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Acoustic deterrence of bighead carp (*Hypophthalmichthys nobilis*) to a broadband sound stimulus

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ABSTRACT

Recent studies have shown the potential of acoustic deterrents against invasive silver carp (*Hypophthalmichthys molitrix*). This study examined the phonotaxic 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 × 5 × 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.

Introduction

The bighead carp (*Hypophthalmichthys nobilis*) is an invasive fish species in North America and has established breeding populations in the Mississippi River Watershed. Range expansion of these fish into the Great Lakes is a concern because they are present in the northern regions of the Illinois River (Kolar et al., 2007; Sass et al., 2010) and have been found in the Chicago Sanitary and Ship Canal (Moy et al., 2011) near Lake Michigan. These fish, along with the closely related silver carp (*H. molitrix*), evolved in Asia and were intentionally brought to the United States for use in wastewater treatment plants and aquaculture facilities (Kelly et al., 2011; Kolar et al., 2007). Both species are an ecological concern because they compete with native species, such as paddlefish (*Polyodon spathula*; Schrank et al., 2003), gizzard shad (*Dorosoma cepedianum*; Sampson et al., 2009), and bigmouth buffalo (*Ictiobus cyprinellus*; Irons et al., 2007), for food and space. While adults from both *Hypophthalmichthys* species can grow up to 40–50 kg, they are planktivores, which precludes them from being caught via angling or baited traps. Furthermore, these filter feeders will consume both zooplankton and phytoplankton and could alter the entire food web in rivers where they are abundant (Sass et al., 2014).

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As part of an integrated pest management strategy, state and federal agencies throughout the Midwest are prioritizing the development of effective non-physical deterrents, including acoustic barriers, to prevent further bighead and silver carp range expansion. Acoustic deterrents, often in combination with other techniques such as bubbles or strobe lights, have been moderately successful at dam and power plant intakes (see Noatch and Suski, 2012 for a review). Barriers utilizing ultrasound (122–128 kHz; Ross et al., 1993) or varied low-frequency sound (20–600 Hz; Maes et al., 2004) successfully repelled 87% and 60% of clupeids, respectively. There is evidence that bighead carp are deterred by sound (20–2000 Hz) combined with bubbles in studies conducted on both captive (Pegg and Chick, 2004; Taylor et al., 2005) and wild fish (Ruebush et al., 2012). However, an investigation into the phonotaxic response of invasive carp to sound alone is important for the evaluation of acoustic deterrents.

Bighead carp are ostariophysans and possess Weberian ossicles, which connect the gas bladder to the inner ear (Fay and Popper, 1999), allowing for higher frequency hearing than many non-ostariophysan species. Lovell et al. (2006) indicated bighead carp frequency sensitivity up to 3 kHz. However, as the researchers did not test above 3 kHz, it is uncertain if bighead carp can hear beyond this frequency. Ladich (1999) studied species from four ostariophysan orders (Cypriniformes, Characiformes, Siluriformes, and Gymnotiformes) and elicited auditory brainstem responses up to at least 5 kHz in all species. Furthermore, brown bullhead (10–13 kHz; *Ameirus nebulosus*;

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Poggendorf, 1952) and neotropical catfish (6 kHz; *Lophiobagrus cyclurus*; Lechner et al., 2011) have frequency sensitivity beyond 5 kHz. Therefore, it is possible that bighead carp can detect higher frequencies than those previously reported by Lovell et al. (2006).

The silver carp is notorious for its jumping behavior, which can be elicited when motorized watercraft move through carp-infested areas. Playbacks of the broadband (0.06–10 kHz) sound emitted by outboard motors caused wild silver carp to jump (Mensinger, unpublished) and elicited negative phonotaxis in captive fish (Vetter et al., 2015), however bighead carp do not jump (Kolar et al., 2007). Therefore, the effect of similar acoustic stimulation on bighead carp is unknown, as their underwater behavior is difficult to monitor in turbid water. Since silver and bighead carp coexist and will hybridize, if bighead carp are affected similarly by sound, the two species could be co-managed by acoustic deterrents.

The goal of this study was to examine the behavioral response of bighead carp to pure tones and broadband sound stimuli, which was successful in modulating silver carp swimming behavior. It was predicted that bighead carp would also demonstrate negative phonotaxis to broadband sound, providing further support for the development of acoustic barriers to manage these species.

Methods

Animal husbandry

All experiments were conducted at the U.S. Geological Survey (USGS) Upper Midwest Environmental Sciences Center (UMESC) in La Crosse, Wisconsin. Bighead carp (n = 50; total length: 212 ± 7.7 mm; wet weight: 101.4 ± 12.3 g; mean ± standard deviation) were obtained in the summer of 2013 from Osage Catfisheries, a private aquaculture farm in Osage Beach, Missouri, USA. Fish were maintained in 1500 L flow-through indoor ponds and fed trout starter diet (Skretting, Tooele, UT) at a rate of 0.5% body weight per day (Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government). A Chapter NR 40 Permit for Possession, Transport, Transfer, or Introduction of Prohibited or Restricted Species was obtained from the Wisconsin Department of Natural Resources prior to acquisition of test animals and movement to outdoor ponds and experiments were conducted under UMESC Animal Care and Use Committee Protocol Number AEH-12-PPTAC-01.

Behavioral experiments

Behavioral experiments were conducted in an above ground 10 × 5 × 1.2 m (60 kL) outdoor concrete flow-through pond. Each group (N = 5) of ten naïve fish was allowed to acclimate in the outdoor pond for at least 48 h prior to the initiation of experiments. Five two-day trials were conducted from June through August 2014. At the conclusion of each trial, the pond was drained, refilled, and naïve fish (N = 10) added.

Sound stimuli

Sound was delivered via one of two pairs of underwater speakers (UW-30, Lubell Labs Inc., Whitehall, OH) that were placed 1.0 m from each end of the pond, 1.6 m from the nearest side-wall, 1.8 m apart, and positioned so that sound was projected along the longitudinal axis of the pond (Fig. 1). Acoustic stimuli consisted of pure tones (500, 1000, 1500, or 2000 Hz), generated by Audacity 2.0.5 software, and broadband sound, recorded underwater from an outboard motor (100 Hp 4-stroke, Yamaha, Kennesaw, GA). The outboard motor sound was recorded with a hydrophone (HTI-96-MIN, High Tech Inc., Long Beach, MS), in the Illinois River near Havana, Illinois, USA (40° 17′ 30″ N, 90° 04′ 20″ W). Sound was recorded in approximately 1 m of water while the boat transited past the hydrophone at 32 km/h at a nearest distance of 10 m.

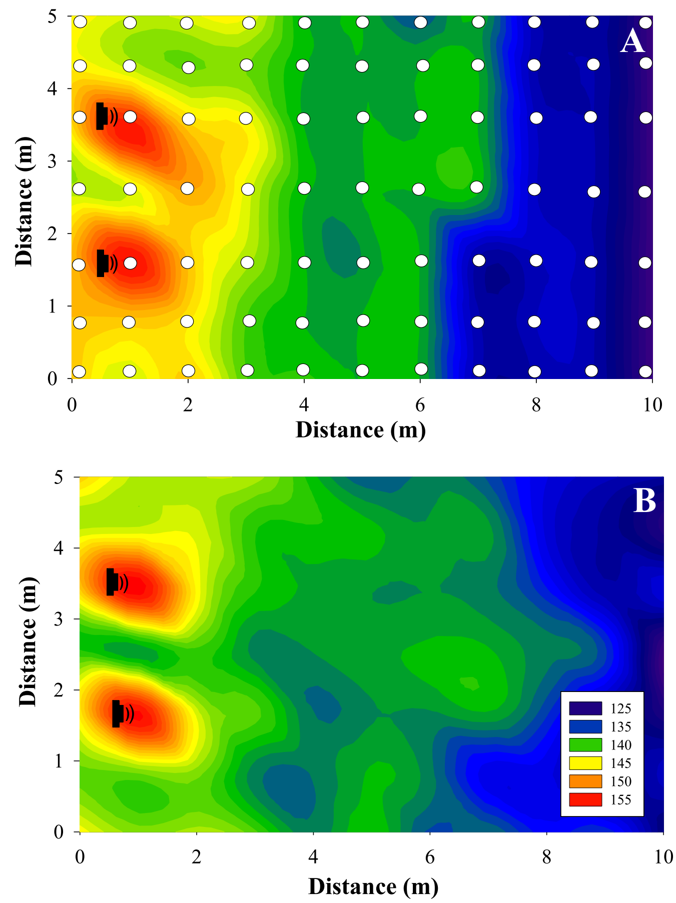

Fig. 1. Sound pressure level in the experimental pond. The sound intensity was measured using a hydrophone at a depth of 0.6 m at 77 intervals throughout the pond during broadband sound playback. The speakers and points of measurement (white circles in upper figure) are indicated. The colors represent the sound intensity level (dB re 1 μPa), indicated in the scale on the lower right. A) 1000 Hz pure tone; B) Broadband sound stimulus. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The sound was amplified with a UMA-752 amplifier (UMA-752, Peavey Electronics, Meridian, MS) and each speaker pair was controlled manually with a switchbox (MCM Electronics, Centerville, OH). Each pond contained a single hydrophone to monitor the sound stimuli, which were recorded using a PowerLab 4SP data acquisition system and LabChart 7 software (AD Instruments, Colorado Springs, CO). To map the acoustic field, recordings of the broadband sound and 1000 Hz pure tone were made at 77 positions throughout the tank at a depth of 0.6 m which was the depth at which fish were most often swimming. Sound pressure levels were approximately 155 dB re 1 μPa directly in front of the speakers for both pure tones and broadband sound and dropped below 120 dB re 1 μPa at the far end of the pond (Fig. 1). All pure tone stimuli showed a narrow energy peak at the dominant frequency (Fig. 2). The broadband sound produced a spectrum of sound from 0.06–10 kHz, with maximal energy contained in two peaks from 0.06–2 kHz and 6–10 kHz (Fig. 2).

Behavior was monitored with eight overhead SONY bullet 500 TVL video cameras connected to ProGold software (Security Camera World, Cooper City, FL). The cameras continuously monitored the fish during daylight hours on testing days and provided full coverage of the pond. The water remained clear throughout the entire study and fish were visible in all areas of the pond. All monitoring equipment (i.e. cameras, speaker switchbox, etc.) was contained within a shelter located approximately 50 m from the test pond, therefore eliminating any experimenter influence on fish behavior. Additionally, hydrophone

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