


Article

Behavioural Response of Juvenile Common Carp (*Cyprinus carpio*) and Juvenile Channel Catfish (*Ictalurus punctatus*) to Strobe Light

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Abstract: The movement of fish can be regulated by behavioural manipulation through non-physical barrier systems. Aquatic invasive species are becoming one of the major management issues in North America, and threaten native aquatic ecosystems, including freshwater fish. Placements of non-physical barriers in waterways can help disrupt the movement of invasive fish. This study examined the effect of a strobe-light stimulus on the avoidance behaviour of two proxy species, juvenile common carp (*Cyprinus carpio*) and juvenile channel catfish (*Ictalurus punctatus*), in a controlled laboratory environment. For each species, three sequential treatments of pre-stimulus, strobe-light stimulus, and post-stimulus for 30 min periods were recorded on acclimated groups of 5 juvenile common carp and 5 juvenile channel catfish using 15 and 13 replicates, respectively. The distribution of juvenile common carp individuals throughout the tank did not change significantly with treatment, nor did cohesive grouping behaviour. Similarly, there were no significant differences across experimental treatments in average location/distance of juvenile channel catfish relative to the strobe light or degree of cohesion in response to the strobe light. Non-physical barriers have been widely reported to vary between species and environmental conditions. These results suggest that strobe lights evoke no avoidance or attractive responses in juvenile common carp and juvenile channel catfish, and will likely not be an effective barrier to inhibit movements of juvenile invasive fishes.

Keywords: fish barrier; deterrence; invasive species; juvenile life stages; fisheries management; conservation

1. Introduction

In recent years, aquatic invasive species has become one of the major management concerns, given their negative impact on our ecosystems, and increasing population size and habitat ranges [1–3]. Physical barriers in aquatic environments are common, effective management techniques that can physically obstruct fish movement [4]. Physical barrier technologies may be useful in managing fishes in reservoir environments, however, areas with high debris loads increase maintenance requirements, rendering the application of such barriers impractical [5]. By contrast, non-physical deterrence systems do not constrain flow or restrict navigation and, in some cases, allow the movement of non-target organisms [6]. Non-physical deterrence systems can be defined as any stimuli that discourages or prevents a species from moving into specified areas [6]. Non-physical deterrence systems rely on the

manipulation of sensory systems that drive species behaviour. Various external stimuli have been used to manipulate fish behaviour, such as stroboscopic lights [7,8], broadband sound [9,10], and chemical cues (e.g., alarm cue) [11–13]. The effectiveness of various non-physical deterrence systems is variable across species, and success is dependent on the nature of the behavioural response [5–7,14–17]. Such variation suggests that no single deterrence method will be a ‘one-size fits all’ solution, and that the installation of non-physical deterrence systems must be tailored towards specific project goals [6]. While barrier success varies with objective, species, device, and location, strobe lights have been effective for the greatest number of species perhaps due to their relatively easier deployment [4,7,8,17].

Fish use several sources to gather information from their external environment [18]. The cues most often used for daily activity (feeding, mating, avoiding predators) are light, sound, temperature, vibration, and chemicals [18]. Therefore, the sensory systems to detect these cues can be well-developed [18]. The aquatic environment is full of visual indicators, and teleost fishes are highly adapted to detect changes in the visual environment [7,13]. Strobe lights are a form of non-physical deterrence system and can be defined as intermittent high-intensity light for short durations [14,19]. The use of strobe lights as a deterrence system for common carp (*Cyprinus carpio*) aims to manipulate this anatomical characteristic [7]. The strobe light provides sufficient light for orientation, however, the abnormal pulsating changes in brightness stimulate avoidance reactions [6,16].

Strobe lights have received greater attention as a behavioural stimulus, predominantly in guiding migrating salmonids [14,20]. Strobe lights have been shown to deter a variety of species (e.g., chinook salmon (*Oncorhynchus tshawytscha*), common carp, gizzard shad (*Dorosoma cepedianum*), largemouth bass (*Micropterus salmoides*), rainbow smelt (*Osmerus mordax*), and yellow perch (*Perca flavescens*)) [7,14,15,17,18,21]. For example, adult common carp stayed away from strobe lights [7]. In general, most studies to date have evaluated sensitivity of fishes to strobe lights in adults or sub-adults, but not juvenile stages. Moreover, most studies tend to focus only on target species, hence limited information is available for potential impacts on non-target or native species including channel catfish [6].

The development of non-physical barrier technologies aims to deter invasive species by disrupting potential dispersal routes. Prevention of aquatic invasive species entering new regions provides a higher probability of conservation success, as removing established populations is nearly impossible [3,22]. For our research, juvenile (i.e., age-0) common carp were used as a model organism for target species, and juvenile (i.e., age-0) channel catfish (*Ictalurus punctatus*) as non-target species. Common carp is an introduced species in Canada, United States, Australia, Kenya, and elsewhere in the world [23–25]. They are considered harmful to native fishes and plants as they destroy submerged aquatic plants and increase the turbidity of surrounding water [24–26]. Channel catfish are native to North America, including the Great Lakes [26]. This study used juvenile common carp and juvenile channel catfish to determine the effectiveness of a strobe-light system on avoidance behaviour in juvenile fishes.

2. Results

The mean number of fishes differed significantly between grid sections (A, B, and C) but not between treatments (pre-stimulus, stimulus, and post-stimulus) for both juvenile channel catfish and juvenile common carp. There was no significant difference on the mean score of cohesive groupings between treatments.

2.1. Juvenile Channel Catfish

There was no significant interaction between grid sections (A, B, and C) and treatments (pre-stimulus, stimulus, and post-stimulus) on the mean number of fish (ANOVA: $F_{4, 126} = 0.83$, $p = 0.51$, Figure 1). The mean number of fish did differ significantly between sections (ANOVA: $F_{2, 126} = 78.60$, $p < 0.001$). Fish spent more time in section A and C compared to B (Figure 1). However, the mean number of fish did not differ significantly between treatments (ANOVA: $F_{2, 126} = 0.17$, $p = 0.85$; Figure 1). Moreover, a two-factor repeated-measures ANOVA yielded no significant difference in the mean score of cohesive

groupings between treatments ($p > 0.05$). In general, juvenile channel catfish stayed in a group of three or more most of the time.

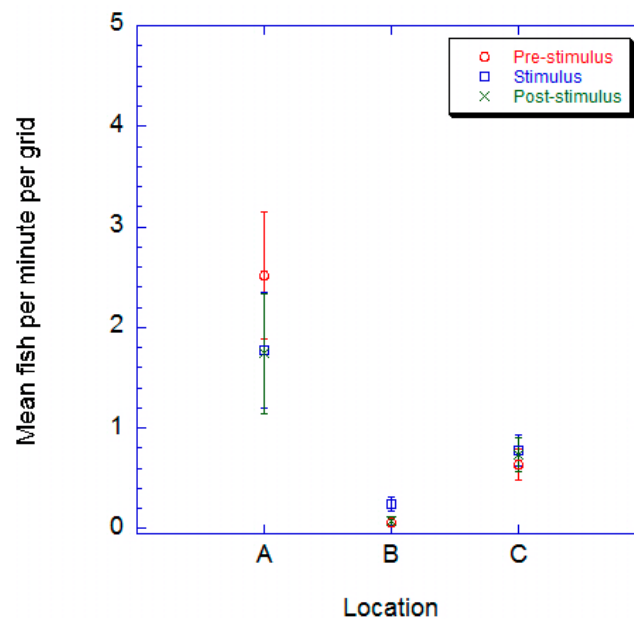


Figure 1. Mean (\pm SE) number of juvenile common carp per minute per grid (N = 15).

2.2. Juvenile Common Carp

There was no significant interaction between sections and treatments on the mean number of fish (ANOVA: $F_{4, 108} = 0.66$, $p = 0.62$; Figure 2). The mean number of fish significantly differed between sections (ANOVA: $F_{2, 108} = 21.3$, $p < 0.001$), where fish spent more time in location A and C, compared to B (Figure 2). However, the mean number of fish did not differ significantly between treatments (ANOVA: $F_{2, 108} = 0.30$, $p = 0.74$; Figure 2). In addition, the mean score of cohesive groupings did not differ significantly between treatments (ANOVA: $F_{2, 21} = 0.93$, $p = 0.41$). Much like juvenile channel catfish, juvenile common carp stayed in a group of three or more most of the time.

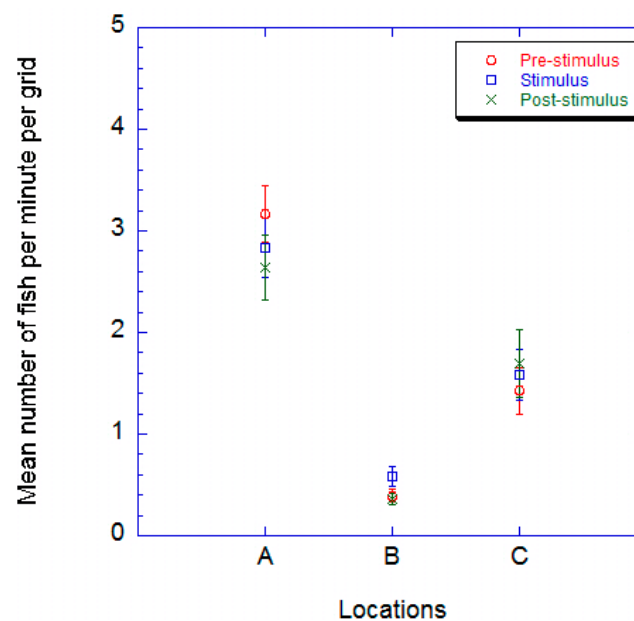


Figure 2. Mean (\pm SE) number of juvenile channel catfish per minute per grid (N = 13).

3. Discussion

Although juvenile channel catfish and common carp did not exhibit significant responses to the three treatments (pre-stimulus, stimulus, post-stimulus), they did exhibit a preference to certain sections within the experimental tank. All grid sections were assumed to be equal, however, the results suggest that the average distributions per grid section were different during the pre-stimulus treatment. This may be an inevitable result of protective cover [27,28] as sections A & C both included corners of the tank that offered more security than the center grid section. Furthermore, the tank drainpipe was also located in grid section A, which could have caused an attractive effect. This may be a more appropriate test of avoidance behaviour, as the test groups demonstrated preference within the tank. Conclusions about the ability of the stimulus to remove fish from previous areas of preference can clearly demonstrate stimulus aversion [29].

The avoidance of the strobe-light stimulus was quantified by the spatial distribution of individuals during the 30 min stimulus treatment. The lack of significance between average frequencies of fish distribution within the tank demonstrates that the strobe light had no effect on the test individuals. While Figures 2 and 3 suggest that there was a decline in the distribution of both species in section A, and an increase in section C, marginal overlap demonstrates no significant change (i.e., $p > 0.05$). Königson et al. [18] suggested that it is not necessary to startle fish, but to provide a component of the response that controls movement in a specific direction. The flash duration of the strobe light is a more important factor rather than the spectral composition of the light source, potential changes to flash duration in the present study could have yielded dramatically different results [17,19].

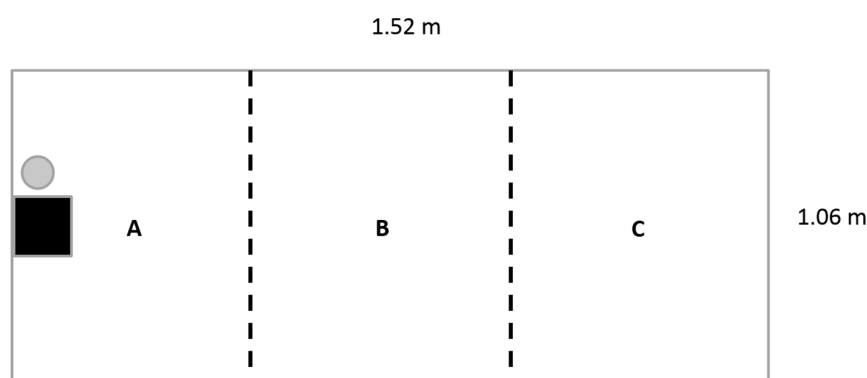


Figure 3. Layout of experimental tanks with scoring grid. Dashed lines represent the grid sections used to determine fish distributions. The black square represents the strobe-light stimulus. The grey circle represents the submerged GoPro camera.

Cohesive behaviour among animals is an attempt to dilute predation risk [30]. A higher number of individuals in a group decreases the probability that an individual will be harmed [30]. This research showed that the frequency of cohesive grouping between test individuals did not vary with treatment. Fish in dense aggregations often produce different responses in comparison to individuals and may respond to light stimuli differently [14]. Cohesive behaviour is used for various activities among species, the formation of temporary or permanent groups allows for potential fitness advantages as a result of higher quality reproduction, foraging or defense [31]. For example, sticklebacks often inspect a predator in pair groupings, as the probability of predation during inspection is reduced by 50% when a partner is present [30]. As the strobe-light barrier provides no harm to individuals, it is possible that experimental individuals evaluated their interactions with the barrier. In escape studies, fish often swim parallel to the barrier, turn away and retreat, and then approach the barrier again [32]. These behaviours were thought to be testing the barrier and when no harm was encountered individuals escaped confinement [32].

The relative indifference of juvenile channel catfish and juvenile common carp to strobe lights suggests that strobe lights would not be an effective barrier. In contrast, adult common carp stayed away

from strobe-lights [7]. Channel catfish also showed low sensitivity to strobe lights when compared to largemouth bass, chinook salmon, and yellow perch [15]. Previous literature has suggested that foraging schedules and activity rates may be linked to the efficacy of non-physical barriers [32]. For example, largemouth bass had higher foraging success during daylight hours while also having greater escape rates during that time [33]. Pelagic fishes, such as alewife (*Alosa pseudoharengus*), gizzard shad, and rainbow smelt, were repelled by bubble barriers, while demersal fishes, such as the white sucker (*Catostomus commersonii*), were attracted [16]. The flash rate of the strobe light was set to random flash (manufacturer setting), which could have been too similar to natural conditions. Strobe-light efficacy depends on a flash rate that is distinguishable from natural light fluctuations produced by waves and clouds [34]. Many studies note lower strobe-light efficacy during daylight hours, suggesting that ambient light dilutes the effect of the strobe light [4,14,19,29]. Furthermore, light as a deterrence system varies with wavelength and turbidity [14,18,19].

The wide range of studies presenting variable degrees of barrier efficacy with environmental and species traits suggests that there must be a case-by-case analysis to determine suitability. Strobe-light barriers are well known in fish management for their low cost and simplicity, and have attracted much attention in the application of invasive species management. This study suggests that strobe lights will not be an effective barrier to the spread of invasive common carp juveniles, however, studies examining the different frequencies of strobe light or using different tank size may provide more reliable results.

4. Materials and Methods

4.1. Experimental Subject and Set-Up

The study was conducted in the Aquatic Life Research Facility at the Canada Center for Inland Waters in Burlington, Ontario, Canada. One experimental tank (3.04 m × 1.06 m × 0.42 m) was used to conduct 1.5 h trials for either juvenile common carp (15 replicates) and juvenile channel catfish (13 replicates). Only one-half of the experimental tank was used, to ensure that individuals could be recorded by camera (Figure 3). Each trial consisted of three sequential 30 min treatment periods on groups of 5 randomly selected juveniles (i.e., age-0) common carp ($n = 75$, length = 6.12 ± 0.67 cm) or juvenile (i.e., age-0) channel catfish ($n = 65$, length = 7.60 ± 0.45 cm). For the experiment, each individual fish was only used once. The three treatments included a pre-stimulus period (strobe light off), a stimulus period (strobe light on), and a post-stimulus period (strobe light off).

Prior to the study in July 2015, juvenile common carp and juvenile channel catfish were purchased from Osage Catfisheries (Osage Beach, MO, USA). Fishes were housed in a series of large recirculating tanks (~689 L). Water temperatures were maintained at approximately 14 °C. Fishes were fed (1.0%–1.5% of fish weight) daily with commercial fish food (Profishent Trout Chow, Martin Mills, Inc., Elmira, ON, Canada) and maintained in a 12 h/12 h (dark/light) cycle.

The experimental tank was enclosed with blackout blinds to maintain controlled lighting conditions. Above-tank lighting was automated on a daylight-hour schedule, dimming from 25% to zero by 21:00, and increasing from zero to 25% by 07:00. For each species, test groups of juvenile fishes were transferred to the experimental tank using disinfected dip nets 17 h before the sequential treatments were applied. Water temperature was maintained at 12–14 °C, and water flow was provided at all times to keep consistent temperatures. An aeration bar was placed on the side of the tank where fish were not present. The physical barrier placed to divide the tank prevented fish from moving out of the filming area without disrupting water flow. The submerged strobe light (See Brite LED Underwater light, IAS Products Ltd., North Vancouver, BC, Canada) with random flashes (0.05–1.0 s flash rate, where each flash lasts 1.5 ms) was placed opposite the barrier and attached to the center of the wall of the experimental tank (Figure 3). This strobe light (See Brite LED Underwater light, IAS Products Ltd., North Vancouver, BC, Canada) uses 110 volt AC $\pm 10\%$ at 50/60 Hz and consists of 4 LED (light intensity = 13,402 lumens) circuit board panels radiating light at 360° with a full spectrum (400–700 nm), and had a 1.8 ampere demand. Strobe-light strength (LED light intensity = 13,402 lumens) was measured

using a portable lux meter with a waterproof probe (Millwaukee Instruments, Inc.). In ambient light conditions (i.e., with experimental room lights on but strobe light turned off), light levels within the tank ranged from 0 to 66 lux in the experimental tank (mean light level = 15.58 lux, $n = 12$), whereas with strobe lights including experimental room lights turned on, light levels ranged from 783 to 31,600 lux (mean light level = 6176.00 lux, $n = 6$) [7]. Due to strobing, precision of the portable light meter, and a relatively small size of tank, we only reported the ranges of light levels measured within the tank. Light levels were kept consistent and appropriate for this experimental design; light levels were highest near the strobe light when flashing and decreased as the distance from the strobe light increased, with the lowest light levels observed at the far end of the tank. At the end of each trial, the experimental tank was drained and rinsed before the next test group was introduced to reduce the potential effect of chemical cues that may have been produced during the previous trial.







4.2. Data Collection and Analysis

Each trial was recorded for the full duration using a submerged camcorder (GoPro Hero) and overhead camcorder (Canon XA-25). Trial recordings were used to quantify juvenile common carp and juvenile channel catfish behaviour during treatment sessions. Within the experimental tank, red waterproof tape was applied to laterally divide the filming arena into three sections, labeled A to C, starting closest to the camera's field of view (Figure 3). The spatial distribution of fish during each treatment session was analyzed using a time-sampling approach. At 1 min intervals, the number of fish in each grid section of the tank was recorded manually, totaling 30 observations per treatment. The total number of fish observed in each grid section over the 1 min interval was totaled and averaged across all trials.

Group cohesion is also a measure of avoidance behaviour in animals [35,36]. Cohesive behaviour was evaluated using JWatcher [37,38] scoring software for behavioural analyses. The ethogram for the analysis aimed to identify a continuous tally of grouping interactions within each treatment session. A grouping was defined as two or more individuals within one body length or less distance, for at least five seconds. The five second duration of grouping ensured that positions were intentional by the individuals in the group, and not a byproduct of passive movement within the tank [35,39,40]. Average total body length of test individuals was 6.12 ± 0.67 cm, representing 4% of the tank length. It was assumed that individual position within less than one body length indicated intentional positioning [7,35,40,41]. Cohesion groups were denoted as '2' through '5', corresponding directly to the number of individuals in the group as events (Table 1). The cohesion group '1' described states where all fish in sight were greater than one body length away from all other individuals (no grouping behaviour present). The '0' cohesion group represented states where no individuals were in the camera's field of view and, thus, no observations of cohesive behaviour could be recorded. The proportion of time spent out of sight was totaled, and treatment sessions that exceeded 15 min were excluded from the analysis. The frequency of grouping type was determined by totaling the number of observations of a grouping and dividing by the total number of observations made during the treatment session. The average frequency was calculated across all trials for each treatment.

For statistical analyses, two-way ANOVAs were used to examine the differences between mean number of fish per minute, per grid, between all treatments. The predictor variables were treatments and grid sections, and the response variable was the total number of fish per grid section. The null hypothesis was that there were no significant differences in the frequencies of fish per grid section between treatments and grid sections. Moreover, single-factor repeated-measures ANOVA was used to determine if there was a significant difference in the mean frequency of a grouping type between treatments. The predictor variable was treatment type, and the response variable was the average frequency of grouping type. The null hypothesis was that there were no significant differences between treatments. All statistical tests used a significance level of 0.05 and were conducted using SPSS v23.0.

Table 1. Rules and examples for cohesion scoring based on number and formation of fishes in the tank.

Cohesion Group and Points	Number of Fish	Example Configurations
0	1	
1	2	
2	3 in a line	
3	3 in tight group or 4 in a line	
4	4 in tight group or 5 in a line	
5	5 in tight group	

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Conflicts of Interest: The authors declare no conflict of interest.

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