Chapter 32
Pile-Driving Noise Impairs Antipredator Behavior of the European Sea Bass *Dicentrarchus labrax*

Kirsty A. Everley, Andrew N. Radford, and Stephen D. Simpson

Abstract In an increasingly industrialized world, man-made noise is changing the underwater acoustic environment. The effects of anthropogenic noise on marine ecosystems are not yet fully understood despite important implications for science and policy, in particular with respect to investment in offshore renewable energy. In this study, a traditional looming-stimulus experimental setup was used to investigate the acute effects of pile-driving noise on the antipredator response of European sea bass (*Dicentrarchus labrax*). Playback of pile-driving noise was found to impair significantly the startle response of individuals, which potentially translates to an increased likelihood of being captured by predators in natural conditions.

Keywords Looming stimulus • Startle response • Survival • Fitness consequences

1 Introduction

Anthropogenic noise levels in the marine environment have increased substantially since the Industrial Revolution and the potential consequences for marine life are of international concern. Pile driving is often the predominant source of underwater noise around the UK coast due to the increasing construction of offshore wind, wave, and tidal installations. These installations provide a crucial element of the UK's response to the need to reduce CO_2 emissions and ensure energy security and, under the European Commission Marine Strategy Framework Directive, noise must now be monitored and managed. It has been suggested by the UK Crown Estate that as a result of the uncertainty surrounding the impacts of noise on aquatic life, 75%

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of wind farm developments are currently at risk of not being built, with implications for the UK economy and industries.

Sound from pile driving and many other human activities is generally low frequency, falling within the hearing range of many fish species (Slabbekoorn et al. 2010). The European sea bass (*Dicentrarchus labrax*) is a commercially important species in many Atlantic and Mediterranean countries, including the UK, both for capture fisheries and increasingly for aquaculture. Little is known about the effects of noise on *D. labrax* despite the potential conflict between the fishing and offshore renewable energy industries.

This study examined the effect of playback of pile-driving noise on the antipredator response of *D. labrax*, providing a measure of an ecologically important behavior that has direct implications for survival. A predator attack was simulated using a looming stimulus (Fuiman and Cowan 2003) to test the hypothesis that antipredator behavior would be altered in fish exposed to playback of pile-driving noise relative to those exposed to ambient harbor noise. We hypothesized that pile-driving noise may either (1) reduce the proportion of fish that startle, with or without an effect on response time, due to stress and/or distraction or (2) increase the proportion that startle due to a heightened state of alert induced by stress.

2 Materials and Methods

2.1 Noise Treatments

Recordings from three UK harbors (Portsmouth, Plymouth, and Gravesend) were used to create ambient noise tracks (three per harbor) and these were combined with three recordings of pile-driving noise to create nine harbor + pile-driving noise tracks (henceforth called pile driving). Thus, to minimize pseudoreplication in the experiment, we used 18 unique experimental tracks in a blocked design, with half of the fish tested in ambient-noise playback and half in pile-driving conditions. The recordings were made using a calibrated omnidirectional hydrophone (HiTech HTI-96-MIN with inbuilt preamplifier, High Tech, Inc., Gulfport, MS) and an Edirol R09-HR 24-Bit recorder (44.1 kHz sampling rate, Roland Systems Group, Bellingham, WA). The recording level was calibrated for the R09-HR using pure sine wave signals, measured in-line with an oscilloscope, produced by a function generator. Experimental tracks were created using the open source audio editor Audacity (http://audacity.sourceforge.net/) and were repeated to create tracks that were a standard 30 min. The WAV sound files were played back via a sound system consisting of a battery (12 V 7.2 Ah sealed lead-acid), WAV/MP3 player (Philips GoGear VIBE, Koninklijke Philips NV, Amsterdam, The Netherlands), and amplifier (M033N, 18 W, frequency response: 40–20,000 Hz; Kemo-Electronic GmbH, Langen, Germany) attached to an underwater speaker (Lubell Labs University Sound UW-30, frequency response 100–10,000 Hz; University Sound, Columbus, OH).

This is the same basic procedure and setup used in previous studies investigating the effects of sound on behavior (Bruintjes and Radford 2013; Wale et al. 2013a, b).

There was no fade in or fade out to the track because pile-driving noise has a sudden onset. Noise in the glass experimental tank was measured during playback of ambient and pile-driving tracks using a calibrated hydrophone. The hydrophone was placed inside the plastic container used to contain each fish during the experiments to ensure that the noise recorded was the same as the noise experienced by the fish. Before the experiment was started, playback recordings were analyzed in Avisoft SASLab Pro v.4.52 (Avisoft Bioacoustics, Berlin, Germany) and then adjusted in Audacity (http://audacity.sourceforge.net) to achieve uniform sound levels between the nine pile-driving tracks and between the nine ambient tracks. The average peak sound level of the pile-driving tracks (averaged from 1-s recordings during pile strikes) was 160.5 ± 0.1 dB root-mean-square (rms) re 1 µPa and the average sound level of the ambient tracks (averaged from 10-s recordings) was 123.2 ± 0.1 dB rms re 1 µPa.

Averaged power spectra were calculated using a fast Fourier transform (FFT) analysis (spectrum level units normalized to 1-Hz bandwidth; Hann evaluation window, 50% overlap; FFT size 1024). For comparative purposes, an ambient track from harbor A (power spectrum averaged from 5-s recordings) is displayed alongside a pile-driving track (power spectrum averaged from 1-s recordings during pile strikes) in Fig. 32.1. Like most fish, *D. labrax* will detect the particle motion element of sound but because they have a swim bladder, they are also likely to be sensitive to changes in pressure. For logistical reasons, we report the sound pressure levels of the playback of tracks for comparison between pile-driving and ambient control conditions (Radford et al. 2012).

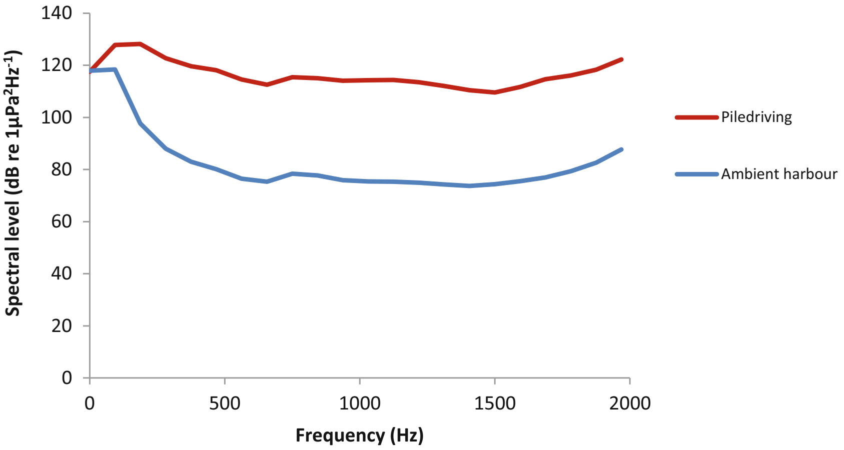

Fig. 32.1 Playback of ambient and pile-driving noise in the experimental tank. Spectral level of ambient and pile-driving tracks from averaged power spectra (fast Fourier transform [FFT] analysis: spectrum level units; Hann evaluation window, 50% overlap; FFT size 1024) recorded in the experimental tank

2.2 Experimental Protocol

Juvenile *D. labrax* were sourced from an aquaculture facility, housed in the Aquatic Resource Centre at the University of Exeter at 16.5 °C, and fed a combined diet of pellets and live *Artemia* several times a day. A total of 36 fish were used in the experiment, with 18 tested during pile-driving noise and 18 tested during ambient harbor noise. The test subjects had not been used in previous experiments and were not reused within the experiment, ensuring that all subjects were naïve to the looming stimulus. Trial order and use of tracks from different harbors were counterbalanced within each block and treatments alternated between ambient harbor noise playback and pile-driving noise playback.

In each trial, a fish was transferred to a small plastic container (15 cm length × 10 cm width × 10 cm depth) using a scoop and allowed to acclimatize for 5 min with the lid off to avoid oxygen depletion. The ambient track was then started in the experimental tank (55 cm length × 45 cm width × 45 cm depth with a water depth of 35 cm) and the container with the lid on was placed close to the edge inside the tank. All the fish experienced 2 min of ambient-noise playback while settling, after which the track was switched either to a different ambient track or to a pile-driving track and the looming predator stimulus was released 10 s later. The looming stimulus consisted of a black squash ball threaded onto thin fishing line to mimic the open mouth of a predator. The release of the squash ball was controlled using a simple mechanism that was not visible to the fish, and the ball was set up so that it swung directly toward the fish but was restrained by a lanyard to avoid hitting the tank. After the trials, the fish were returned to a separate holding tank, the plastic container was washed, and the water was refreshed before the next trial.

Experiments were filmed using a video camera mounted on a tripod at the side of the tank. The experimenter was hidden from the fish by a hide, which was positioned in a way that ensured that the movements to start and stop recording were not visible to the fish. The underwater speaker was placed in the center of the tank under a false bottom, facing upward, with the container with the fish placed above. To minimize vibrations, the tank was placed on top of 5 cm of expanded insulation foam. The entire setup was surrounded by an opaque partition divider to block out external disturbances.

2.3 Statistical Analysis

Trial videos were exported to a PC and analyzed in Windows Media Player at 25 fps with the sound switched off to eliminate observer effects. Each fish was scored for a C-start type of startle response to the looming stimulus, and for those that startled, the lag response time from the "predator" beginning to move to the fish eliciting a response was measured. Data were analyzed using SPSS (version 10). A χ^2 test was used to determine whether the number of fish that exhibited a startle response was significantly different between the control group and the group exposed to playback of pile-driving noise. An independent-samples *t*-test was used to compare the lag response times between fish from the two treatment groups that did startle.

3 Results

Antipredator behavior was impaired in *D. labrax* subjected to a simulated predator attack when pile-driving noise was playing. During pile-driving noise playback, fish were significantly less likely to startle in response to the looming stimulus compared with those experiencing an attack during ambient harbor noise playback ($\chi^2=5.46$, df = 1, $n=36$, $P=0.019$; Fig. 32.2). Of the fish that startled, there was no significant difference in response time to the "predator" between those experiencing ambient harbor noise playback and those experiencing pile-driving noise playback (independent-samples *t*-test, equal variances not assumed: $t=1.91$, df = 4.25, $n=17$ [12 in ambient, 5 in pile driving], $P=0.125$).

4 Discussion

Antipredator responses are of ecological importance for any animal in determining survival, yet to date little experimental work has considered the impact of anthropogenic noise in this regard. Notable exceptions to this shortfall in the literature include recent work by Chan et al. (2010), Bruintjes and Radford (2013), and Wale et al. (2013a). The startle response is crucial in avoiding attacks from ambush predators so any stressor that impairs this response likely reduces an individual's chance of survival. In this study, playback of pile-driving noise significantly reduced the number of individuals that startled during a simulated attack. This suggests that

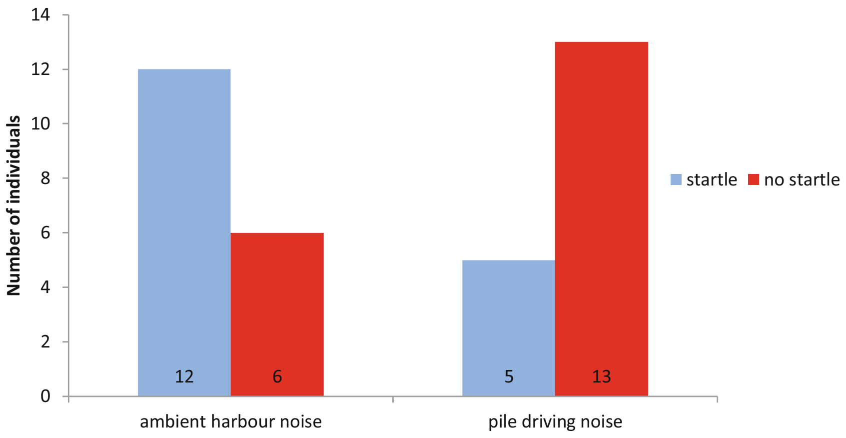

Fig. 32.2 Startle response of *Dicentrarchus labrax* during playback of ambient harbor noise or pile-driving noise ($n=18$ for each treatment)

D. labrax are more vulnerable to predation when experiencing playback of pile-driving noise, although it may also be the case that in natural conditions pile-driving noise also impacts the strike efficiency of the predator. Thus, the possible effects of pile-driving noise on natural predators also need to be understood to gain better insight into the overall impact of pile driving on predator–prey interactions. If pile-driving noise is also detrimental to the natural predators of *D. labrax*, then the impact of impaired antipredator behavior may be reduced.

Further research is needed to determine the effects of pile-driving noise on other aspects of fish behavior and physiology. It is important to consider the implications of other effects in conjunction with impaired antipredator behavior to provide a perspective of the "big picture." Change in antipredator behavior is likely one facet of an allostatic response and so it is not enough to assess the effects of pile-driving noise on antipredator behavior in isolation. For example, Simpson et al. (2014) have found that eels exposed to ship-noise playback increase their oxygen consumption and, as a consequence, their energetic demands. If this is also true of *D. labrax*, then they would need to increase the time spent foraging to fulfil their higher energy expenditure while also being more vulnerable to predators.

The mechanism responsible for the reduction in the number of individuals that startled is not known but may be a consequence of stress and/or distraction. Stress may impair the ability of fish to detect and classify predators (Wright et al. 2007). Furthermore, if repeated exposure of pile-driving noise results in chronic stress, then there will likely be significant effects on metabolism, growth, and, ultimately, reproductive fitness (Kight and Swaddle 2011). If attention is narrowed, with fish either ignoring stimuli or focusing on a smaller spatial scale, then predators may be less likely to be detected. Such attention-mediated effects are driven by a limited capacity to attend simultaneously to multiple stimuli (Chan and Blumstein 2011).

The effects of pile-driving noise on antipredator behavior discussed in this paper may be conservative estimates because sound levels nearer the source can be as loud as 205 dB re 1 μPa (Bailey et al. 2010). However, in the open ocean, fish may move away from pile-driving noise to minimize its impact on their behavior and physiology. It is likely that as fish move away from the source, the sound will get less intense and have a smaller effect, but if fish remain significantly impacted over large distances from the pile-driving operation, then fish populations could be affected. It is uncertain how intense pile driving needs to be to compromise antipredator behavior and this is a valuable question for further research. Avoidance behavior could be detrimental to important breeding or feeding grounds close to sites of offshore construction (Slabbekoorn et al. 2010). If fish are unable to access breeding grounds, there will be negative repercussions for recruitment to fisheries in future years.

In this experiment, *D. labrax* were exposed to 10 s of pile-driving noise playback. Further research is needed to determine whether the effect seen on antipredator behavior is a temporary response to the sudden onset of the noise source. It has yet to be tested whether habituation or sensitization may occur and whether fish show an immediate or gradual recovery at the cessation of exposure; these are important future considerations (see Chapter 111 by Radford et al.).

This study demonstrates that pile-driving noise has the potential to negatively affect the antipredator behavior of *D. labrax* that, if true in natural conditions, would increase the likelihood that individuals will suffer mortality from predation. Further studies are needed to determine the full impact of pile driving on inter- and intraspecific interactions and its potential to disrupt complex interactions within ecosystems.

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