Analysis of an agent-based model for predicting the behavior of bighead carp under the influence of acoustic deterrence

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Introduction

Bighead carp have been identified as an invasive species posing an immediate threat to The Great Lakes, warranting research and action. This project focuses on the following:

- Investigating the ecological influence of bighead carp
- Applying primary research on acoustic deterrence to a real-world simulation.
- Quantifying parameter levels that influence barrier efficacy.

Goals:

- Determine if broadband acoustic deterrence is a viable method of keeping bighead carp out of The Great Lakes
- Identify what ecological impact such implementation would have

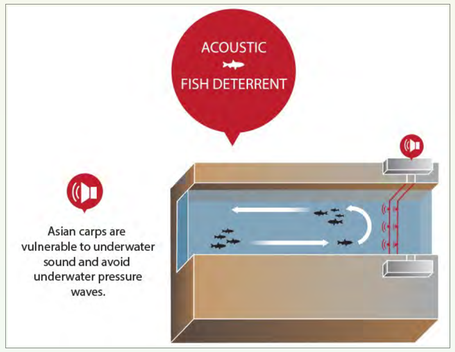


Figure 1: Proposed effects of underwater acoustic deterrence for invasive bighead carp [USACE]

Background

Historical highlights of bighead carp:

- Introduced to U.S. aquaculture in the early 1970's in an effort to control phytoplankton and keep retention ponds clean
- Escaped their contained environment into the Mississippi River in the 1990's after a series of floodings.
- Spotted as close as the T.J. O'Brien Lock and Dam, 7 miles outside Lake Michigan.

Primary research on bighead carp under the influence of acoustic deterrence was conducted by Vetter et al, in which live specimens were used in an above ground pool.

- Specimens were subjected to several frequencies of pure tones (50, 100, 1500, and 2000 Hz) as well as a broadband sound stimulus.
- Speakers were placed at either end of the environment and played asynchronously over 30-second intervals before switching to the opposite side.
- 10-minute trials were conducted with a 15-minute recovery period for pure tone trials and a 30-minute recovery period for broadband trials.

Biological Framework

Several model parameters were incorporated from primary research studies of live subjects. These parameters were incorporated into our model to more accurately replicate a live environment.

Parameter		Literature Reference
Sound Production	Sound Production in simulated environment	*Vetter 2016*
Speaker Placement	Placement of speakers within bounds	*Vetter 2017 & FWS 2016*
Invasion Parameter	∼20 adult fish or ∼1 adult fish per year for 10 years	*Cuddington 2014*
Resource Consumption	Resource competition between: Carp, Gizzard shad & Bigmouth buffalo	*Sampson 2009*
Species Behavior	Feeding behavior and swim patterns	*FWS 1988*
Carp-Sound Wave Interactions	Carp respond to acoustic stimulus by: Increasing swim speed Turning at an angle of 45 degrees	*Zilenski 2017*

Simulation & Analysis

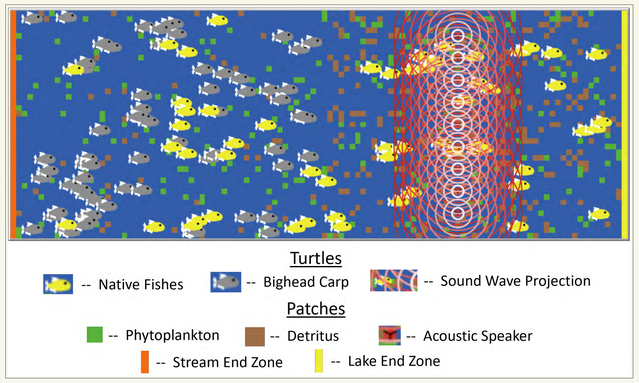
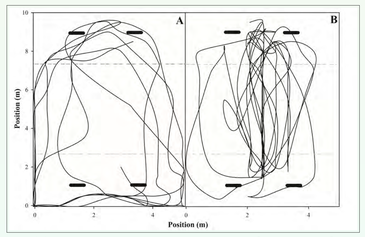


Figure 2: Simulation of fish behavior under the influence of acoustic deterrence

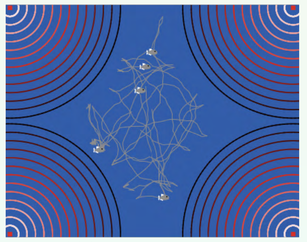
NetLogo is an agent-based programmable modeling environment. Agents are autonomous, decision-making entities based on a defined set of programmed parameters.

- Turtles - mobile agents
- Patches - non-mobile agents

Bighead carp behavior under the influence of acoustic deterrence was validated with results reported by Vetter et al.



(a) Primary research swim patterns [Vetter et al]



(b) Simulation swim pattern

Figure 3: Comparison of bighead swim patterns between primary research and simulation

A full-scale invasion is defined as 20 bighead carp getting past the barrier and into the lake (yellow end zone). BehaviorSpace in NetLogo was utilized to produce data on which statistical analyses could be performed.

- Simulations were run on a full factorial experimental design resulting in 19,845 individual runs mapping each possible parameter combination.
- Variance Based Sensitivity Analysis: used to verify parameter importance to designated outcomes - invasion (Fail) / no invasion (pass)
- Conditional Inference: used to compare outcome likelihood based on combinations of parameters values used in the simulation.

References

1. Cuddington, K. Could an asian carp population establish in the great lakes from a small introduction? Journal of Great Lakes Research, 16:903917, 2014.
2. Environmental Protection Agency.
3. Ferris, R. Why are there so many toxic algae blooms this year, 2016. [Online; accessedNovember 30, 2018].
4. US Army Corps of Engineers.
5. Vetter et al. Acoustic deterrence of bighead carp (Hypophthalmichthys nobilis) to a broad-band sound stimulus. Journal of Great Lakes Research, 43:163171, 2017
6. Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

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Results

Significant Parameters: initial number of bighead carp and native fishes, growth-rate of plankton and detritus, energy of plankton and detritus, and amount of required energy for reproduction

Significant Simulation Measures: count of bighead carp and native fishes in simulation, count of detritus and plankton in simulation, number of carp successfully deterred by barrier, count of plankton and detritus both in front and behind the barrier, native fishes swimming through barrier upstream, bighead carp swimming downstream

Prediction accuracy for both random forest and neural network models is > 99 %

1. Variable Importance
   - Parameter values and simulation measures were found to be statistically significant

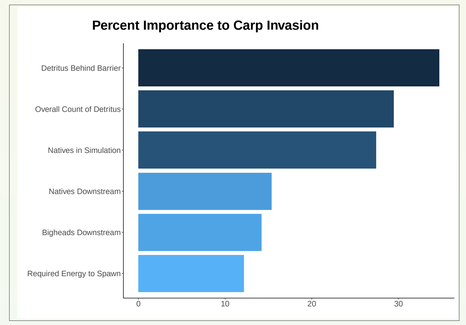

Figure 4: Variable importance

2. Conditional inferences
   - Conditional inferences are significant at $p < 0.05$

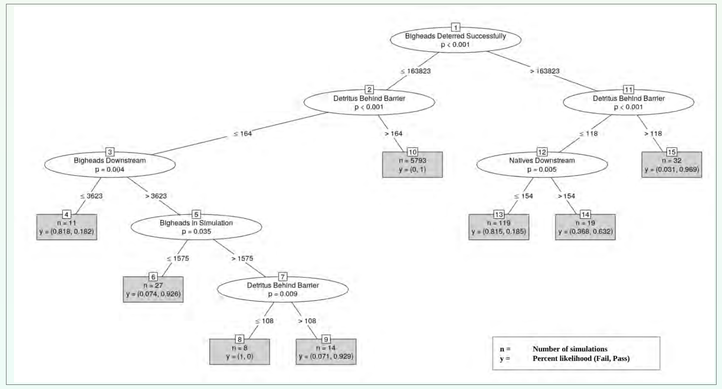

Figure 5: Conditional inference tree predicting percent likelihood of invasion

Conclusions & Future Work

Conclusions:

- Per Figure 5, the most important factors in determining barrier efficacy are:
  - The quantity of both detritus and plankton behind the barrier
  - The number of bigheads and native fishes downstream from the barrier - invasion likelihood increases based upon the ratio of native fish to carp in the system.
- The strength of the broadband wave and the detection radius of the bighead carp have no correlation with the simulation outcome.
- Invasion probability will increase in situations where large numbers of plankton and detritus are abundant, as this can cause population spikes. Such situations could include the following:

  (i) Algal blooms **(ii)** Spring **(iii)** Climate change

Future Work:

- This model has the potential to be used in conjunction with current reported research and development of the acoustic speakers at the University of Kentucky.
- Proper implementation has the potential for herding the invasive species, allowing for the ecological integrity of The Great Lakes to be preserved.