Chapter 55
Playback Experiments for Noise Exposure

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Abstract Playbacks are a useful tool for conducting well-controlled and replicated experiments on the effects of anthropogenic noise, particularly for repeated exposures. However, playbacks are unlikely to fully reproduce original sources of anthropogenic noise. Here we examined the sound pressure and particle acceleration of boat noise playbacks in a field experiment and reveal that although there remain recognized limitations, the signal-to-noise ratios of boat playbacks to ambient noise do not exceed those of a real boat. The experimental setup tested is therefore of value for use in experiments on the effects of repeated exposure of aquatic animals to boat noise.

Keywords Anthropogenic noise • Invertebrates • Particle acceleration • Acoustic pressure

1 Introduction

As international concern about the effects of underwater anthropogenic noise grows (Slabbekoorn et al. 2010; Tasker et al. 2010), the need for experimental data revealing the range and extent of impacts is becoming clearer. Given the logistical constraints involved with conducting in situ experiments near to the original sources of

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Table 55.1 Some of the issues involved with playbacks of anthropogenic noise in experimental setups

Issue	Reason	Effect
Frequency response of playback equipment	Frequency response of media player, amplification of signal, frequency response of loudspeaker	Small speakers are often unable to reproduce low frequencies accurately. Frequency content of playback may differ from original noise source
Constructive and destructive interference	Reflections from surface/bottom/edges	Some frequencies are louder, some are quieter. Frequency content of playback will differ from original noise source
Echoes	Reflections from surface/bottom/edges	Temporal content of signal will differ from original noise source
Near-field effects	Sound source (loudspeaker) often closer to experimental animals than the original sound source would be for logistical reasons	Particle motion and pressure could be out of phase, particle motion component of sound could be higher than that of original noise (dependent on frequency and distance to loudspeaker)
Cutoff frequency	Acoustic waves below established frequencies cannot travel when the water depth is too shallow	Low frequencies cannot propagate. Other types of waves may be involved

noise, it can be useful to employ playback experiments to test the effects of noise. However, playbacks do not fully replicate sound exposures that could be expected from real sound sources (Parvelescu 1967). Various issues that come into play include (but are not necessarily limited to) those discussed in Table 55.1.

The majority of marine macroorganisms are fish and invertebrates that, via commercial fisheries and other ecosystem services, have great ecological and socioeconomic value (Cheung et al. 2005). Although some species of fishes can detect sound pressure, all teleost fishes are able to use their otoliths to detect the particle motion component of sound (Bleckmann 2004). It is also becoming apparent that many invertebrates are able to detect the particle motion component of sound using statocysts (Mooney et al. 2010). Thus, although there are inherent limitations, attempts to improve the validity of playbacks should consider both acoustic pressure and particle motion. Here we used a field experiment in French Polynesia as a case study of an in situ field-based experimental setup. We present recordings of sound pressure and particle acceleration of original sound sources (outboard motorboats) and their playbacks in the experimental setup.

2 Recordings of Boats

Our study was conducted from the Insular Research Center and Environment Observatory (CRIOBE) Research Station, Moorea, French Polynesia. Boat traffic recordings were made during the day (on 4–5 November 2010) at a depth of 2 m in a deep bay in the lagoon on the east coast of Moorea using a hydrophone

(HiTech HTI-96-MIN with a built-in preamplifier, sensitivity −165 dB re 1 V/μPa, frequency range 2 Hz to 30 kHz, High Tech, Inc., Gulfport, MS) and a solid-state recorder (Edirol R-09HR 16-bit recorder, sampling rate 44.1 kHz, Roland Systems Group, Bellingham, WA). The recorder was fully calibrated using pure sine wave signals generated in SAS Lab (Avisoft), played on an MP3 player, and measured in-line with an oscilloscope. Thirty-six recordings of passes made by two typical outboard motorboats with 25-hp Yamaha engines were made; only 1 boat was used per recording. Boats started 50 m from the hydrophone and drove past in a straight line for 100 m, passing the hydrophone at a closest distance of 20 m. Boats were driven at one of three speeds: slow, medium, or fast. Each recording containing a boat pass lasted 45 s. Twelve 1- to 10-min ambient-noise recordings (without boats) were also made on location each day.

Pressure and particle accelerations of the same boats were recorded concurrently during the daytime (on 4–5 January 2013) at a depth of 2 m in a bay where the water depth was 5 m in the lagoon on the north coast of Moorea using the same hydrophone setup as above and an M201 acclerometer, (sensitivity, 0–3 kHz, GeoSpectrum Technologies, Dartmouth, NS, Canada; recorded on a laptop via a calibrated USB soundcard, MAYA44, ESI Audiotechnik GmbH, Leonberg, Germany; sampling rate 44.1 kHz).

3 Playbacks

Two sites that were similar in depth, water quality, prevailing currents, and proximity to the reef (>10 m) and nearest boat channel (>60 m) were used for playback experiments. The sites were 100 m apart and playbacks at one site could not be heard above the local ambient-noise levels from the other (verified with sound pressure and particle acceleration recordings made using the hydrophone and accelerometer detailed in Section 2).

Recordings were played using underwater loudspeakers (UW-30, frequency response 0.1–10 kHz, University Sound, Columbus, OH) fixed to the sandy bottom of a lagoon flat where the depth was 1.3–1.8 m. Each loudspeaker was powered by a 40-W amplifier (Kemo M034) powered by two 12-V batteries connected in parallel. Playbacks were played using MP3 players (Sansa Clip+, SanDisk, Milpitas, CA) that were on constant charge via a 5-V USB cable connected by a transformer to a separate 12-V battery. The playback system was fixed underwater in a waterproof case (Peli 1 200, Peli Products, Barcelona, Spain) inside a concrete block chained to the seafloor with a waterproof cable connecter (Standard Buccaneer, Bulgin, Cambridge, UK) for the speaker cable (underwater loudspeakers were situated on the seabed). Sound pressure and particle acceleration were measured 1 m from the speaker and compared with pressure and particle acceleration recordings of real boats and ambient noise from 4 to 5 January 2013. Five real-boat passes were compared with playback of five boat passes at each site along with 10-min of ambient noise and a random selection of 64-s samples of ambient-noise playbacks for 5 min.

4 Acoustics Analysis

Power spectral densities (PSDs) were calculated in MATLAB version 2010a. The data were calibrated according to the instrument sensitivities provided by manufacturers and split into 1-s windows that were Hamming filtered. A fast Fourier transform (FFT) was performed on each 1-s subsample to translate the data into the frequency domain. The FFT length was set equal to the sampling frequency of the recording (44.1 kHz) so that an absolute value for every 1 Hz could be obtained for each second of recording between 0 and 22.05 (the Nyquist frequency). These values were squared to obtain the PSD, multiplied by 2, and divided by 1.36 to correct for the noise power bandwidth. The mean, median, and 5th and 95th percentiles of all the 1-s values were taken at each frequency within each recording before multiplying by 10 $\log_{10}$ to convert the values into decibels re 1 µPa^2/Hz for sound pressure PSD levels and decibels re 1 (µm/s^2)^2/Hz for particle acceleration PSD levels. The three axes (horizontal: *x*; perpendicular horizontal: *y*; vertical: *v*) of particle acceleration were examined separately.

5 Results

The *x*-axis of particle acceleration revealed the greatest difference between ambient noise at the playback site and boat playback levels; thus, for ease of presentation, this is the only axis shown in Figs. 55.1 and 55.2 (boat playback in the *y*- and *v*-axes

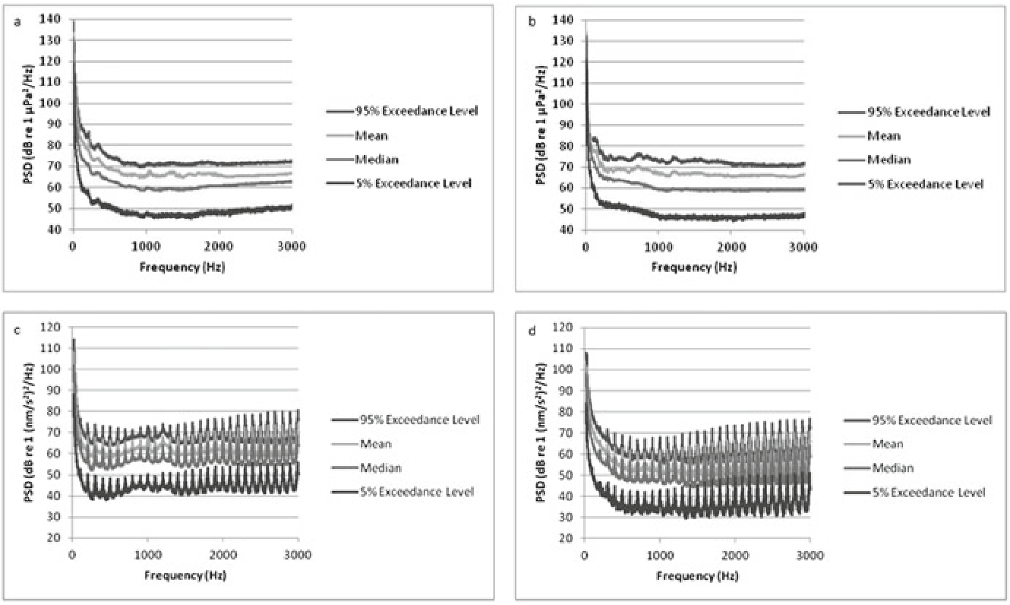

Fig. 1 Mean, median, and 5th and 95th percentile power spectral densities (PSDs) of 10-min ambient noise in pressure (**a** and **b**) and particle acceleration (**c** and **d**) at sites 1 and 2, respectively. Only one axis of particle acceleration is shown for clarity of presentation

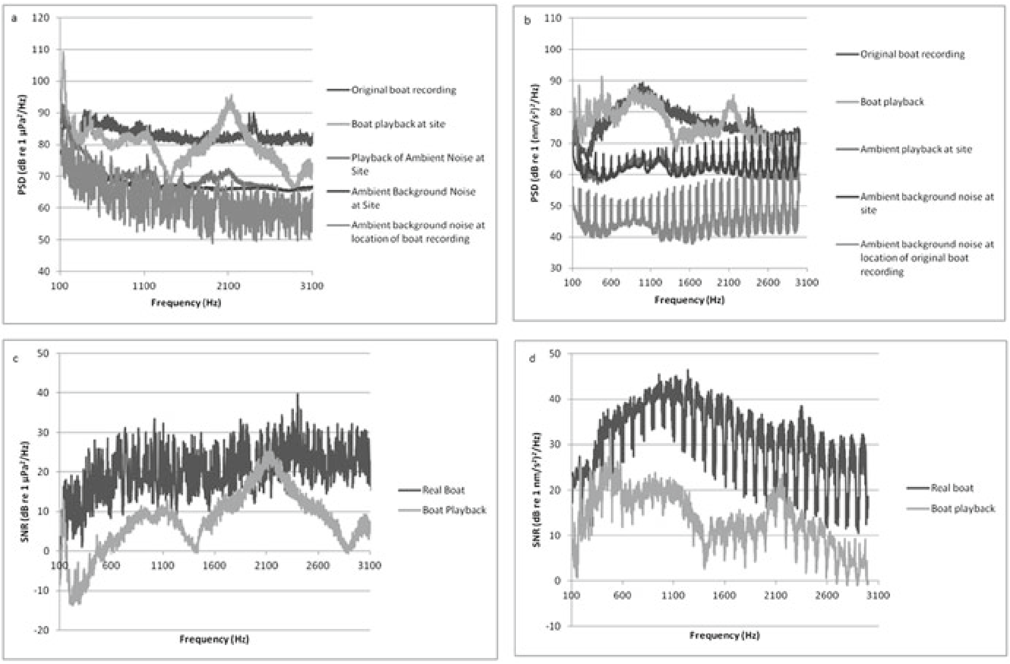

Fig. 55.2 PSDs (means) of five real boat passes, five playbacks of boat passes, 10-min ambient noise, and 5-min ambient-noise playback in pressure (**a**) and particle acceleration (**b**) at each site and signal-to-noise ratios (SNRs) of real boat and boat playback to ambient noise and ambient-noise playback, respectively, in sound pressure (**c**) and particle acceleration (**d**). Only one axis of particle acceleration is shown for clarity of presentation. Frequencies below 100 Hz are not shown here because our loudspeaker was unable to produce frequencies below 100 Hz

was a maximum of 17.8 dB above ambient noise at the playback site in any 1-Hz band, while in the *x*-axis, the maximum difference was 32.1 dB). The ambient-noise levels and variability at both experimental sites were similar to each other in terms of both pressure and particle acceleration (Fig. 55.1). PSDs of playbacks in comparison with the original recordings revealed that the sound pressure levels of boat playbacks were higher than those of real boats below 464 Hz and between 1,879 and 2,301 Hz. Particle acceleration levels of boat playbacks were higher than those for real boats below 598 Hz and between 1,995 and 2,205 Hz (Fig. 55.2a, b). However, the signal-to-noise ratio of a real boat to the ambient noise where the boat was recorded was not exceeded by that of boat playback to ambient-noise playback in terms of either sound pressure or acceleration (Fig. 55.2c, d). Our recordings of particle acceleration contained electrical noise with regular peaks every 100 Hz (Figs. 55.1c, d and 55.2c, d).

6 Applications

Previously, comments on running experiments in close proximity to loudspeakers had suggested that the particle motion component of sound would dominate the sound field at a magnitude that was unrealistic in relation to real exposure to anthropogenic noise sources. Our recordings from this particular setup suggest that for frequencies above 598 Hz, the particle acceleration of playbacks matched that of real boats more closely than the sound pressure. Although the particle acceleration at frequencies below 598 Hz does exceed that of a real boat driving at a distance between 10 and 50 m, the signal-to-noise ratio of a real boat to the ambient noise where it was recorded was greater than the signal-to-noise ratio of the boat playback compared with the ambient-noise playback. Although this is likely due to our choice of site having a louder ambient noise than the location where the boat was first recorded, the locations were representative of the habitats where our study species of choice for the experiments using these playbacks may be found. The experimental setup described here has been used to investigate the effects of repeated noise exposure on fish and sea hares (marine gastropod mollusks; Nedelec et al. 2014; Nedelec, Mills, Lecchini, Simpson, and Radford, in preparation). An ideal approach for future work will be to combine the use of playbacks with real noise exposures to confirm the validity of the use of a particular model species (see Chapter 129 by Simpson et al.).

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