and force more fish into the net. These was preliminary trials and we learned a great deal from the net deployment. We believe that the nets can be effective however we will change the area in which we drive fish to a straighter section of the river that contains much less woody debris. We also may place speakers in the woody debris to drive the fish out of these sections. The addition of the sonar units to the boats was extremely valuable and we are still analyzing the data to learn more about fish behavior and how to optimize the sound.

We also tried herding fish in a shallow bay by the Coal docks in Havana. We were extremely successfully in driving fish towards the net with several hundred fish observed to jump over the net however only a few were entangled. Several net modifications could solve this problem and there will be attempted next time. 1) a Double row of nets so after fish jump the first net, they land in the second; 2) a tilapia net that has an extension that floats on the water and prevents fish from jumping 3) raising the net above water so the fish land in the aerial portion of the net.

We also used this area to accurately sound map the sound field that is being generated by the boat. We found that the sound does project several hundred meters in front the boat and maintains high sound pressure levels for 50 to 100 m in front of the boat. This is encouraging as the water was reasonably shallow and this experiment gives further insight into the sound field and its effective range.

We spent the Fall months planning with the US Fish and Wildlife, the Illinois Department of Natural Resources and the USGS to conduct unified field methods the herd and capture carp in a large gravel pit in Morris Illinois. We have designed and contributed to the sound part of the experimental design and we will be following the fisherman as they drive the carp using their own methodology to hopefully increase the capture yields. This experiments will be conducted in March of 2017.

Activity Status as of 7/15/2017

A large scale, multi agency (US Fish and Wildlife, the Illinois Department of Natural Resources and the USGS) carp herding experiment was conducted over the course of five days in a large gravel pit in Morris Illinois. This was derivation of the unified method approach that is used in China to herd fish for capturing. Commercial fisherman set nets daily to herd the fish through designated channels. The commercial fisherman then moved their boats while banging on the hulls. This was followed by electrofishing boats and finally by sound boats playing the acoustic deterrent. Fish positioned was monitored by underwater sonar. On the final day, after the fish were herded into a small area, fish were netted and removed. This results of the study are still being processed and will be reported in future updates.

We contributed by providing equipment and personnel for the sound boats. We also recorded the sounds from the commercial fisherman boats to understand the difference in the sound that these boats generate and the sounds that we have identified being used for the acoustic deterrents. We are currently analyzing the sounds made by the fishing boats and will compare them to the sounds of the acoustic deterrents.

Activity Status as of 3/1/2018

We attended a meeting at the USGS in Columbia, MO to plan further strategies for carp herding and the Creve Couer Lake carp herding that was scheduled for February, 2018. We continue to try to optimize sound and deterrence. In cooperation with the USGS in Columbia, we have extend the trials of native species and found very few native species react to the sound that drive the carp away. The data concerning the native species is currently being prepared for submission to a journal.

Final Report Summary:

Broadband sound proved to be effective deterrent both in outdoor ponds and in small tributaries. Silver and bighead carp displayed consistent negative phonotaxis to the sound.

Trials in outdoor ponds:

This study found that complex broadband sound (0-10 kHz) is effective in altering the behavior of Silver Carp with implications for deterrent barriers or potential control measures (e.g., herding fish into nets). The phonotactic response of Silver Carp was investigated using controlled experiments in outdoor concrete ponds (10 x 4.9 x 1.2 m). Pure tones (500-2000 Hz) and complex sound (underwater field recordings of outboard motors) were broadcast using underwater speakers. Silver Carp always reacted to the complex sounds by exhibiting negative phonotaxis to the sound source and by alternating speaker location, Silver Carp could be directed consistently, up to 37 consecutive times, to opposite ends of the large outdoor pond. However, fish habituated quickly to pure tones, reacting to only approximately 5 % of these presentations and never showed more than two consecutive responses. Previous studies have demonstrated the success of sound barriers in preventing Silver Carp movement using pure tones and this research suggests that a complex sound stimulus would be an even more effective deterrent.

Recent studies have shown the potential of acoustic deterrents against invasive silver carp (*Hypophthalmichthys molitrix*). This study examined the phonotactic response of the bighead carp (*H. nobilis*) to pure tones (500-2000 Hz) and playbacks of broadband sound from an underwater recording of a 100 hp outboard motor (0.06-10 kHz) in an outdoor concrete pond (10 x 5 x 1.2 m) at the U.S. Geological Survey Upper Midwest Environmental Science Center in La Crosse, WI. The number of consecutive times the fish reacted to sound from alternating locations at each end of the pond was assessed. Bighead carp were relatively indifferent to the pure tones with median consecutive responses ranging from 0 to 2 reactions away from the sound source. However, fish consistently exhibited significantly ($P < 0.001$) greater negative phonotaxis to the broadband sound (outboard motor recording) with an overall median response of 20 consecutive reactions during the 10 min trials. In over 50% of broadband sound tests, carp were still reacting to the stimulus at the end of the trial, implying that fish were not habituating to the sound. This study suggests that broadband sound may be an effective deterrent to bighead carp and provides a basis for conducting studies with wild fish.

Field studies

Invasive silver carp (dominate large regions of the Mississippi River drainage, outcompete native species, and are notorious for their prolific and unusual jumping behavior. High densities of juvenile and adult (similar to 25 kg) carp are known to jump up to 3 m above the water surface in response to moving watercraft. Broadband sound recorded from an outboard motor (100 hp at 32 km/hr) can modulate their behavior in captivity; however, the response of wild silver carp to broadband sound has yet to be determined. In this experiment, broadband sound (0.06-10 kHz) elicited jumping behavior from silver carp in the Spoon River near Havana, IL independent of boat movement, indicating acoustic stimulus alone is sufficient to induce jumping. Furthermore, the number of jumping fish decreased with subsequent sound exposures. Understanding silver carp jumping is not only important from a behavioral standpoint, it is also critical to determine effective techniques for controlling this harmful species, such as herding fish into a net for removal.

Silver carp, an invasive planktivorous fish species in North America, pose a threat to aquatic ecosystems throughout the Mississippi River Drainage. These fish are well known for their airborne leaps in response to passing watercraft, but the trigger for, and functional significance of jumping remains unknown. The behavior of wild silver carp responding to moving (16, 24, 32, and 40 km/hr) 6 m aluminum boats equipped with 4-stroke outboard motors (100 or 150 hp) was quantified. Experiments were conducted at three sites on the Illinois River near Havana, IL and most boat transits (57.9%) stimulated five or more fish to jump. The frequency of jumping

(fish/min) was independent of speed and motor type and the vast majority of fish (> 90.0%) jumped after the boat had passed their position but avoided the area directly astern (< 4.0 m). Furthermore, 79.8% of fish vectored away from the moving watercraft. The results suggest that jumping direction is not random and fish can localize the stimulus source. The "delayed" jumping until after the boat had transited the area indicates that the trigger may be turbulence and/or higher sound pressure levels. This is the first study to model silver carp jumping in response to motorized watercraft and can aid fisheries managers in predicting the direction and location of airborne fish to develop effective herding and capture methods.

ACTIVITY 3: Carp deterrence

Description: One of the key strategies for integrated invasive species management is to deter fish from entering areas in which they have been eliminated or from invading new areas. Permanent barriers are expensive to maintain and interfere with commercial ship traffic and native fish movement. The aversion of carp to complex sounds has the potential to provide an environmentally friendly barrier that will not impact ship or native fish movement. We have determined that pure tones (same sound frequency) that normally are used for fish behavior and/or deterrent barriers is ineffective in deterring carp movement, however silver carp will readily swim away from complex sounds (playbacks of outboard motor noise). These preliminary experiments indicate that sound either alone or as part of a combined light and bubble barrier, may provide a cost effective and environmentally friendly barrier to silver or bighead carp migration or repel them from breeding areas.

Carp have specific tank locations either associated with three dimensional structures, sunlight or feeding location at which they prefer to reside. The first series of experiments in outdoor concrete tanks will identify the tank locations and use underwater speakers to deter the carp from these locations. Sound intensity, frequency, duration will be varied and the length of time that fish stay away from the location will be monitored to gain an understanding of how effective sound is as a deterrent.

We will then divide the tank into two sections with an expandable barrier/divider that will allow us to regulate the opening between the two sections of the tank. Three dimensional structures (i. e. milk crates) will be placed in one half, shade cloth erected over the same area to minimize light levels and all feeding will transpire in this section which will make this portion the "preferred" section for the carp to inhabit. We will then use sound from the underwater speakers submerged in the tank to drive the fish from the preferred section to the other half of the tank. Additional speakers will be positioned near the opening in the barrier to repel fish that attempt to return to the preferred half. The width of the barrier opening will be gradually expanded to determine how effective sound can be in larger passageways.

The same experiments will be performed in the large ½ acre pond described for previous activities. Again, a preferred location will be established and then sound used to displace the carp out of this area. Additional speakers will be placed at the barrier openings and use to repel fish that try to return to the original location. The opening in the barrier will be gradually expanded to determine the effective width of the deterrent system.

Field trials will be conducted in a large sand pit (5 mile length) that parallels the Illinois River or appropriate alternative open water site. Carp will be herded or netted to the narrow end of the sand pit and a barrier placed across the pit. An opening will be made in the barrier and underwater speakers placed to at the opening to enable use to use sound to deter the carp from leaving the terminal end of the sand pit and migrating back into the main channel. The barrier opening will be gradually widened to determine the effectiveness of the underwater sound in deterring carp from entering large channels.

Summary Budget Information for Activity 3:

ENRTF Budget: \$ 80,583
Amount Spent: \$ 79,121
Balance: \$ 1,462

Activity Completion Date: 6/30/2017

Outcome	Completion Date	Budget
1. Outdoor tank deterrent trials	12/31/14	\$ 27,083
2. Outdoor pond deterrent trials	12/31/15	\$ 26,000
3. Sandpit/ open water trials	12/31/16	\$ 27,500

Activity Status as of 1/15/2015

Preliminary outdoor tank trials were conducted with silver or bighead carp at the USGS facility. The tank was divided in half with cinder blocks with an approximately 1 meter opening left in the middle of the barrier to allow egress into half of the tank. Two speakers were placed in each half of the tank and when fish approached the barrier opening, complex sound was initiated to prevent fish crossing the opening.

Trials were delayed until late summer and early Fall due to funding and weather conditions. Behavior appeared temperature dependent as during low temperatures, carp were not affected by the sound. However, during warmer conditions, sound was very effective at preventing crossing during the initial experiment and reduced the number of crossing in subsequent experiments. The trials were initiated using smaller speakers than the ones that had the greatest success in the field and it is anticipated using the larger speakers would be more effective. This is the first controlled trial to indicate that water temperature may be needed to be factored when trying to move or displace fish.

Activity Status as of 7/15/2015

The experiments evaluated the effectiveness of an acoustic barrier to prevent the movement of the invasive silver (*Hypophthalmichthys molitrix*) and bighead (*H. noblis*) carp. Controlled experiments were conducted in outdoor ponds (10 x 5 x 2 m) that were divided into equal halves by a concrete-block barrier (0.4 x 2 x 2 m) with a small channel (1 m across) allowing access to each side of the pond. Underwater speaker pairs were placed on each side of the opening and underwater outboard motor noise (1 to 10 KHz) was used to repel carp that approached to within 1 m of the channel. The complex sound was effective in stopping schools of silver and bighead carp and a combined school of each species. Repulsion rates were 81.6%, 94.4% and 90.5% for silver carp, bighead carp, and mixed species respectively. This study demonstrates that complex sound is effective in deterring fish movement and could be used to deter carp from entering strategic waterways.

The fish swam slowly through the pond in loose schools and transited readily from the north and south end in the absence of sound (Fig. 8) crossing the barrier approximately every three to five minutes. However, when confronted with sound after entering the reaction zone, the majority of fish turned away and did not cross the barrier (Fig. 8).

Silver carp averaged significantly (Kruskal-Wallis, $P = 0.002$) fewer attempted crossings per minute during each of the five periods compared to bighead carp or the mixed schools (0.30; 0.20, 0.42). However, there was no significant difference for attempted crossings per minute during the five intervals within any of three groups (Kruskal-Wallis: silver, $P=0.66$; bighead, $P= 0.62$; mixed, $P= 0.11$).

Sound playbacks significantly decreased the number of successful crossings for each group. Figure 9 shows the number of successful crossings per minute during the control (non sound) and sound intervals. All groups showed a significant decrease in the number of successful crossing attempts when challenged with sound (Mann-Whitney, $P<0.001$). For silver carp, successful crossings decreased significantly (Mann-Whitney, $P< 0.001$). Bighead carp also showed a significant decline (Mann-Whitney, $P< 0.001$). The mixed schools also were significantly inhibited from crossing (Mann-Whitney, $P< 0.001$).

Sound playbacks were successful in stopping fish transiting through the barrier in all three groups with 81.6%, 94.4% and 90.5% repulsion rates for silver carp, bighead carp, and mixed species, respectively. The first

trials were the most successful with sound stopping the silver carp during all 13 attempts during the first sound period for the three groups. Success rates dropped slightly during subsequent trials before rebounding to 91% during trial 5. Bighead carp were less likely to cross the sound barrier with five of the six trials achieving 100% repulsion with 85 out of a total of 90 attempts repulsed. The mixed school also displayed sound avoidance behavior with high (> 90%) repulsion rates observed until the last trial.

The fishes reacted relatively quickly to the sound onset. During successful repels, silver carp exited the reaction zone in a median time of 5.0 sec (3.0, 11.3) while bighead and mixed schools were significantly faster (Mann Whitney $P < 0.001$) with the same median times of 3.0 (2.0, 4.0) sec with less variability.

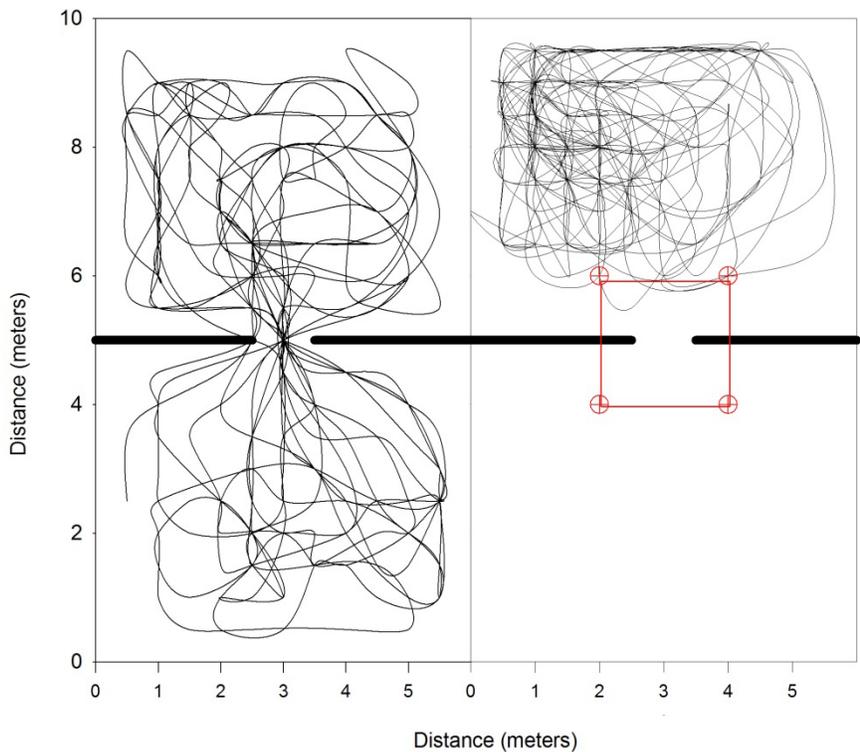


Figure 10. The effect of complex sound on fish movement. The position of a mixed school of bighead and silver carp is plotted in the horizontal axis while inside a partitioned concrete tank. Fish position was recorded every 5 seconds. During the control period (left), speakers were inactive and fish swam throughout the tank. During the experimental trials (right), complex sound was broadcast every time the fish entered the reaction zone (red box).

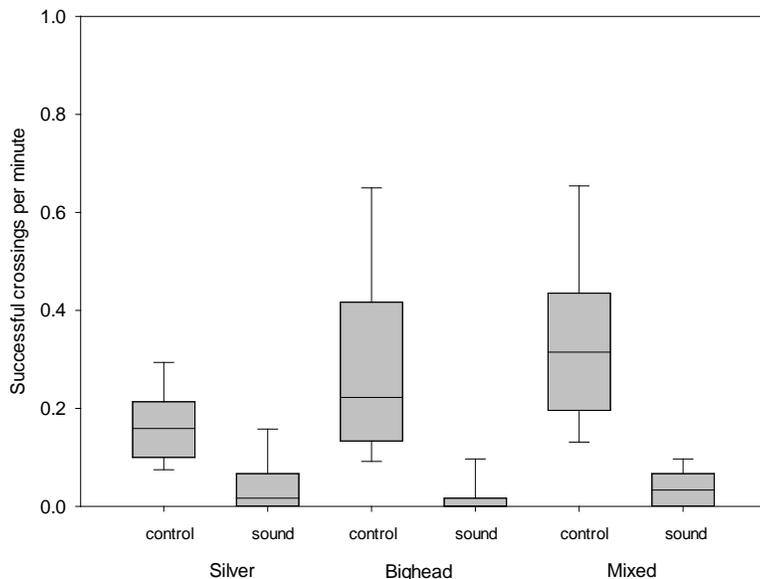


Figure 11. The average number of crossing per minute is plotted during control (no sound) and sound trials for silver, bighead and mixed schools.

Field trials were initiated in Morris Illinois this summer. Both silver and bighead carp were tagged and placed in a partitioned sand pit. A small channel was made with nets in the middle of the waterway and six speakers were suspended from floats. Complex sound was broadcast continually from the speakers and the tagged carp placed on either side of the channel. Controls consisted of an additional group of tagged fish placed under the same conditions with the speakers turned off. Three sets of both experimental and control fish were tested. The fish movements were monitored for 48 hrs. The fish tracking movements are still being processed however preliminary indications suggest that fewer fish remained in the area when the speakers were active.

Activity Status as of 1/15/2016

The field trials were further analyzed from Morris Illinois. There were several reasons why experiment was not conducted under optimal settings. Previous trials investigating water guns observed fish almost immediately escaping the enclosure. Therefore, fish were tagged and immediately subjected to the sound instead of being acclimated for two days. Additionally, the sound field was increased to cover the far reaches of the enclosure and this resulted in very high sound pressure fields throughout the enclosure and few “quiet” areas for the fish to escape the noise. Despite these issues, the trials showed promise with preliminary analysis indicating fewer fish crossing the barrier and movement limited when the sound was broadcast. The fish appeared to find the quietest area of the enclosure and remain there throughout the experiment. Control studies showed the fish more evenly distributed and crossed the inactive barrier more often. Preliminary results also indicated that fish crossing during sound was in different areas than during non sound events with subsequent sound mapping suggesting that the few fish that crossed the barrier were exploiting low sound pressure areas. It is hypothesized that a more uniform sound field will increase success rates. We are currently designing our speaker array to provide a more uniform field.

We are incorporating the information learned from the field trial in Morris to scale up to larger ponds in LaCrosse. We are expanding into 1/10 and ½ acres ponds and attempting to create “lock and dam” like structures to understand how the sound works with hard substrates and if the sound is as effective in the large ponds as it is in the smaller ones. We will also be testing the sound habituation. Additionally, the Morris field site may not be available this in the summer of 2016 and we are working with the USGS to test other open water sites such as Starved Rock Lock and Dam or Brandon Roads Lock and Dam on the Illinois River

Activity Status as of 7/15/2016



Figure 12: Closeup of barrier in 1/2 acre pond showing channel with speakers

We have set up 3 1/10 acre and 1 1/2 acre pond at the USGS center in LaCrosse, WI. Both silver and bighead carp are tagged and placed in the ponds. There is a hydroacoustic array to determine the position of the fish. The ponds are divided into two sections with a channel equipped with speakers connecting the two halves. Sound is played via the speakers and the behavior and the position of the carp is monitored. Sound is played throughout the 24 hr periods. We are conducting long duration trials to determine if the fish habituate to the sound and varying the sound pressure levels to determine what is the most effective stimulus. Trials will continue throughout the fall until weather conditions force pond closure. Sound mapping has been completed and we are currently putting together the sound map

The initial trials in the 1/10 acre ponds have just been completed and we are currently analyzing the data. In the first pond, there were many crossing when the sound was off but very limited number of crossing when the sound was on. Preliminary data is shown for trials through day 4 that were observed with video camera. All the trials will be analyzed with positional tag information however the figure shows the preliminary results from the cameras. Two ponds were analyzed through day 4. There were 40 crossing when sound was off and only 4 crossing (all during the same trial) when sound was on. The sound appears to be effective at preventing crossings at least during the daylight hours and fish are not habituating to the sound.

Sound mapping is starting in the 1/2 acre ponds with trials set to start in early August. The speakers will project different pressure levels than in the 1/10 acre ponds and habituation trials are set to run for longer periods of time. Both silver and bighead behavior will be monitored in response to difference frequencies, durations and intensities

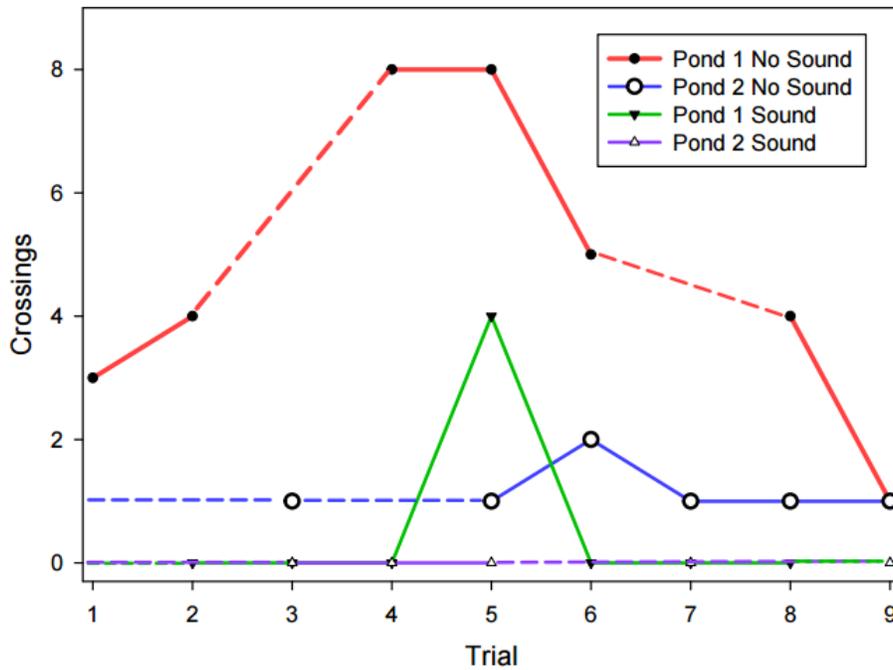


Figure 13. Preliminary data from the 1/10 acre ponds. Trials were conducted over 4 days. Only during one trial did carp cross when sound was on.



Figure 14. Barrier at Emiquon preserve

We have also been invited at no additional cost to the project, to consult with using sound at a barrier connecting the Emiquon reserve with the Illinois River. The Nature Conservancy would like to determine if sound can repel carp from entering from the river into the reserve when the water is flowing out. The Conservancy has purchased their own equipment and Mensinger is providing consultation. The site is just a few miles away from the Spoon River where the fall field studies will be conducted. The Conservancy hosted Mensinger for a site visit and he has designed an experiment where speakers will be placed in the structure shown in Figure 13 to assess whether they are effective in preventing carp egress. The structure contains two parallel channels and sound will be played in one channel with the other acting as a control.

The equipment has been purchased this summer and will be installed with Mensinger serving as a consultant in August. Water flow in and out of the reserve is dependent on river levels so the earliest tests will be Fall of 2016 or spring of 2017

Activity Status as of 1/15/2017

Three 1/10 acre ponds were equipped with barriers with a small channel connecting the two halves. Underwater speakers were set close to each barrier. The acoustically deterrent was cycled on and off similar to a lock/dam opening closure schedule of 30 min on (open) 90 min off (closed). All fish were fitted with acoustical tags. Preliminary results use underwater video cameras showed clear repulsion of the carp during the first 24 hrs. The acoustic tags had issues with battery life and many of them failed during the experiment. The USGS is currently analyzing the data to determine if any additional information can be obtained from the tags.

The barrier at the Emiquon became fully operational this fall. Speakers have been installed in both raceways and preliminary studies showed them to be operational. Water was released from the Emiquon into the Illinois River and sound was played during this time to deter fish from the river swimming into the Emiquon. Additional work will be needed to deploy the proper sonar (USGS) in the area to more accurately count the fish however few in any silver or bighead carp were positively identified in the area during the sound playback. Additional trials are planned in 2017 when water again is released from the Emiquon.

Activity Status as of 7/15/2017

In conjunction with the USGS, we initiated several month long trials on their LaCrosse campus. The 2016 trials were compromised by battery issues with the tags so the trials were repeated.

Three 1/10 acre ponds were equipped with barriers with a small channel connecting the two halves. Underwater speakers were set close to each barrier. The acoustically deterrent was cycled on and off similar to a lock/dam opening closure schedule of 30 min on (open) 90 min off (closed). All fish were fitted with acoustical tags. The preliminary results showed that fish were dispersed to areas away from the sound. Data analysis of exact fish position is currently being performed by the USGS.

We also attempted to determine the effect of sound exposure on fish reaction to the acoustic deterrent. We exposed fish to either 30 mins or 24 hours of sound and repeated the "ping-pong" experiments where we tried to move both control fish and experimental back and forth across the tank using sound. While the first weeks of experiments indicated that the sound exposed fish were less responsive, the results were compromised by lack of fish movement in both the controls and the experimental fish during the rest of summer. This was surprising as most of the time the fish would continuously school in the tank and change behavior when confronted with sound. It is hypothesized that as the control fish did not show steady swimming, they were sick and therefore we were unable to show a difference between experimental and control fish.

However, to optimize the acoustic deterrents, we initiated an experiment using Auditory Evoked Potentials that determined the hearing range of the silver and bigheaded carp. We found that the fish can detect higher frequencies than previously reported and we will be adjusting our acoustic deterrent to maximize the power in these frequencies to optimize the acoustic deterrent.

Activity Status as of 3/01/2018

We have continued to use Auditory Evoked Potentials to understand carp hearing abilities and optimize sound for deterrents in partnership with the USGS. These experiments have been performed at no additional cost of the grant however will allow us to better optimize sound deterrents.

The Auditory Evoked Pontentail or AEP is an external, minimally invasive method to measure hearing. Electrodes are inserted on the fish’s head and the gross electrical potential of the inner ear and brain is measured in response to sound. This is somewhat analogous to the EKG that monitors electrical activity of the heart. We have used AEPs to determine the sensitivity of the carp auditory system to sound as well as examine the effect of sound exposure on hearing threshold.

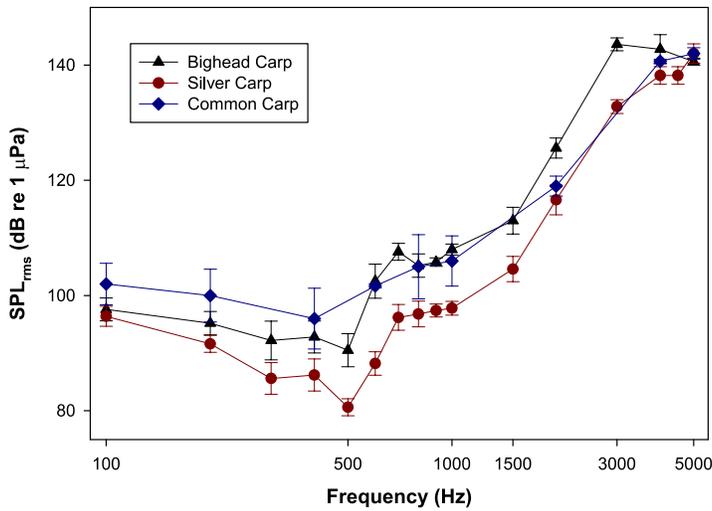


Figure 14

Figure 14 shows the hearing sensitivity of bigheaded carp. Previous work had indicated that hearing threshold only extended to 3 kHz however the AEP show that the hearing range extends to at least 5Khz. This has allowed us to modify our deterrent to produce greater energies in over a small frequency range.

We also investigated the effects of prolonged sound exposure on the bigheaded carp. There needs to be a balance between the intensity and duration that causes repulsion but not hearing loss. Reductions in hearing sensitivity will make the acoustic deterrents less effective. Figure 15 shows that even 30 minutes of sound exposure reduces hearing sensitivity in the carp while 24 hr exposure causes prolonged hearing loss. As this deterrents may work best at a Lock and Dam structure, we are examining the opening and closing of the lock chambers to outline a plan of sound duration that will optimize deterrence while minimizing hearing damage.

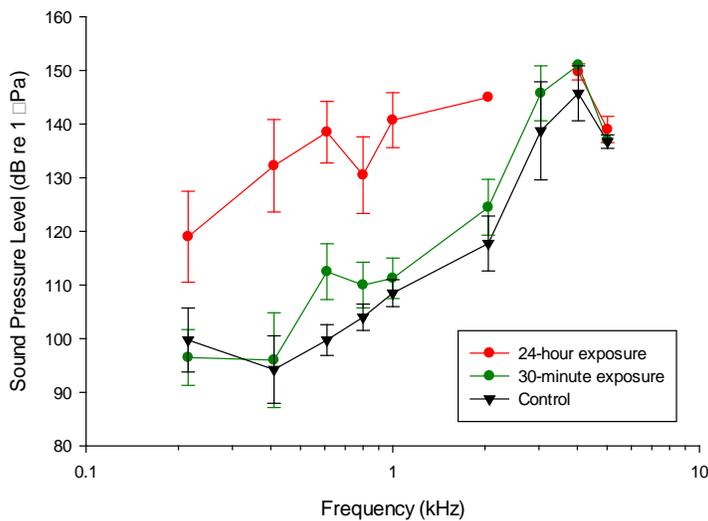


Figure 15

Final Report Summary: Broadband sound was effective in deterring carp from entering a small channel in a concrete pond. Additional experiments characterized the hearing frequency of the bigheaded carp to allow future acoustic deterrents to be optimized against the fish. Preliminary studies show the effect of extended sound exposure on hearing thresholds and indicated that the intensity of sound needs to be balanced against potential hearing damage.

Acoustic barrier:

The effectiveness of an acoustic barrier to deter the movement of silver carp and bighead carp, was evaluated. A pond (10mx5mx1.2m) was divided in half by a concrete-block barrier with a channel (1m across) allowing fish access to each side. Underwater speakers were placed on each side of the barrier opening, and an outboard motor noise (broadband sound; 0.06-10kHz) was broadcast to repel carp that approached within 1m of the channel. Broadband sound was effective at reducing the number of successful crossings in schools of silver carp, bighead carp and a combined school. Repulsion rates were 82.5% (silver carp), 93.7% (bighead carp) and 90.5% (combined). This study demonstrates that broadband sound is effective in deterring carp and could be used as a deterrent in an integrated pest management system.

Bigheaded carp hearing:

Controlling bigheaded carp is a priority of fisheries managers and one area of focus involves developing acoustic deterrents to prevent upstream migration. For an acoustic deterrent to be effective however, the hearing ability of bigheaded carp must be characterized. A previous study showed that bigheaded carp detected sound up to 3 kHz but this range is narrower than what has been reported for other ostariophysans. Therefore, silver and bighead carp frequency detection was evaluated in response to 100 Hz to 9 kHz using auditory evoked potentials (AEPs). AEPs were recorded from 100 Hz to 5 kHz. The lowest thresholds were at 500 Hz for both species (silver carp threshold: 80.6 +/- 3.29 dB re 1 mu Pa SPL_{rms}, bighead carp threshold: 90.5 +/- 5.75 dB re 1 mu Pa SPL_{rms}; mean +/- SD). These results provide fisheries managers with better insight on effective acoustic stimuli for deterrent systems, however, to fully determine bigheaded carp hearing abilities, these results need to be compared with behavioral assessments.

V. DISSEMINATION:

Description: All results of the study will be published in peer reviewed publications. Mensinger and the graduate student will present the results at the appropriate state, regional and national meetings. Mensinger will develop a web page that will contain information, pictures and video of the experiments and results to provide wide dissemination. The USGS will also place information and material about the project on their web site. Mensinger also will be available to consult (at no charge) for the appropriate end users of this technology such as local, state and federal agencies including the MN DNR for the duration of the grant. Mensinger will develop a web page that will have video of carp jumping behavior and the sound deterrent experiments. The web page will also provide updates on the progress of the experiments and incorporate appropriate tables and graphs.

Status as of 1/15/2015

A manuscript is currently under review in the journal *Biological Invasions* entitled "Acoustical Deterrence of Silver Carp (*Hypophthalmichthys molitrix*)"

An oral presentation was delivered by Brooke Vetter at the American Fisheries Society meeting in Quebec in August describing acoustic control of carp movement.

Status as of 7/15/2015

A manuscript currently under review in the journal *Biological Invasions* entitled "Acoustical Deterrence of Silver Carp (*Hypophthalmichthys molitrix*)" has received provisional acceptance

A manuscript tentatively entitled "Bioacoustic deterrence of silver and bighead carp" is currently undergoing internal review at USGS with plans for a Fall 2015 submission to a peer reviewed journal

Status as of 1/15/2016

The following manuscript has been published. This was before LCCMR support however it provided the basis for subsequent LCCMR funded experiments:

Acoustical deterrence of Silver Carp (*Hypophthalmichthys molitrix*) Vetter, Brooke J.; Cupp, Aaron R.; Fredricks, Kim T.; Gaikowski, Mark; Mensinger, Allen F. (2015) *BIOLOGICAL INVASIONS* 17:3383-3392

The following manuscript "The effect of broadband sound on the movement of bighead carp (*Hypophthalmichthys nobilis*)" has been submitted, reviewed and is currently under revision for the Journal *PLOS ONE*

The manuscript entitled "Potential implications of acoustic stimuli as a non-physical barrier to silver (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis*)" by Murchy, Kelsie; Cupp, Aaron; Amberg, Jon; Vetter, Brooke; Fredricks, Kim; Gaikowski, Mark; Mensinger, Allen, has been successfully submitted and is presently being given full consideration for publication in *Fisheries Management and Ecology*.

Allen Mensinger gave an oral presentation, "Grounding the flying carp: Applied neuroethology" and the Society of Integrative and Comparative Biology in Portland Oregon. December 2015

Graduate student Brooke Vetter gave an oral presentation, "Silver Carp *Hypophthalmichthys molitrix* behavior and bioacoustics" and graduate student Kelsie Murchy gave an oral presentation "The effect of temperature on acoustical deterrence of bighead *Hypophthalmichthys nobilis* and Silver Carp *H. molitrix*" at the Midwest Fish and Wildlife Conference in Grand Rapids, MI January 2016.

Status as of 7/15/2016

The following talks were presented at the Invasive Aquatic Species conference

Bigheaded Carp Behavior and Bioacoustics: Brooke J. Vetter, University of Minnesota Duluth

The Effect of Temperature on Acoustical Deterrence of Bighead (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*): Kelsie A. Murchy, University of Minnesota Duluth

In situ Observations of Silver Carp Behavior when Presented with Broadband Sound: Allen F. Mensinger, University of Minnesota Duluth

The following talks were presented at the Effects of Noise on Aquatic Life conference

Effect of Outboard Motor Sound on Invasive Silver Carp (*Hypophthalmichthys molitrix*) Jumping Behavior:

Brooke J. Vetter

Effects of Anthropogenic Sound on Native and Invasive Fish Behavior in the Upper Mississippi River: Kelsie A. Murchy

The Mensinger lab presented on the results of the project to date at the Sound Deterrent workshop hosted by the USGS in LaCrosse, WI.

The manuscript entitled "Potential implications of acoustic stimuli as a non-physical barrier to silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis*)" by Murchy, Kelsie; Cupp, Aaron; Amberg, Jon; Vetter, Brooke; Fredricks, Kim; Gaikowski, Mark; Mensinger, Allen, is under review in *Fisheries Management and Ecology*.

The manuscript "The effect of broadband sound on the movement of bighead carp (*Hypophthalmichthys nobilis*)" is currently under review at the *Journal of Great Lakes Research*

Status as of 1/15/2017

The results of our study were broadly disseminated with talks at national and international meetings. The Minnesota Environmental Trust Fund was acknowledged in each paper and presentation. Five full publications including one in press and a published abstract were published during this time period. Presentations were made at the Effect of Noise on Aquatic Life Conference and the Society of Integrative and Comparative Biology. Many of the figure and graphs had been already included in previous reports.

Mensinger, A. F. (2016). Grounding the flying carp: Applied neuroethology. *Integrative and Comparative Biology* 56, E147-E147.

Vetter, B.J., Caspar, A.F. and Mensinger, A.F. (2017). Characterization and management implications of silver carp (*Hypophthalmichthys molitrix*) jumping behavior in response to motorized watercraft *Management of Biological Invasions* 8:113-124.

Vetter, B., Murchy, K., Cupp, A., Amberg, J., Gaikowski, M. and Mensinger, A. (2017a). Acoustic deterrence of bighead carp (*Hypophthalmichthys nobilis*) to a broadband sound stimulus. *Journal of Great Lakes Research* 43.

Murchy, K.A., Cupp, A. R., Amberg, J.J., Vetter, B.J., Fredricks, K.T. Gaikowski, M.P. and Mensinger, A. F. Potential implications of acoustic stimuli as a non-physical barrier to silver carp and bighead carp (2017) *Fisheries Management and Ecology*. In press

Vetter, B.J. and Mensinger A.F. (2016). Broadband sound can induce jumping behavior in invasive silver carp (*Hypophthalmichthys molitrix*) *Proceedings of Meetings on Acoustics* 27, 010021 (2016); <http://doi.org/10.1121/2.0000279>

Murchy, K.A., Cupp, A. R., Amberg, J.J., Vetter, B.J., Fredricks, K.T. Gaikowski, M.P. and Mensinger, A. F. (2017). Not all carp are created equal: Impacts of broadband sound on common carp swimming behavior *Proceedings of Meetings on Acoustics* 27, 010032 (2016); <http://doi.org/10.1121/2.0000314>

Status as of 7/15/2017

Vetter, Brooke J.; Calfee, Robin D.; Mensinger, Allen F. (2017) Management implications of broadband sound in modulating wild silver carp (*Hypophthalmichthys molitrix*) behavior. *MANAGEMENT OF BIOLOGICAL INVASIONS* Volume: 8 Issue: 3 Special Issue: SI Pages: 371-376 Published: SEP 2017

Status as of 3/1/2018

The carp hearing work was presented at the MN AFS meeting in February by graduate student Andy Nissen.

Dr. Brooke Vetter (former graduate student in the lab) presented her carp work at the Society for Integrative Biology meeting in San Francisco in January.

Dr. Vetter also submitted a paper entitled “Reexamining the frequency range of hearing in silver (*Hypophthalmichthys molitrix*) and bighead (*H. nobilis*) carp” that is currently undergoing its second revision.

Allen Mensinger attended the Carp Workshop in Bloomington, MN in the fall and summarized the acoustic studies.

Final Report Summary:

Current (7/18) list of publications pertinent to the study

Murchy, K. A., Cupp, A. R., Amberg, J. J., Vetter, B. J., Fredricks, K. T., Gaikowski, M. P. and Mensinger, A. F. (2017). Potential implications of acoustic stimuli as a non-physical barrier to silver carp and bighead carp. *Fisheries Management and Ecology* **24**, 208-216.

Vetter, B., Murchy, K., Cupp, A., Amberg, J., Gaikowski, M. and Mensinger, A. (2017b). Acoustic deterrence of bighead carp (*Hypophthalmichthys nobilis*) to a broadband sound stimulus. *Journal of Great Lakes Research* **43**.

Vetter, B. J., Brey, M. K. and Mensinger, A. F. (2018). Reexamining the frequency range of hearing in silver (*Hypophthalmichthys molitrix*) and bighead (*H. nobilis*) carp. *Plos One* **13**.

Vetter, B. J., Calfee, R. D. and Mensinger, A. F. (2017c). Management implications of broadband sound in modulating wild silver carp (*Hypophthalmichthys molitrix*) behavior. *Management of Biological Invasions* **8**, 371-376.

Vetter, B. J., Casper, A. F. and Mensinger, A. F. (2017d). Characterization and management implications of silver carp (*Hypophthalmichthys molitrix*) jumping behavior in response to motorized watercraft. *Management of Biological Invasions* **8**, 113-124.

Vetter, B. J., Murchy, K. A., Cupp, A. R., Amberg, J. J., Gaikowski, M. P. and Mensinger, A. F. (2017e). Acoustic deterrence of bighead carp (*Hypophthalmichthys nobilis*) to a broadband sound stimulus. *Journal of Great Lakes Research* **43**, 163-171.

Vetter, B. J., Cupp, A. R., Fredricks, K. T., Gaikowski, M. P. and Mensinger, A. F. (2015). Acoustical deterrence of Silver Carp (*Hypophthalmichthys molitrix*). *Biological Invasions* **17**, 3383-3392.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	\$ Amount	Explanation
Personnel:	\$ 195,400	Salary is budgeted for the Principal investigator (0.55 FTE total for three years) , two graduate students (3.25 FTE total for three years) and two undergraduate students (0.49 FTE total for three years) for the project

Equipment/Tools/Supplies:	\$34,500	Funds are budgeted to build the early warning system and the sound arrays for carp movement and deterrence
Other: Travel to LaCrosse WI and Havana, IL	\$32,100	Out of state travel is necessary to combat the invasive carp before they become established in MN. The outdoor tank and pond studies will take place in LaCrosse, WI and the field trials will take place in Havana, IL. Rates are based on University of MN travel plan rates
TOTAL ENRTF BUDGET:	\$262,000	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than \$5,000: N/A

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:
4.29

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

B. Other Funds:

Source of Funds	\$ Amount Proposed	\$ Amount Spent	Use of Other Funds
Non-state			
Integrated Biological Sciences graduate program (cash)	\$ 9,516	\$9,516	The Integrated Biological Sciences graduate program will provide summer salary match for the graduate student budgeted in the project (pending)
UMD (cash)	8,400	4,500	Undergraduate research opportunities grants from UMD to further support undergraduate research in this proposal (pending)
UMD (cash)	5,500	5,500	Pilot grants were obtained from UMD to support preliminary data collection
Mensinger Salary (In-kind)	79,324	79,324	Two months of academic year salary will be provided as in kind support for the proposal (secured)
USGS (In-kind)	10,000	10,000	Access to silver and big head carp, outdoor tank and pond use (secured)
INHS (In-kind)	9,000	9,000	Boats and personnel for field studies on the Spoon River
TOTAL OTHER FUNDS:	\$126,650	\$114,340	

VII. PROJECT STRATEGY:

A. Project Partners:

1) Professor Allen Mensinger of the University of Minnesota Duluth will supervise all aspects of the project. He and UMD will receive \$253,000 from the appropriation

2) Mark Gaikowski, USGS, Lacrosse Wisconsin. The PI will work closely with Mark Gaikowski throughout the project. The USGS is providing the outdoor tanks and ponds, fish and support personnel at no cost to the grant. Mensinger and Gaikowski will develop the experimental protocols, train the students, analyze the data and be responsible for dissemination of the work. Mr. Gaikowski will not receive any funds from the appropriation.

3) Illinois Natural History Survey. The INHS will provide boats and personnel for the field trials planned in Havana, IL. This assistance has been changed to an in-kind contribution.

B. Project Impact and Long-term Strategy:

Since their introduction in the southeastern US, silver and bighead head carp have migrated north into the upper Mississippi Valley and pose severe ecological consequences to native Minnesota fish. Currently, the only barriers to carp are large dams or expensive electrical barriers. Based on the carp’s avoidance or jumping to boat motors, we propose to use bioacoustics to 1) develop early warning systems 2) herd carp for capture and 3) develop acoustical deterrents. As the sound stimulus is well above the hearing threshold of most native fish, it is unlikely to harm the native population. Bioacoustical deterrence is inexpensive, environmentally friendly and portable and can be used both in small streams and larger lakes.

The strategy is to develop bioacoustic early warning and deterrent systems and perform controlled tests in outdoor tanks and ponds to develop the optimal sound intensities and frequencies for carp management. The equipment will be then field tested on wild carp population in the Illinois River. The technology will be made available to interested management agencies as part of an integrated pest management strategy for controlling carp.

C. Spending History: M.L. 2010 Chp. 362, Sec. 2, Subd 6d. – Bioacoustic traps for Management of Round Goby. This project was related to sound work on invasive species and much of the hardware will be used for the carp study.

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14
LCCMR			175,000		

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. VISUAL ELEMENT or MAP(S):

Bioacoustics to detect, deter and eliminate flying carp



1) Sound makes carp jump

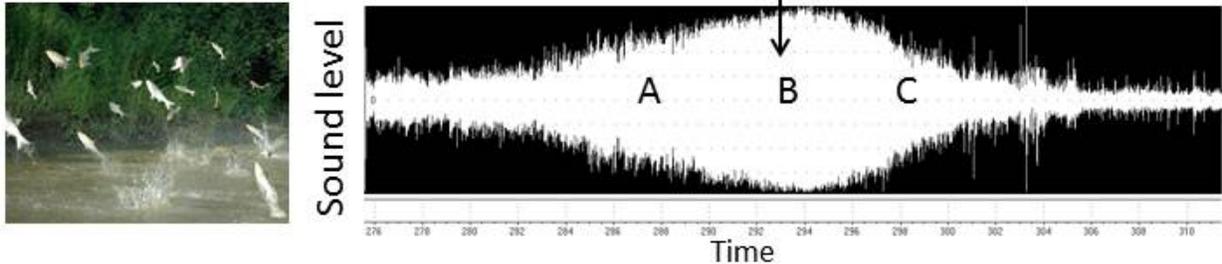


Figure 1. Field recording of underwater outboard motor noise motor boat noise that stimulated carp to jump in the Illinois River as boat passed by designated recording area. Arrow indicates when boat was in center of area. A) initiation of jumping; B) peak jumping; C) cessation of jumping.

2) Different sounds and boat speeds will effect carp jumping

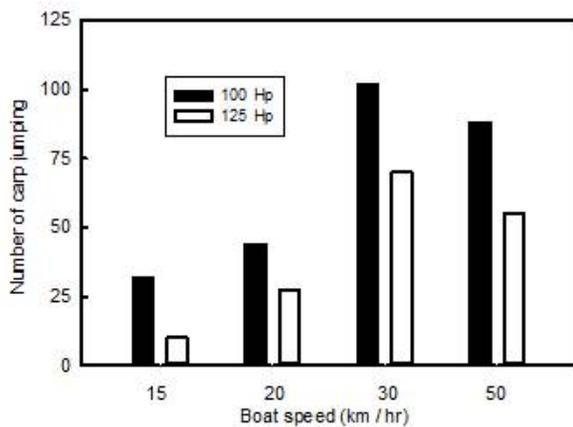


Figure 2. Number of carp jumping vs boat speed (km / hr) and engine size (hp).

3) Sound will repel carp

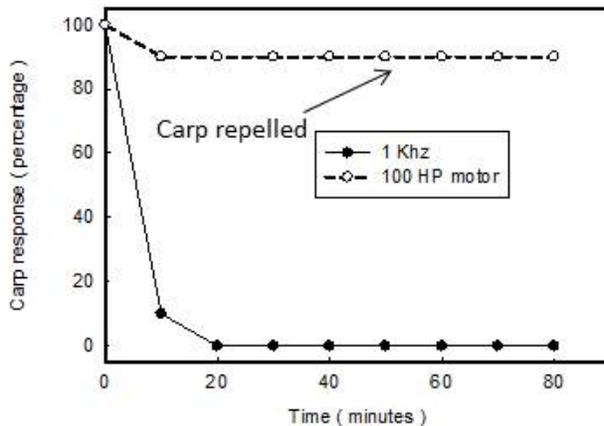


Figure 3. Percentage of carp (N=10) repelled by a 1 KHz pure tone sound and 100 hp outboard motor sounds versus time (min).

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A

XI. RESEARCH ADDENDUM: N/A

XII. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 15, 2015; July 15, 2015; January 15, 2016; July 15, 2016; and January, 15 2017. A final report and associated products will be submitted between June 30 and August 15, 2018.



Environment and Natural Resources Trust Fund											
M.L. 2014 Project Budget											
Project Title: Bioacoustics to detect, deter and eliminate flying carp											
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 04b											
Project Manager: Allen F. Mensinger											
Organization: University of Minnesota Duluth											
M.L. 2014 ENRTF Appropriation: \$ 262,000											
Project Length and Completion Date: 4 Years, June 30, 2018											
Date of Report: 8/20/2018											

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget revised	Amount Spent	Activity 1 Balance	Budget revised 2-10-	Amount Spent	Activity 2 Balance	Budget revised	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	<i>Early warning</i>			<i>Bioacoustical monitoring</i>			<i>Carp deterence</i>				
Personnel: PI Allen F. Mensinger PhD. The PI has a 9 month position at the University of Minnesota Duluth. A total of 3 months of summer salary (1 month /yr) is budgeted. The PI will be on sabbatical during the 2014-15 academic year which is a 50% salary appointment. Two months of salary is budgeted for this period to work on the project. Total salary reflects 5 months total over 3 yrs and reflects 74.8% salary and 25.2% fringe (.55 FTE). Estimated total (\$67,218) Graduate student - support is budgeted for 30 months of support for one graduate student. Total reflects 57.3% salary and 42.7% fringe (2.5 FTE). Estimated salary (\$103,471). Graduate student summer salary. 50% summer salary is budgeted for an additional graduate student for 3 summers (total 4.5 months) 80.6% salary and 19.4% fringe (.75 FTE). Estimated salary (\$12,711). Undergraduate student summer salary: 2 months summer salary is budgeted for two undergraduate students each summer (total 12 months) 93.1% salary and 6.9% fringe (.49 FTE). Estimated salary (\$12,000).	\$65,134	\$64,288	\$846	\$65,133	\$65,133	\$0	\$65,133	\$63,671	\$1,462	\$195,400	\$2,308
Equipment/Tools/Supplies: Bouy or floating platform for early warning system plus floats, mooring lines, cables and materials	\$7,500	\$7,500	\$0							\$7,500	\$0
Equipment/Tools/Supplies: Two amplifiers for underwater speakers arrays @\$1000	\$2,000	\$2,000	\$0	\$0	\$0	\$0				\$2,000	\$0
Equipment/Tools/Supplies: Wireless video cameras, digital video recorders and DC power supplies for filming carp jumping from bouy or boats	\$2,500	\$2,500	\$0	\$2,500	\$2,500	\$0				\$5,000	\$0
Equipment/Tools/Supplies: Electronics supplies including cables, wireless routers, camera and underwater speaker and control units for remote operation of early warning system, sound exhaustion and deterrent systems	\$5,000	\$5,000	\$0	\$9,500	\$9,500	\$0	\$4,500	\$4,500	\$0	\$19,000	\$0
Equipment/Tools/Supplies: Fish food and water testing kits for carp in captivity	\$500	\$500	\$0	\$250	\$250	\$0	\$250	\$250	\$0	\$1,000	\$0

<p>Other: Out of state travel: Travel to the Illinois Biological Research Station in Havana, IL. This out of state travel is essential to the project as it allows us to test the equipment and strategies in carp infested water. We will travel in spring, summer and fall for one week each. Car (\$620 per trip based on 1100 miles RT @ \$0.565 per mile), lodging (\$77 per night) and meals (\$46 per day) based on Univeristy of Minnesota travel plan rates = \$861 per person per week. 9 weeks total for grant with two people each week.</p>	\$7,000	\$7,000	\$0	\$7,000	\$7,000	\$0	\$7,000	\$7,000	\$0	\$21,000	\$0
<p>Other: Out of State Travel: Travel is requested to the USGS facility in Lacrosse, WI to monitor carp behavior in outdoor ponds and test equipment. This out of state travel is essential for the project as these are the only large and outdoor secure ponds that house silver carp that are available for this research. The graduate student will spend approximately one month in residence at the facility each year to complete the experiments. Car (\$283 per trip based on 500 miles RT). Lodging and meals are \$861 per week and 4 weeks are anticipated each year. All rates are based on University of Minnesota travel plan rates.</p>	\$3,700	\$3,700	\$0	\$3,700	\$3,700	\$0	\$3,700	\$3,700	\$0	\$11,100	\$0
<p>COLUMN TOTAL</p>	\$93,334	\$92,488	\$846	\$88,083	\$88,083	\$0	\$80,583	\$79,121	\$1,462	\$262,000	\$2,308