AQUATIC INVASIVE SPECIES

An Evaluation of Barriers for Preventing the Spread of Bighead and Silver Carp to the Great Lakes

Final Report

Abstract

Nonindigenous bighead carp *Hypophthalmichthys nobilis* and silver carp *H. molitrix* are rapidly moving up the Illinois River towards Lake Michigan. These large, filter-feeding planktivores will enter the Great Lakes in vast numbers if nothing is done to halt their upstream spread. It is believed that this introduction would pose a serious ecological threat to these systems as all species of fish require and consume plankton at some point during their lives. Consequently, the use of behavioral fish guidance technology to deter the range expansion of these invaders has generated considerable interest. Experiments using an electric field barrier, hybrid Sound Projector Array driven BioAcoustic Fish Fence (SPA driven BAFF), and a combination of the two technologies were conducted to evaluate their effectiveness in repelling bighead carp and silver carp in outdoor fish raceways. The electric barrier halted the movement of all larger fish (>600-mm) that attempted to cross the barrier. However, smaller fish (< 150-mm) were able to pass through our original design. Subsequent alternate designs incorporating new electric field strengths and operational parameters were effective at stopping the smaller individuals 100 percent of the time.

We tested two frequency ranges using the SPA driven BAFF system using bighead carp. The first sound signal (20 - 500 Hz) provided some deterrence, but successfully repelled 57 percent of the attempts to swim through the barrier. In contrast, the second sound signal (20 - 2000 Hz) successfully repelled 95 percent of the attempts to move through the barrier. These results indicate that the SPA driven BAFF using the second sound signal can be an effective means of keeping bighead carp away from regions were their presence is unwanted, but may be further improved through a better understanding of the hearing sensitivities of these species.

Finally, we conducted an experiment that integrated both barrier types using bighead carp. The SPA driven BAFF was placed at the midpoint of the electric field and effectively repelled 83 percent of the attempts to move through the barrier. While some fish did initially successfully move through the barrier, this only occurred within about the first hour of each trial suggesting that there may be other factors that influenced this response.

Our findings generally indicated that both barrier types, in addition to being used in tandem, could be effective in restricting the movement of bighead and silver carp under the proper conditions.

Introduction

The introduction and spread of nonindigenous organisms to the inland waters of North America has increased dramatically during the past 150 years. Unfortunately, the rate of introduced non-native organisms remains on the rise in many aquatic ecosystems (Nico and Fuller 1999). The Great Lakes ecosystems provide several examples of recent introductions ranging from zooplankters *Bythrotrephes cederstroemii*, zebra mussels *Dreissena polymorpha*, and fish including several salmonid species, white perch *Morone americana*, and round goby *Neogobius melanostomus*. Predicting which species are likely to invade a given ecosystem is rarely possible and resource managers often have little opportunity to devise methods of preventing the introduction of nonindigenous species to inland waters. Moreover, predicting the consequences of new introductions is extremely difficult. It is believed, however, that the potential ecological and economic impacts could be substantial and will almost certainly create new management concerns once

viable populations are established. Consequently, the search for effective and economical control mechanisms to block the movements of fishes without the use of physical impediments remains one of the greatest challenges of fisheries management (Popper and Carlson 1998).

Although physical structures, in the form of dams and weirs have been effective in preventing aquatic nuisance species dispersion, they pose serious ecological and economic concerns that limit their usefulness when applied to shipping lanes. Physical structures not only prohibit the movement of fish and other aquatic organisms but also limit the ability to move cargo through shipping corridors. Alternatively, technologies based on altering fish behavior are generally less costly and are often logistically easier to implement than are structural barrier systems (Coutant 2001). Therefore, potential use of behavioral technologies to deter and/or repel fish from entering regions where their presence is unwanted has generated considerable interest.

Development and management of the Illinois Waterway, formed by several inter-connected rivers including the Illinois, Des Plaines and Chicago rivers and a series of canals, to connect the Great Lakes with the Mississippi River has a long and well documented history (Schneider 1996). The result has been an open waterway that freely connects an important shipping corridor between the Great Lakes and the Mississippi River. However, this link can also facilitate rapid exchange and range expansion of nonindigenous aquatic species into ecosystems that have historically been somewhat isolated. Existing examples of nonindigenous species that have used this connection between ecosystems include the aforementioned zebra mussels and white perch (Irons et al. 2002). Other non-native species are poised to move through this “revolving door” including planktivorous bighead carp *Hypophthalmichthys nobilis* and silver carp *Hypophthalmichthys molitrix*, collectively known as Asian carp. Both species are currently moving up the Illinois River towards Lake Michigan.

Asian carp were originally brought to the United States in the 1970’s for use in aquaculture, where it was hoped they would improve water quality when used in polyculture with other fishes (Freeze and Henderson 1982; Jennings 1988). Soon after their introduction, these carp escaped into the lower Mississippi River Basin and have considerably expanded their range since first being collected in the Mississippi River in the 1980’s (Robinson and Buchanan 1988; Tucker et al. 1996). There are now reproducing populations established in portions of the Mississippi, Missouri, Ohio and Illinois river basins (Jennings 1988; Burr et al. 1996; Tucker et al. 1996). Furthermore, the population growth of this species appears to be exponential at this point (Chick and Pegg 2001). Therefore, it is likely bighead carp will soon enter the Great Lakes in large numbers unless something is done to prevent their upstream spread.

As filter-feeders, Asian carp primarily consume zooplankton, but are able to switch to phytoplankton and other organic particles when zooplankton are not available (Hepher and Pruginin 1981; Dong and Li 1994; Schrank 2000; Xie 2001). Given that all fishes typically feed on zooplankton in their larval and/or juvenile stages, Asian carp have the potential to adversely affect every species of fish in both the Upper Mississippi River System (UMRS) and the Great Lakes if food resources become limited. Therefore, there is a strong need to identify possible control mechanisms to manage and subsequently limit the range expansion of these invaders. Identifying and evaluating various types of behavioral technologies that can limit movements of bighead carp may prevent or at least limit their entry into the Great Lakes or other systems where their presence is not desired.

The major goal of our study was to evaluate and assess the efficacy of fish barrier types (i.e. electric barriers and acoustic-bubble barriers) and combinations of these barrier types (i.e. sound / bubble / electric) in preventing the upstream movement of bighead and silver carp into the Great Lakes from the Illinois Waterway. Our specific objectives were to evaluate:

- The effectiveness of electric barriers in restricting the movement of bighead and/or silver carp;

- The effectiveness of acoustic/bubble barriers in restricting the movement of bighead and/or silver carp;
- The effectiveness of combined barrier types (i.e. electric / acoustic / bubble) in restricting the movements of bighead and/or silver carp.

Narrative Report

Methods

Study Design

We conducted experiments using three 24.7-m x 2.4-m x 1.8-m outdoor fish raceways located at the Illinois Department of Natural Resources' Jake Wolf Memorial Fish Hatchery. Each raceway represented one treatment with treatments consisting of a raceway containing a functional barrier, a raceway containing a non-functional "pseudo" barrier, and a control raceway containing no barrier equipment (the midpoint of this raceway was marked; Figure 1). The latter two treatments were used to ensure that there were no behavioral responses by Asian carp to the actual physical structure of the functional barrier system or its visual appearance. Each experiment typically consisted of three, 3-d trials where the movements of Asian carp were monitored daily over a 6-h period. However, in some instances, the number of trials was less than three when mortalities from a barrier design clearly indicated effectiveness. Each trial used equal numbers of individuals for each trial that ranged from eleven to twenty fish per treatment. All fish were placed in their respective raceway and allowed an acclimation period of at least 12 hours prior to initiating a trial.

Adult Asian carp (> 500-mm) were initially collected from the La Grange Reach, of the Illinois River using 91-m x 1.8-m monofilament trammel nets with external panels of 34.0-cm bar mesh and an internal panel of 7.6-cm bar mesh. Trammel nets were typically set for less than 10-min to achieve the appropriate sample size and were then immediately transported to the hatchery in oxygenated tanks. Juvenile Asian carp (< 500-mm) were collected using minnow-fyke nets set overnight following methods by Gutrueter et al. (1995). Individuals caught in the minnow-fyke nets were also immediately transported to the hatchery after net retrieval.

Electric Barrier

Relative to the experimental Chicago Sanitary and Shipping Canal Barrier that is now in operation, considerable effort has been put forth to reduce risk to human health in the event that a person passes through the barrier in the water. The result has been fairly detailed barrier specifications including the use of pulsed DC current of relatively low voltage with a very low frequency (< 20 Hz) and a pulse duration of 5 - 10 milliseconds. Our initial experiments were aimed at evaluating the effectiveness of the electric barrier under these operational conditions. Therefore, we established our initial electric barrier criteria from "real-time" information supplied by Smith-Root, Inc. However, some modifications to this original design were required to stop juvenile fish as this study evolved. The end result was the evaluation of three distinct electric barriers (graduated, three-electrode, gated burst). The critical element is that the electric barrier operating parameters used during our experiments continued to remain well within the present, safe operating conditions at the active barrier in the Chicago Sanitary and Shipping Canal.

Graduated Electric Barrier

A graduated electric field array is designed such that as a fish moves across this array it experiences an increase in the amount of electric current passing through its body. To minimize this current, the fish must orient itself perpendicular to the electrodes to reduce the effects of the electrical field. The fish can then swim back out of the array to its direction of origin. We used two Smith-Root Inc. pulsators (Model BP-1.5 POW) to create a graduated electric barrier that consisted of a composite electric field of two strengths. The electric fields were created using eight aluminum 25-mm wide by 5-mm thick aluminum bars or electrodes (four for each field) placed across the raceway and connected to the pulsators using electrical wire. The

weaker field was located on the side of the raceway where all fish were initially placed during the acclimation period. The weak field had a voltage gradient of about 1 volt/cm; whereas, the second set of electrodes that produced the stronger electric field had a gradient of 2 volts/cm. Using this array configuration, we were better able to emulate active barrier conditions in the Chicago Sanitary and Shipping Canal at Romeoville, IL.

Three-Electrode Barrier

The original graduated electric field indicated there were peaks in voltage gradients that corresponded to areas in the immediate vicinity of the electrodes. This resulted in a less than uniform electric field that may not be as effect the efficiency of this barrier technology. One option for remedying the non-uniform field phenomenon was to alter the wiring design in an attempt to create a consistent field across the length of the barrier. A three electrode array, designed to function as one composite voltage gradient, was developed in an attempt to accomplish a uniform electric field (Figure 2). Therefore, we also evaluated a three-electrode array during the course of the electric barrier evaluations. Specific operating parameters remained within safe operating levels, but were somewhat different than the graduated electric barrier as noted in the results section that follows.

Gated Burst Barrier

The gated burst electric barrier was physically similar in design to the original graduated field barrier but differed substantially in operational settings. A regular, pulsed DC current is designed to supply a predetermined burst or pulse of electricity for a certain length of time at regular intervals (Figure 3A). The gated burst design differs in that several bursts of electricity occur over a relatively short period of time with a fairly large time break between the next pulse. For example, Figure 3B illustrates a gated burst signal that contains five pulses within a burst with each pulse spaced 9.60-milliseconds apart compared to the larger space between bursts.

Sound-Bubble Barrier

The hybrid Sound Projector Array driven BioAcoustic Fish Fence (SPA driven BAFF) system employs an air bubble curtain that contains a pneumatically generated sound signal creating a sound field that can be used to keep fish away from regions where their presence is unwanted. The SPA driven BAFF system used in this investigation consisted of a linear array of four underwater sound projectors (Fish Guidance Systems Ltd., United Kingdom; FGS) centered at the mid-point in one of the three raceways coupled to an air bubble curtain generator. Two experiments were conducted using the SPA driven BAFF system. Each experiment represented a different pre-designated sound signal generated by a signal control unit and then amplified. This allowed underwater sound waves to propagate within a rising curtain of air bubbles. The two signal types evaluated were based upon artificially generated waveforms that cycled rapidly in amplitude and frequency content. The sound signal used in the first experiment consisted of a random series of cyclic sound bursts at frequencies ranging from 20 Hz to 500 Hz (FGS Type 1 signal). The sound signal used in the second experiment consisted of a random series of cyclic sound bursts ranging in frequency from 20 Hz to 2000 Hz (FGS Type 2 signal).

Composite Electric, Acoustic, and Bubble Barrier

Creating a redundant system that does not rely on similar technologies may also prove useful in the event of a power or some other failure. Therefore, an experiment merging the two barrier types was also tested using the original graduated electric barrier and the SPA driven BAFF (FGS Signal Type 1) following the experimental procedures outlined above. This barrier was designed to have the acoustic-bubble barrier placed at the transition point between the weak and strong electric fields of the electric barrier.

Data Acquisition and Analysis

We evaluated the effectiveness of each barrier system in repelling (a failed 'attempt' to cross the functional

barrier) Asian carp movements. We did this by continuously recording the number of attempts made to cross the functional barrier array during each 6-h observation period. Each attempt, consisting of a fish moving onto the functional barrier array, was then categorized as either a successful repel or pass-through. A successful repel occurred when a fish coming onto the functional barrier array turned around and exited the array. A successful pass-through involved a fish coming onto the functional barrier array and successfully crossing over the barrier. At the end of each experiment, we tallied the total number of observed attempts and repels made by bighead carp. The number of repels in relation to the total number of attempts was then expressed as a percentage. In addition, we calculated both the mean number of observed attempts and repels in the functional barrier raceway during each of the three days averaged across the three trials for each experiment.

We also counted the number of Asian carp remaining above (and below) the midpoint of each raceway at 15–min intervals during each daily observation period. Fish that did not move through the barrier or were later located on the half of the raceway where the experiment began were recorded as being located above the barrier, whereas fish that had passed through the mid-point of each raceway were recorded as located below the barrier. Each count was then expressed as a proportion to the total number of fish in each raceway. This was done to assess the propensity of fish in the three treatments to move throughout the entire raceway.

Results

Water conditions were similar for each experiment with water depths regulated at 61 cm, a water conductivity of 330 µS/cm, water temperatures that averaged 10.9°C (SD± 0.01°C), and dissolved oxygen (DO) that averaged 9.94 mg/L (SD± 0.17 mg/L) in each raceway. Flow rates were negligible in all raceways.

We completed a total of 27 experiments in addition to numerous exploratory trials using a myriad of operational parameters for each of the electric, SPA driven BAFF, and combined technologies. The following summarizes key findings from those experiments.

Electric Barrier

Graduated Electric Barrier. Our experiments using bighead carp larger than 600-mm indicate the graduated electric barrier is a very effective barrier. Across three trials using the graduated electric barrier, we observed 59 attempts to move through the electric barrier. All individuals were successfully repelled (Figure 4) and was significantly different from the responses of fish in the other treatments ($P<0.05$). Similar trials conducted on silver carp < 150-mm using the graduated electric barrier with the same and alternative operating parameters had varying degrees of success (Figure 5). The outcome typically led to one of two results: 1) the barrier was not effective in stopping the fish from moving through the barrier or 2) the field was so strong that all fish that attempted to cross the barrier were immediately stunned in the field and could not escape the barrier leading to mortality.

Three-Electrode Barrier. The three electrode array was generally successful in stopping fish moving through the barrier (Figure 6). However, several individuals were able to successfully pass through the electric field having a pulse width of 10 milliseconds and frequency of 3 Hz. The second three electrode array (pulse-width 1 millisecond; frequency 15 Hz) was considerably more effective in that no fish attempted to move through the barrier field. One caveat to this experiment was that the applied voltage was about 240 V which is at the extreme high end of the operational parameters that may limit its practical application in a real world application.

Gated Burst Barrier. Several trials were conducted using various settings of the gated burst barrier (Table 1). Trials that included voltages over 150-V resulted in mortalities relatively quickly upon exposure to the electric field. However, the gated burst setting for experiment 10 (Table 1) did appear to be effective, while allowing fish to survive if they turned around to escape the electric field.

Sound-Bubble Barrier

Type 1 Signal. A total of 3,219 observed attempts to cross the functional SPA driven BAFF barrier were made by bighead carp. Of those attempts 57% were successful repels. We also observed a consistent decrease in mean number of attempts and a concurrent increase in the mean number of repels through time (Figure 7A).
Analysis of variance (ANOVA) of raceway treatment effects on the mean percentage of bighead carp remaining 'above barrier' was significant (P =0.001). All post hoc pairwise comparisons between the three raceway treatment means were also significant (P < 0.05). Of the three raceway treatment types, the control barrier raceway had the highest mean percentage of fish located above the barrier. The mean percentage of bighead carp above the functional barrier and non-functional barrier were both significantly lower (P < 0.05) than the control raceway barrier treatment mean and significantly different from each other. Our ANOVA indicated that treatment effects on the mean percentage of bighead carp activity was also significant (P = 0.001). Post hoc pairwise comparisons between treatment means revealed that the mean percentage of bighead carp moving across the functional barrier and non-functional barrier were similar, but that the level of activity was significantly higher in the control treatment.

Type 2 Signal. A total of 284 bighead carp attempts to cross the functional SPA driven BAFF system were made using the second sound signal (no data available for trial three, day three). Of those observed attempts, 95% were successful repels. We also observed a marked decrease in both the number of attempts and a consistently high number of repels in relation to those attempts on the second and third day (Figure7B).
Analysis of variance of treatment effects on the mean percentage of bighead carp 'above barrier' was significant (P = 0.001). Post hoc pairwise comparisons between raceway treatment means revealed that the mean percentage of bighead carp remaining above the functional barrier was significantly higher than 'above barrier' mean percentages for both the non – functional barrier and control barrier which were both low and not significantly different from each other. Analysis of variance also showed significant treatment effects on the mean percentage of bighead carp activity (P = 0.001). Post hoc pairwise comparisons between treatment means revealed that the mean percentage of bighead carp moving across the functional barrier was significantly lower than mean percentages for either the non-functional barrier or the control barrier that were not significantly different from each other.

Composite Electric, Acoustic, and Bubble Barrier

Eighty-seven bighead carp attempted to move across the composite barrier. Of the individuals that attempted to move through the barrier, 83% were successfully repelled (Figure 8). No attempts to cross the barrier were made after the first 4-h of the trial on Day 1 of any of the three trials and our observations suggested that all fish remained well away from the barrier once oriented to the array.

Discussion

Electric Barrier

The electric barrier was extremely effective for larger fish tested in our experiments indicating that bighead carp are sensitive to this type of barrier design. Anecdotal field observations during routine sampling on the Illinois River seem to corroborate this observation as both species can be readily observed avoiding an electric field produced by a boat mounted electrofisher well beyond the range of most native fishes. A larger concern with electric barriers is the fact that there can be size-dependent differences in effectiveness. We did observe size selective biases in that small fish were able to pass through the original design of the electric barrier. However, this problem was remedied using both the three-electrode and gated burst arrays. The gated burst array typically required a lower voltage and output power to achieve the desired result of

stopping fish from passing through the barrier area, so it seems this may be a good fit for future barrier designs given economic operation and human safety concerns in areas where this technology could be implemented.

Sound-Bubble Barrier

Detection of sound by fishes typically involves two primary sensory systems – the ear, and the lateral line. An important difference between these systems is the distance from the fish over which they function. The lateral line system detects signals that originate relatively close to a fish (i.e., near the array) whereas the ear system detects signals at further distances from the fish (i.e., far from the array; Popper and Carlson 1998; Fay and Popper 1999). Consequently, when developing effective behavioral guidance technologies for fish using underwater sound, fish must be able to 'hear' the projected sounds. Specifically, the sound frequencies used must be within the detection range of the fish species of interest, signal compositions must be of a type that are repellent to fish and the sound level used must be high enough to elicit an appropriate behavioral response (Lambert et al. 1997). The SPA driven BAFF system used in this investigation has been successful in deterring and repelling certain species of fish away from regions where their presence is unwanted in a number of large scale field situations (Welton et al. 2002). However, our investigation was the first in which the SPA driven BAFF system was used in an environment where fish could not entirely escape the ensonified region.

The first sound signal tested was not very effective in deterring and/or repelling bighead carp. We observed a large number of attempts by bighead carp to cross the functional SPA driven BAFF system comprised of the first sound signal. This result suggested an overall lack of sensitivity (low determent) to sounds far from the array. Additionally, only 57% of all bighead carp were successfully repelled. This suggests an additional lack of sensitivity to sounds near the array. On numerous occasions, bighead carp were observed swimming around and across the functional array to no apparent effect. However, we did observe a decrease in the mean number of attempts to cross the functional barrier array and an increase in the mean number of repels associated with those attempts over time. This result may indicate a heightened sensitivity to sounds projected both near and far from the array through time, resulting in increased determent (a decrease in the number of attempts) and an increase in the number of repels. Indeed, prolonged exposure to intense sound could result in negative physiological and/or behavioral responses, including heightened sensitivity and consequential increased avoidance (Popper and Carlson 1998) and further study on the long term effects of a SPA driven BAFF system on bighead carp is warranted.

Results from the second sound signal experiment showed that the overall number of attempts made by bighead carp to cross the functional barrier array was approximately 11 times lower than the first signal evaluated. The reduction in the number of attempts may be confounded in part by a general lack of activity in all treatments relative to the first experiment. However, of the 284 attempts to cross the functional barrier, the percentage of successful repels was very high (95%), representing a 60% increase over the first sound signal evaluated. Moreover, we observed a significant increase in the mean percentage of bighead carp remaining above the functional barrier and a corresponding decrease in activity level as compared to each of the two control raceway barrier treatments. We interpret these results to mean that bighead carp were most likely exhibiting an elevated sensitivity to sounds projected by the second signal generator. Specifically, we believe that bighead carp were exhibiting avoidance responses to associated sounds projected both near the array and far from the array.

Bighead carp have evolved a specialized hearing ability through an additional acoustic coupling between the swim bladder and the ear, via the Weberian ossicles, that facilitate sound transmission. This physical difference allows bighead carp to detect sounds not only at longer distances (Carlson and Popper 1998; Fay and Popper 1999; Ladich 2000) but also across a much wider frequency range than fishes that do not have this coupling (Popper and Carlson 1998). Therefore, we hypothesize that bighead carp were behaving in

response to an elevated sensitivity to frequencies that approximated the span of their entire hearing range (e.g., 20 Hz – 2000 Hz) rather than a certain portion (e.g., 20 Hz–500 Hz).

Composite Electric, Acoustic, and Bubble Barrier

Our results using the composite barrier were somewhat different than expected. However, it seems that there may be external biases and/or size restrictions in the environment we used to evaluate this barrier array that may not accurately represent the combined abilities of the two technologies. Field experiences reveal that both bighead and silver carp are extremely sensitive to electric fields and sound. Specifically, these species may be able to sense an electric field well below that of the probes we used to measure the electric field. Therefore, the fish may not have been able to determine specifically where the sound, bubble, and electrical stimuli were located until a suitable acclimation period had occurred. Ultimately, there may have been some initial disorientation at the onset of each trial that may have interfered with each individual fish's ability to detect and remain clear of the barrier. In situations where the fish could start well away from the barrier and out of the range of their sensitivities to the barrier, our results may have differed in that all fish would have been repelled.

A second possible consideration is the actual location of the two technologies relative to each other. Our composite barrier was setup to have the acoustic-bubble barrier placed at the transition point between the weak and strong electric fields of the electric barrier. Other configurations and/or signals may prove as or more effective, but were not tested in this study.

Conclusions

The barrier technologies we tested have proven to be effective in stopping movements of bighead and silver carp under controlled situations and provide promise for similar results under applied conditions. However, we did not address many extraneous factors that could also influence the outcome of these species moving through a given barrier (e.g., barge traffic, unexpected equipment failures, etc.). Nonetheless, our results provide a significant amount of promise in applying either or both technologies in the field as a management tool to prevent the spread of bighead and silver carp into Lake Michigan.

Asian carp represent only two of many non-native species threatening the ecosystems throughout North America and the world. Coupled with this threat of establishment is the fact that the short and long term ecological impacts of these species are not well understood in many cases. This further highlights the need to prevent the establishment of non-native species in new ecosystems. Our experiments using various deterrent systems on Asian carp can be an effective means of stopping or slowing these species' current range expansion. However, further research on the effects of prolonged exposure to these technologies and identifying the precise sensitivities (e.g., hearing range) will further refine and improve the efficiency of this management tool.

Table 1. Young-of-year (< 150-mm) silver carp responses to the gated burst electric barrier design under various operational settings.

Experiment	Applied Volts	Bursts/Pulse	Pulse Duration (Msec)	Pulse Frequency (Hz)	Attempts	Passes	Percent Effectiveness (%)
1	242	5	1	15	20	0	100
2	205	5	1	15	20	0	100
3	170	5	1	15	20	0	100
4	128	5	1	15	20	2	95
5	85	5	1	15	20	20	0
6	85	5	0.4	15	20	11	55
7	133	5	0.4	15	20	20	0
9	133	3	1	15	22	2	91
10	133	3	5	10	20	20	100

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Keywords
Bighead Carp, Silver Carp, Fish Barrier, Electric Field, Acoustic Barrier, Bubble Barrier, Great Lakes, Illinois River, Asian Carp, Zooplankton, Phytoplankton, Filter – Feeders, Competition, Smith – Root, Inc., Fish Guidance Systems, Ltd.

Lay Summary
Bighead and silver carp, large filter-feeding fishes originally from Asia, are moving upstream in the Illinois River and are now threatening the Great Lakes ecosystem. These fish grow rapidly and can attain sizes well over 25-kg. In addition to their large size, there are concerns that both species may limit food resources for many other fish species. Both bighead and silver carp consume microscopic organisms found in the water (plankton) by straining or filtering the water column. Zooplankton is also an important and necessary food source for several species of adult fishes native to the Great Lakes (i.e. whitefish). Additionally, larval and juvenile fishes require plankton in order to grow and develop properly. As a result, there is concern regarding the possible ecologic and economic impacts the introduction of bighead and silver carp into the Great Lakes may have. However, an electric fish barrier, built in the Chicago Sanitary and Ship Canal near Romeoville, Illinois, may have created a check on the upstream migration of bighead and silver carp.

Our goal was to evaluate the efficacy of the existing electric barrier in addition to test other potential barrier types using controlled experiments. We tested an electric barrier with similar operating parameters to the fish dispersion barrier near Romeoville, Illinois; an experimental sound-bubble barrier; and a barrier that incorporated the electric and sound-bubble technologies. Our experiments, were conducted in fish raceways at the Jake Wolf Memorial Fish Hatchery (Illinois DNR) with each experiment consisting of three, three-day trials. The electric barrier suite of trials proved very effective at stopping bighead carp with no fish successfully moving through the barrier. However, tests on small silver carp (< 150-mm) required changes in design and operation of the electric barrier to become 100% effective. We then conducted two separate experiments with the sound-bubble barrier. The first experiment used a relatively low frequency range and had a 57% successful repel rate; whereas the second experiment used a wider range of frequencies and had a 95% successful repel rate. Our final experiment integrated both barrier types. While some fish did initially successfully move through the barrier, this only occurred within about the first hour of each trial suggesting that there may be other factors that influenced this response. Our findings were somewhat mixed, but generally indicate both barrier types, in addition to being used in tandem, could be effective in restricting the movement of bighead and silver carp under the proper conditions.

International Implications
The majority of fishes that are the focus of commercial and recreational fisheries in the Great Lakes depend on zooplankton and phytoplankton during some portion of their life history. In light of the stress to the Great Lakes ecosystems from previous invasions by non-native species, bighead and silver carp are likely to have negative impacts on both Canadian and United States commercial and recreational activities and on the economies of coastal communities that depend on these resources. Our research is critical in implementing effective barriers to prevent bighead carp and silver carp from entering the Great Lakes via the Illinois Waterway. In recognition of this issue and in response to our research findings, the International Joint Commission (IJC) and Great Lakes Fishery Commission (GLFC) contributed funds to bring experts from Fish Guidance Systems Ltd. from the United Kingdom to Illinois to provide assistance in creating an acoustic-bubble barrier array and develop audiograms specific to both species. The IJC is a bi-national organization established by the Boundary Waters Treaty of 1909 to help Canada and the United States prevent and resolve disputes over use of waters along their common boundary. Similarly, the GLFC coordinates research, invasive species control, and management of the Great Lakes with state, provincial, non-government, and federal governments in Canada and the United States Great Lakes Region.

Media Coverage

Since the inception of this project, we have participated in over 100 radio, newspaper and television interviews including regional and national television coverage by CNN, NBC, ABC, FOX and CBS news. Our research has also gained international attention with interviews aired in Canada (CBC), United Kingdom (BBC), and Japan (Fuji News). A partial list of printed media coverage follows:

New Lake Threat: Asian Carp, Can They Be Kept Out Of The Great Lakes
Source: The Chicago Sun Times (Illinois, USA)
Date: April 18, 2002

Wildlife Officials Erect Electric Barrier – Officials Seek To Keep Asian Carp From Lake Michigan
Source: NBC National Television News
Date: April 19, 2002

Biological Pollution: Exotic Species Pose A Bigger Threat To The Great Lakes Than Chemical Contaminants
Source: Earthwatch Radio
Date: April 23, 2002

Something Fishy This Way Comes
Source: The Daily Southtown (Chicago, Illinois, USA)
Date: May 5, 2002

Asian Carp Invasion
Source: Outdoor Illinois, (Illinois, USA.)
Summer 2002

Bones of Contention
Source: Outdoor Illinois, (Illinois, USA.)
Date: Summer 2002

Electric Barriers May Be Used To Keep Carp Out Of Lake Michigan
Source: The Mason County Democrat (Havana, Illinois, USA)
Date: Summer 2002

Electric Barrier Nay Block Invasive Asian Carp
Source: unknown media release
Date: July 2002

Flying Fish Become Menace
Source: Peoria Journal Star (Illinois, USA)
Date: July 6, 2002

Asian Carp Threaten Great Lakes
Source: Champaign News Gazette (Illinois, USA)
Date: July 12, 2002

Scientists Warn Fish Invader Could Endanger Great Lakes
Source: Canadian Broadcasting Corporation (CBC) (Windsor, Ontario, Canada)
Date: July 12, 2002

Giant Carp Ready To Eat Way Through Great Lakes
Source: The Chicago Tribune (Illinois, USA)
Date: July 18, 2002

Mrs. O'Leary's Cow, Meet the Asian Carp
Source: The Los Angeles Times (California, USA)
Date: July 19, 2002

Asian Carp Threaten To Invade Lake Michigan – Will Harm Native Fish
Source: Milwaukee Journal Sentinel (Michigan, USA)
Date: July 19, 2002

Voracious Carp May Be Great Lakes Ruin
Source: The Los Angeles Times (California, USA)
Date: July 19, 2002

Nature's Alien Invaders
Source: The Springfield Journal Register (Illinois, USA)
Date: July 20, 2002

Duck! – Here Comes A Giant Carp!
Source: The New York Times (New York, USA)
Date: July 19, 2002

Lake Erie Health Again Facing Crisis
Source: Pittsburgh Post Gazette (Pennsylvania, USA)
Date: July 21, 2002

Local Researchers Attempt To Control Carp
Source: The Pekin Times (Illinois, USA)
Date: July 27, 2002

Sea Grant Research Shows Electric Barrier May Stop Carp
Source: Public Release – National Sea Grant College Program
Date: July 22, 2002

Migration Of Asian Carp Threatens Great Lakes Fish
Source: The Los Angeles Times (California, USA)
Date: July 25, 2002

Alien Invasions Threatens Fish – Bighead Carp Destroy Food Chain, Snakeheads Gobble Up Survivors
Source: The Toledo Blade (Ohio, USA)
Date: July 28, 2002

Carp Threatens Great Lakes – Asian Variety Could Wipe Out All Other Species Of Fish
Source: The Los Angeles Times
Date: July 28, 2002

River Station Work At Havana Goes Beyond The La Grange Reach
Source: The Mason County Democrat (Havana, Illinois, USA).
Date: July 31, 2002

Fish – Invasive Species Approach River
Source: The Quad-City Times (Illinois, USA)
Date: Aug 3, 2002

Invasive Fish Species Threatens Mississippi River
Source: The Quad – City Times (Illinois, USA)
Date: Aug 3, 2002

Invasive Species Here On River
Source: The Quad-City Times (Illinois, USA)
Date: Aug 4, 2002

Giant Carp May Eat Up Great Lakes
Source: FOX Television National News
Date: Aug 21, 2002

Guess What's Coming For Dinner – Unless We Act Fast, The Great Lakes Are About To BE Invaded By Giant Fish
Source: The Toronto Globe and Mail (Ontario, Canada)
Date: Aug 26, 2002

Simulated Barrier Stop Bighead Carp
Source: THE HCLM – News and Information from the Illinois – Indiana Sea Grant Program (Illinois/Indiana, USA).
Date: Fall 2002

IJC Funds Testing Of Potential Second Barrier To Stop Asian Carp
Source: International Joint Commission – Media Release
Date: Oct 3, 2002

Voracious Carp Threatens Fish Supply In Great Lakes
Source: ABC Television National News
Date: Nov 12, 2002

Funds To Beef Up Fight To Stop Carp – Fish Barrier To Get Back-Up Generator
Source: The Chicago Tribune (Illinois, USA).
Date: Nov 20, 2002

State To Participate In Construction Of Second Barrier To Combat Asian Carp
Source: Illinois Department of Natural Resources (DNR) – Media Release
Date: Dec 12, 2002

Scientist May Kill Section of Chicago River to Stop Infestation
Source: Peoria Journal Star (Illinois, USA)
Date: Dec 15, 2002

Steps Urged To Stop Alien Aquatic Species
Source: The Toronto Globe and Mail
Date: Oct 2, 2002

Leaping Asian Carp Threaten Boaters
Source: The Columbus Dispatch (Ohio, USA.)
Date: Oct 29, 2003

Public Outcry Absent From Invasives Problem
Source: Great Lakes Radio Consortium
Date: Nov 11, 2002

Barrier Urged For Area River – Scientists Call Invasive Species A Major Threat
Source: Chicago Tribune (Illinois, USA)
Date: May 13, 2003

Environment: Giant Carp Gone Wild
Source: Newsweek Magazine
Date: Jan 14, 2004

Partnerships with other institutions/individuals initiated or continued by your project
This research facilitated partnerships with staff from Smith-Root, Inc. and Fish Guidance Systems (FGS) Ltd. These partnerships lead to additional funding from the International Joint Commission and Great Lakes Fishery Commission. This work also facilitated collaboration with Eastern Michigan University. Researchers involved with this project were also actively involved in the multi-agency Chicago Sanitary and Ship Canal Dispersion Barrier Advisory Panel. Furthermore, we collaborated with Illinois Department of Natural Resources, Fisheries Division staff at the Jake Wolf Memorial Fish Hatchery in Topeka, Illinois.

Publications & Presentations

Taylor, R.M., M.A. Pegg, and J.H. Chick. Submitted. Effectiveness of two bio-acoustic fish guidance systems for preventing the spread of bighead carp to the Great Lakes. Submitted to North American Journal of Fisheries Management.

Taylor, R.M., M.A. Pegg, and J.H. Chick. 2003. Some observations on the effectiveness of two behavioral fish guidance systems for preventing the spread of bighead carp to the Great Lakes. Aquatic Invaders 14:1-5.

Taylor, R.M., M.A. Pegg, and J.H. Chick. 2002. Aquatic nuisance species: An evaluation of barriers for preventing the spread of bighead carp to the Great Lakes. Final report submitted to the International Joint Commission, Washington, D.C.

Dettmers, J., and M.A. Pegg. 2003. Evaluating the Effectiveness of an Electric Barrier. INHS Reports 377:1-2.

Pegg, M.A., R.M. Taylor, and J.H. Chick. Use of electric and bioacoustic technologies as cross-channel barriers to bighead carp. Presented at the 134th American Fisheries Society meeting, Madison, Wisconsin, August, 2004.

Pegg, M.A. Evaluating barriers to prevent the spread of bighead carp into Lake Michigan. Presented at the bi-annual Illinois-Indiana Sea Grant Research Symposium, Chicago, Illinois, May, 2004.

Pegg, M.A., R.M. Taylor, and J.H. Chick. Evaluating barriers to prevent the spread of bighead carp into Lake

Michigan. Presented at the 64th Midwest Fish and Wildlife Conference, Kansas City, Missouri, December, 2003.

Taylor, R.M., M.A. Pegg, and J.H. Chick. Experimental evaluation of barriers for preventing the spread of bighead carp to the Great Lakes. Presented at the American Fisheries Society meeting, Quebec City, Quebec Canada, August, 2003.

Taylor, R.M., M.A. Pegg, and J.H. Chick. Aquatic nuisance species: an evaluation of barriers for preventing the spread of bighead carp to the Great Lakes. Presented at the International Conference on Invasive Species, Windsor, Canada, June 2003.

Pegg, M.A, Taylor, R. M., and J.H. Chick. Aquatic nuisance species: an evaluation of barriers for preventing the spread of bighead carp to the Great Lakes. Presented at the Annual Meeting of the Upper Mississippi River Conservation Committee, Collinsville, Illinois, March, 2003.

Taylor, R. M., M.A. Pegg, and J.H. Chick. Aquatic nuisance species: an evaluation of barriers for preventing the spread of bighead carp to the Great Lakes. Presented at the Illinois Chapter American Fisheries Society Annual Meeting, Rend Lake, Illinois, March, 2003.

Pegg, M.A., R.A. Taylor, and J.H. Chick. Assessment of electric and sound-bubble barriers in preventing the movements of bighead carp. Presented to the Dispersion Barrier Advisory Panel, Chicago, Illinois, January, 2003.

Related projects with other funding agencies resulting from this Sea Grant-sponsored research

Bighead Carp in the Upper Mississippi River: Competition with Native Filter-Feeding Fishes and Potential Threats to the Great Lakes, Illinois-Indiana Sea Grant, 2002-2004 ($99,000).

An Evaluation of Acoustic/Bubble Barriers for Preventing the Spread of Asian Carp to the Great Lakes. International Joint Commission, 1 October, 2002 - 31 January, 2003 ($10,000).

Movement and dispersion of juvenile Asian carp and round gobies. U.S. EPA, 1 January, 2003 - 31 December, 2004 ($56,000; Pegg co-PI w/ Uli Reinhardt, Eastern Michigan University).

Measurement of Audiograms of Silver Carp and Bighead Carp for Chicago Canal Acoustic Barrier Optimization. Great Lakes Fishery Commission. 1 June - 31 December, 2004 ($36,750).

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Research Information

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- **Initiation Date**: January 1, 2001
- **Completion Date**: June 30, 2004
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