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Going the Distance: Influence of Distance Between Boat Noise and Nest Site on the Behavior of Paternal Smallmouth Bass

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Abstract The effects of anthropogenic noise have garnered significant attention in marine ecosystems, but comparatively less is known about its impacts on freshwater ecosystems. For fish that provide parental care, the effects of acoustic disturbance could have fitness-level consequences if nest tending behavior is altered. This study explored the effects of motorboat noise on the parental behavior of nesting male smallmouth bass (*Micropterus dolomieu*; Lacépède, 1802), an important freshwater game fish in North America that provides sole paternal care to offspring. Specifically, we evaluated how boat noise proximity to a bass nest (ranging from 4.5 to 90 m) influenced paternal care behaviors. A total of 73 fish were exposed to a 3-min motorboat playback designed to simulate a boat sound that typically occurs in areas near littoral nesting sites. The fish were video recorded, and their behaviors were analyzed before, during, and after exposure to the playback. Residency time was the only behavioral metric to be adversely affected by noise playbacks but only when in close proximity to the speaker. Our results suggest that boat noise may have an impact on bass reproductive fitness in specific contexts where combustion motors are used near shore during the nesting period. The largely null findings may indicate a resilience to boat noise and/or habituation to the noise. In addition, boats displace water and create waves that represent another form of disturbance that could be experienced by fish but was not simulated here. Future research should integrate behavioral and physiological responses to boat noise and other aspects of boat disturbance to better understand the fitness impacts of boating activity on freshwater fish.

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1 Introduction

Noise pollution arising from human activities is a global phenomenon affecting all ecosystems (Kight and Swaddle 2011). Research into the effects of noise pollution has largely focused on birds (Ortega 2012) and mammals (Tyack 2008; Barber et al. 2010), with a more recent effort to understand the effects on fishes, particularly in the marine realm (Celi et al. 2016; Herbert-Read et al. 2017; Cox et al. 2018; Hasan et al. 2018).

Much of the anthropogenic noise contributing to the soundscape in freshwater ecosystems is attributed to recreational boat motors (Mosisch and Arthington 1998; Slabbekoorn et al. 2010) with its prevalence likely to increase with significant rise in recreational boating traffic (Graham and Cooke 2008; NMMA 2015). Consequently, there is growing need to understand the effects of noise from boating activities on fish in freshwater ecosystems (Graham and Cooke 2008).

Critical life history periods represent a crucial link between behavior and fitness (e.g., Brommer 2000; De Block and Stoks 2005). This is quite apparent in the centrarchid fishes which exhibit strong paternal care behaviors during their reproductive period (Blumer 1979). Briefly, this involves the male of the species constructing and guarding a nest throughout the brood's development from egg to fry. The strength of the parental care exhibited by the male varies between species and individuals (reviewed in Neff and Knapp 2009). Consequently, alterations to the nest tending behaviors of the male can have serious implications for reproductive success. For example, anthropogenic activities including angling, shoreline development, and simulated stressor exposures have been shown to reduce reproductive outputs notably through an increased rate of nest abandonment (Suski et al. 2003; Wagner et al. 2006; Dey et al. 2010; Zolderdo et al. 2015). While investigated to a much lesser extent, teleost parental care behaviors such as nest defense and maintenance can be adversely affected by acoustic disturbances (Bruintjes and Radford 2013; Nedelec et al. 2017; Maxwell et al. 2018). In one of the only published centrarchid studies of its kind, parental largemouth bass (*Micropterus salmoides*) demonstrated hyper vigilance during the egg-sac fry stage of development (Maxwell et al. 2018). In a similar work, parental longear sunfish experienced longer nest absences following exposure to a boat motor playback, relative to controls (Mueller 1980). Interestingly, this contrasts some of the marine work where complete brood loss (~32% of all broods were completely lost) has been seen to occur under such conditions (Nedelec et al. 2017). Given that different environments and contexts can have an influence on sound propagation and thus may influence behavioral effects (Rogers and Cox 1988), comparisons in the behavioral responses of marine and freshwater organisms may not be directly equivalent. Clearly, the lack of information regarding the influence of acoustic stimuli on reproductive success in freshwater species highlights the need for further study in this area, especially given the intensification of anthropogenic activities in freshwater aquatic systems (Nedelec et al. 2017).

The objective of this study was to examine the effects of noise pollution associated with recreational boating on the parental care behavior of smallmouth bass (*Micropterus dolomieu*), an important game fish in many parts of North America (Quinn and Paukert 2009). Specifically, we were interested in addressing how the distance from noise produced by an outboard motor influenced paternal behavior. We expected that the greatest disturbances to nest tending would occur where the sound pressure level was at its greatest (i.e., sound emission closest to the nest) and would decline thereafter until it reached a point below the animals' auditory threshold. In testing this, nesting male smallmouth bass were exposed to a 3-min pre-recorded audio clip of a 2-stroke outboard boat motor at varying distances from the nest. Nest tending behavioral responses were recorded prior to and following audio playbacks.

2 Methods

2.1 Study Site and Study Subjects

Data were collected on Big Rideau Lake (44.7706° N, 76.2152° W), in Portland, Ontario, Canada, in May and June 2017. Big Rideau Lake is part of the Rideau Canal system and is a deep, oligo-mesotrophic lake containing bays with a rocky and sandy bottom (Forrest et al. 2002). This location provides ideal nesting habitat for smallmouth bass populations. During the data collection, the average daily water temperature was 15.4 °C ± 0.78 °C. Much of the boating activity on Big Rideau Lake is recreational, including motorboating and canoeing.

Nest-guarding male smallmouth bass ($n = 73$) were identified using snorkeling surveys. Each nest site included recordings of the nest score, egg score, nest depth, and water temperature. All nests used in the study were in the egg developmental brood stage (see Ridgway, 1988 for a description of the developmental brood stages). Nest score was assessed as the relative number of eggs present in the nest and given a ranking from 1 to 5 (low to high; Suski et al. 2003; Suski and Philipp 2004; Zolderdo et al. 2016). Egg score was assessed as the maturity of the eggs in the egg developmental stage, ranging from 1 to 5 (newly spawned eggs to eggs which would shortly enter the wriggler stage; see

Hubbs and Bailey 1938, Ridgway 1988, & Cooke et al. 2002a for details). The nest depths ranged from 0.5 to 3.5 m. A PVC identification tile was placed near the nest to mark individual nests upon their identification.

2.2 Experimental Procedure

A motorboat recording was used in the playback experiment, designed to emulate the sound of a typical recreational motorboat passing through the littoral zone. The recording was taken from real motorboat drive-bys in Lake Opinicon (44.5590° N, 76.3280° W), an interconnected lake that is part of the Rideau system, which is in close proximity to the study site, and has a similar water depth and other environmental features. To create the recording, a hydrophone (SoundTrap 300 STD, Ocean Instruments Inc., New Zealand; sample rate: 48 kHz) was mounted underwater at 2 m depth (a depth where smallmouth bass typically nest), while the boat passed by at different speeds. First, a high-speed drive-by recording was produced by driving a 5.4-m aluminum-hulled fishing boat with an outboard motor (75 HP E-Tec, 2-stroke, Evinrude, USA), operating at 5000 rpm, past the hydrophone at a distance of 10 m. Next, a low-speed drive-by recording was produced using the same boat and motor, operating at 600 rpm. The recordings were then compiled together to create a 3-min recording consisting of a 1-min high-speed boat drive-by, a 1-min low-speed drive-by, followed by a second 1-min high-speed drive-by.

A total of 73 nest-guarding male smallmouth bass were exposed to a 3-min motorboat playback treatment at distances ranging from 4.5 to 90 m ($N = 73$). Consequently, distance represented a continuous variable. Fish were marked in cluster of 3 or 4 individual fish which were > 5 m apart from one another along a shoreline and thus unable to see each other. They were exposed to the sound playback with the approximate distance of the playback being determined randomly and varying for each fish based on shoreline configuration. Actual distances were determined using a range finder immediately following the behavioral trial. Each individual fish was only used once, and nontarget fish were not subsequently used for the experiment. We avoided this by using multiple sites with similar habitat characteristics throughout the experiment. Also, nests in areas with similar habitat/substrate composition were used to avoid issues related to varying acoustic profiles between nesting sites (Rogers and Cox 1988). After the initial nest characterization, an underwater camera (Hero 3+, GoPro Inc., USA) was placed 1 m in front of the nest to record the nesting behaviors. The hydrophone was placed at variable distances depending on the treatment distance (see above). Upon getting close to the nesting sites (> 100 m), the outboard motor on the boat was turned off, and we paddled quietly up to the desired playback distance to avoid any issues associated with noise or physical disturbance generated from our own boat. Here, the distance to each nest site from the speaker was determined using a high precision rangefinder (Bushnell Sport 850), aimed at a snorkeler floating above the nest. The snorkeler then returned to the boat, and the fish was given 10 min to acclimate to the camera and allow any disturbed sediment surrounding the camera to settle (Prystay et al. 2019). While it is possible that the fish may have been disturbed by the snorkeler following camera placement, we were interested in the relative change in the fish's behavior to the boat noise treatment.

Playbacks were conducted in the following manner. The sound treatment was delivered using an underwater speaker (University Sound UW30, Lubell Labs Inc., USA; see Maxwell et al. 2018), a widely used model in the aquatic acoustic literature (e.g., Kunc et al. 2014; Bruintjes et al. 2016; Simpson et al. 2016). The speaker was attached to a wooden pole and consistently held off the side of the research boat at a depth of 1 m from the water's surface to simulate the depth of an outboard boat motor. The hydrophone was placed at each nest to record the received levels during each playback. The output for this can be found in Fig. 1. After the 10-min acclimation period, there was a 5-min control used to assess baseline behaviors, followed by a 3-min motorboat playback treatment and a 10-min post-treatment period (for a total of 18 min of recording per replicate). All fish were subject to sound exposure (i.e., no use of no sound controls) as each individual's pre-exposure data served as its own control, and we were interested in the relative change in the fish's behavior when exposed to the acoustic disturbance. All assessments occurred during weekdays when boating activity is negligible relative to spring weekends.

2.3 Data Analysis

The behavioral responses in each 18-min video were analyzed using the event recorder J Watcher (Blumstein et al. 2006; http://www.jwatcher.ucla.edu/). The behavioral responses used on this study included (1) number of 90° turns on the nest, (2) time on nest (residency), (3) time fanning, and (4) number of darting behaviors. Residency time was used as a proxy for defense (Algera et al. 2017). The fish was considered to be on the nest when > 50% of the fish's body was within the nest. The number of 90° turns (a proxy for vigilance) was found to be altered when nesting largemouth bass were exposed to noise at ~3 m (Maxwell et al. 2018). Fanning was used to approximate nest maintenance and was defined as any intentional and directional movement of the caudal or pectoral fins near the eggs (Coleman and Fischer 1991; Algera et al. 2017). Darting was indicative of chasing away a nest predator, defined as rapid swimming across or away from the nest (Algera et al. 2017). The behaviors were then grouped into three time phases: control (5 min), treatment (3 min), and post-treatment (10 min).

All statistical analyses were conducted in R (v. 3.2.3, R Foundation for Statistical Computing, Vienna, Austria; R Core Team 2019). General linear mixed models (GLMMs), using the package "lme4" (Bates et al. 2015), were used to test for the effects of motorboat playback distance on male smallmouth bass parental care behaviors. Continuous explanatory variables were standardized here (subtracting the mean and dividing by the standard deviation) to ensure model convergence and standardize coefficients on a similar scale for comparisons (see Zuur et al. 2009). Fish ID was included as a random effect in the model to account for repeated measurements in behavior. The number of 90° turns on the nest for each time interval was analyzed using a Poisson-distributed GLMM fitted by maximum likelihood (Laplace approximation) offset by time in minutes. Offset was included as a factor in the model to account for the given time that data was recorded (i.e., the exposure period) and was included in the model by adding + offset (time) after the factors in the GLMM. The offset was used to account for the variation in time in each time phase of the experiment. The correlation between proportion of time spent on the nest and proportion of time spent fanning was essentially 1 ($r = 0.999$); therefore, only the proportion of time spent on the nest (residency time) was further analyzed. The residency time at each time interval was analyzed using a binomial GLMM fitted by maximum likelihood (Laplace approximation). No offset was required in this particular instance as residency was measured as a proportion of time, and therefore the variable itself is related to time making a further addition of an offset to be redundant. In two separate models, the number of darts and the number of 90° turns on the nest for each time interval were analyzed using a Poisson-distributed GLMM. These behaviors are summarized in the Results section.

3 Results

All raw data used in this project can be found in a Dryad database (https://datadryad.org/stash/dataset/? https://doi.org/10.5061/dryad.fxpnvx0nm). There was no significant relationship between the number of 90° turns and the time phase (control, treatment, post-treatment) nor was there a significant interaction between each time phase and distance (Table 1). Visual observation of Fig. 2 suggests that the number of turns throughout all the time intervals only varied by ~3 turns (i.e., the confidence intervals of the model), with most variation occurring in treatment and post-treatment periods.

For residency time, there was a significant interaction between treatment and distance as well as post-treatment and distance. Both of these terms scale in a positive manner indicating that as the playback becomes closer to the nest, residency time on the nest is reduced during both the treatment and post-treatment phases (Table 1). Furthermore, there appears to be a trend toward an effect of treatment ($Z = 1.666$; $P = 0.095$) and a statistically significant effect of post-treatment ($Z = -4.147$; $P < 0.001$) on residency time. Conversely, there was no effect of the control period or distance alone on modifying residency time here (Table 1). The variation in residency time was minimal (< 4%; Fig. 3).

The number of darting behaviors, while showing statistical significance for control and post-treatment periods (Table 1), did not have a relationship with the distance to motorboat playback in either the control, treatment, or post-treatment time intervals (Fig. 4; Table 1). The statistical effects noted for the control and post-treatment period were largely driven by two individual fish and thus do not represent a biological effect of the noise per say. The summary statistics for darting behaviours can be found in Table 2.

4 Discussion

In this study, we examined the effects of boat noise on paternal care in nesting smallmouth bass in a natural

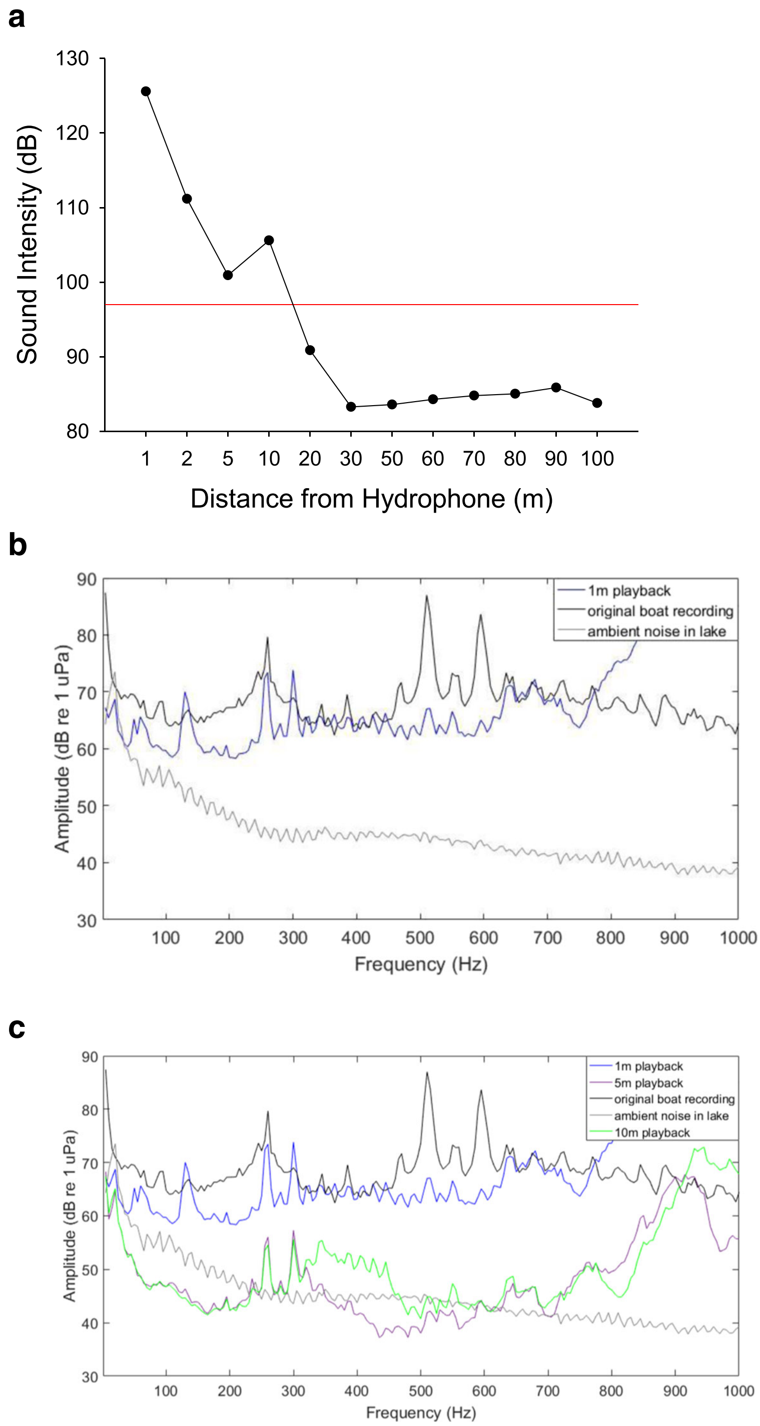

Fig. 1 **a** Relationship between the intensity of the sound of the boat noise recordings and the distance from the hydrophone in the natural lake environment with each dot representing a single measurement. The red line depicts ambient noise levels at 97 dB. **b** Acoustic spectra of the original boat recording (black line), the playback of boat noise received at 1 m distance from the speaker, and ambient noise in the lake (in the absence of boats). **c** Acoustic spectra of the original boat recording, ambient noise in the lake, and playbacks at 1, 5, and 10 m distances from the nest

setting. We predicted that parental care behaviors of nesting males would decrease as the fish's proximity to the motorboat noise increased. The predictions of the study were somewhat supported by the results. While there was no effect the playback on darting and turning behaviors, there was an effect of the playback on the treatment and post-treatment phases (Table 1) where residency time was lowered as the speaker approached

Table 1 Summary statistics of GLMM for male guarding smallmouth bass behaviors (number of 90° turns and proportion of time on nest)

PC variable	Fixed effect	Estimate (SE)	Standard error	*Z*	*P*
# 90° turns	Control	1.379106	0.052536	26.251	*< 2e-16*
	Treatment	0.050083	0.040246	1.244	0.213
	Post-treatment	0.020948	0.030549	0.686	0.493
	Distance	− 0.002326	0.052687	− 0.044	0.965
	Treatment × distance	0.023787	0.040684	0.585	0.559
	Post-treatment × distance	− 0.021568	0.031087	− 0.694	0.488
Proportion of time on nest (residency)	Control	3.96699	0.22941	17.292	*< 2e-16*
	Treatment	0.09245	0.05548	1.666	0.09563
	Post-treatment	− 0.16615	0.04007	− 4.147	*3.37e-05*
	Distance	− 0.18027	0.22677	− 0.795	0.42665
	Treatment × distance	0.16558	0.05583	2.966	*0.00302*
	Post-treatment × distance	0.27529	0.04012	6.861	*6.83e-12*
Darting behaviors	Control	− 6.80540	0.41693	− 16.323	*< 2e-16*
	Treatment	0.71908	0.50550	1.423	0.155
	Post-treatment	− 4.42463	0.29462	− 15.018	*< 2e-16*
	Distance	0.00072	0.00694	0.103	0.918

the proximity of the nest. Specifically, this occurred at small distances between the speaker and the nest itself. Together, these effects suggest that boat noise has the potential to affect the parental behaviors of nesting smallmouth bass in instances where boats operate near the shore during the nesting period.

Smallmouth bass nest in the shallow littoral zones of freshwater lakes, in areas with a rocky and sandy substrate, and in little vegetation (Lukas and Orth 1995) which are frequented by boaters. Our results appear to indicate that nesting behaviors in smallmouth bass can be impacted by the noise produced by 2-stroke outboard motors. Residency time on the nest was significantly reduced during and after treatment for fish that where in close proximity to the speaker. Increasing time away from the nest may be problematic from a fitness

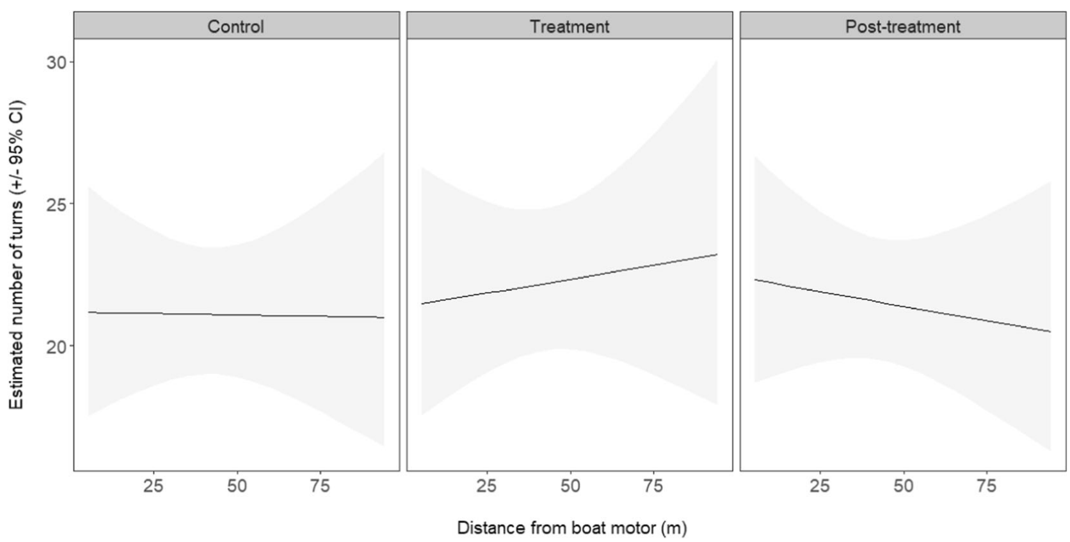

Fig. 2 Estimated number of turns (± 95% CI) made by nest-guarding male smallmouth bass at varying distances from a motorboat playback (4.5–90 m) for control, treatment, and post-treatment phases

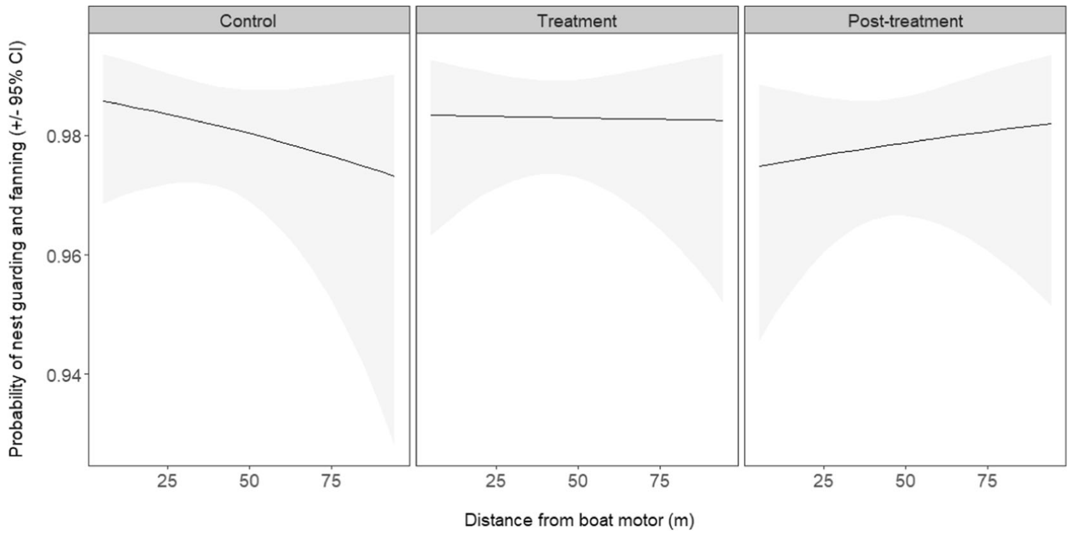

Fig. 3 Estimated probability (± 95% CI) of residency and fanning behavior in smallmouth bass at various distances from a motorboat playback (4.5–90 m) for control, treatment, and post-treatment phases

perspective as this leaves the nest vulnerable to nest predators as well as decreasing the amount of time that the fish is tending the eggs, both important factors in dictating black bass recruitment (Cooke et al. 2000, 2002b; Steinhart et al. 2005; Algera et al. 2017). However, it is important to note that absences were quite brief and disturbance would likely need to occur repeatedly over the entire parental care period to likely have any effect on the animal's reproductive success. In support of our findings, Mueller (1980) found that nest-guarding longear sunfish, a closely related species to smallmouth bass, had a lower residency time on the nest as the distance to a boat traveling by the nest decreased. However, this study did not isolate the motorboat noise from the physical presence of the motor. Given the close proximity of the motorboat to fish nest (0.5–4.5 m) in the Mueller (1980) study, the disturbance in behavior may have been due to compounding effects

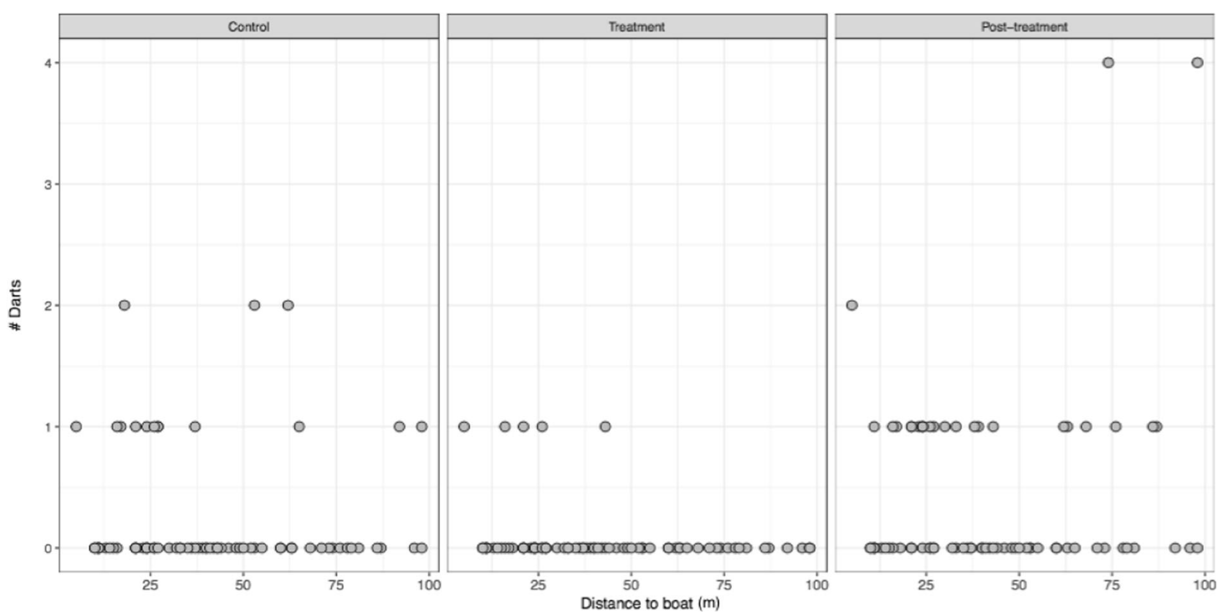

Fig. 4 The number of darting behaviors exhibited by nesting smallmouth bass at various distances from a motorboat playback (4.5–90 m) for control, treatment, and post-treatment phases

Table 2 Summary statistics of the number of darting behaviors of nesting smallmouth bass

Time interval	Mean	Median	Min. turns	Max. turns
Control	0.243	0	0	2
Treatment	0.067	0	0	1
Post-treatment	0.419	0	0	4

of noise and the physical presence of the boat motor causing water turbidity and changes in particle motion. In nesting largemouth bass, Maxwell et al. (2018) found that boat noise largely had no effect on nest tending behaviors, although, like our study, they did see some transient effects of the playback on nest tending behaviors supporting the notion that boat noise may affect reproductive activities in black bass.

Our results, in part, appear to agree with the literature on the topic of boat noise-behavioral interactions in fishes where behavior is often adversely affected (Slabbekoorn et al. 2010; Cox et al. 2018). However, while we did see some minor effects of noise on residency times, our other behavioral metrics were unaffected by the playback. We suspect that detection of the sound itself was not an issue as previous studies have shown that *Micropterus* sp. are capable of detecting sound, especially at low frequencies (best hearing sensitivity at 100–400 Hz; Holt and Johnston 2011). At the closest distances, our playbacks did present acoustic stimuli above ambient noise at these frequencies (Fig. 1), and in prior work with largemouth bass, there were behavioral alterations associated with sound exposure when the speaker was placed ~ 3 m from the fish's nest (Maxwell et al. 2018). Without a published audiogram for *Micropterus dolomieu*, it is difficult to know whether the fish were able to detect the acoustic stimuli presented in this experiment, but our results suggest that any behavioral response was short-lived and therefore difficult to distinguish from normal behavior. Furthermore, Graham and Cooke (2008) demonstrated that largemouth bass experience sublethal physiological disturbances in response to exposure to various boat motors. However, the individual effects of the noise and mechanical disruption could not be isolated from one another in that study, and thus the observed stress response may result from non-acoustic disturbances. While the environment may modulate the sound profile, these studies seem to indicate that the particle motion field created by the physical presence of the boat motor may be required to elicit a change in nest-guarding behavior and that the particle motion produced by an underwater speaker is not sufficient to elicit such changes in general. However, this result is promising because it suggests that efforts to restrict boats (through regulations or boater education) from the most nearshore areas could be sufficient to mitigate the effects of boat disturbance on smallmouth bass. Indeed, no wake areas exist near shore in many waterbodies which may already afford incidental protection to nesting bass.

Our study is also limited by the fact that we only incorporated the acoustic aspect of an outboard motor and not the physical effects associated with the thrust generated by the propeller itself. While studies appear to be limited on the topic, the physical thrust from boat propellers can have a significant influence on the well-being of a fish which can include both behavioral alterations and physical damage to the organism (reviewed in Asplund 2000). In some cases, the shear stresses generated from the propeller's thrust can result in mortality of larval fish (Killgore et al. 2001) which may have consequences for nesting bass offspring. Thus, it would be of interest to include both the physical effects of outboard motors alongside the acoustic disturbances in future works. However, we must caution that we are uncertain if the bass used in our study were exposed to disturbances associated with recreational boat traffic prior to our experimental series which may confound our results if the animals were repeatedly exposed. However, during the spring season, boat traffic is rather sparse (especially on weekdays when we collected data), and boats often keep clear of the rocky shorelines where nesting occurs given that they are a boating hazard. Additionally, any individual scale effects of habituation were likely controlled in our experimental design by the use of the pre-sound exposure control.

Our study system, Big Rideau Lake, is the largest lake on the Rideau Canal system and is connected to the busiest lockstation, seeing approximately 7595 vessel passages through the Narrows Lock in 2017 alone (Watson, 2018). Big Rideau Lake is also one of the most fished waterbodies in Ontario, Canada, with numerous bass angling tournaments each summer (both days on almost every weekend) with up to 150 participants which alone is a significant noise generator. Given that heavy boating traffic begins at about the same time as the bass nesting season, at least on weekends, it is possible that smallmouth bass have become habituated to motorboat noise in an effort to maintain a high degree of reproductive fitness. However, habituation of popular game fish to motorboat noise may result in higher risk of predation from fishing due to a lack of startle response from an approaching fishing craft (Bejder et al. 2009). Further work is necessary to determine whether smallmouth bass habituate to motorboat noise. Picciulin et al. (2010) hypothesized that the lack of behavioral response to boat noise in *Chromis chromis* could be due to high fitness risk associated with altering parental care. Alternatively, the authors postulated that fish may adopt a conditional behavioral strategy to cope with the environmental disturbance. Such a strategy would presumably contribute positive benefits to fitness in populations where sublethal environmental disturbance is high.

Overall, the results of this study show that the distance between the boat noise and the nest site has minimal impact on smallmouth bass nesting behavior particularly if the noise is distant from the nest. However, if repeated close exposures to boat noise were to occur with no habituation, then we may expect some degree of fitness impacts resulting from nest predation and/or lack of egg care (e.g., Steinhart et al. 2005). It is unclear how much boating activity would be needed to lead to meaningful fitness impacts. The general lack of any behavioral response could be explained by smallmouth bass adopting conditional strategies to cope with boat noise disturbances or simply that the sound levels were undetected and/or because of the absence of a real boat motor (thus removing any physical stimuli that may have elicited a behavioral change). While habituation to a nonthreatening source is beneficial in the parental care period by conserving energy for parental care behaviors, desensitization to anthropogenic noise may negatively affect fitness in other life stages by reducing a response to boats, thus making bass an easier fishing target. In order to reduce fish habituation to boats, limiting boat activity near nesting habitat in the parental care period when fish are in the closest proximity to boats may be necessary. However, we recognize that given the shallow nesting sites of these fish, sound disturbances may be greatly attenuated or altered by the environment by the time they reach the fish, particularly if the boat is a great distance from the nest (Rogers and Cox 1988). Future research should consider incorporating both behavioral and physiological measures to develop a better mechanistic understanding of the responses to anthropogenic noise and the potential for habituation. In addition, studies that combine noise with other aspects of boating disturbance (including water displacement and turbulence) in the wild would be particularly helpful.

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