Impacts of Substrate-Borne Vibrations from Pile Driving in a Benthic Marine Invertebrate

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Contents

Abstract

Many anthropogenic activities in the ocean involve direct contact with the seabed. These benthic interactions can potentially be harmful to marine fauna. For example, pile driving is commonly used for coastal and offshore

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constructions, including wind farms that overlap with vital marine habitats. The sound from pile driving is a major pollutant of international concern, although studies on substrate-borne vibrations arising from these activities are scarce, particularly those which address impacts to key benthic invertebrates. In a field-based study, the impacts of substrate-borne vibrations from pile driving were quantified on the giant scallop (*Placopecten magellanicus*), an ecologically and commercially important bivalve. Behavioral responses of tagged scallops to pile driving were assessed at two spatial scales ($<$ 10 and 50 m from the source). Pile driving induced valve closures in scallops at substrate-borne vibration levels similar to those measured hundreds of meters from wind turbine constructions. These responses could have long-term energetic consequences on scallops, rending them more vulnerable to predation. The results suggest offshore wind farm constructions have the potential to impact scallop populations.

Keywords

Climate change · Offshore wind farm · Anthropogenic sound · Pollution · Bivalve

Introduction

Offshore wind farms (OSW) are proliferating dramatically worldwide, often overlapping with important ecological habitats and fisheries, consequently raising concerns about their potential impacts on marine species. Pile driving (PD) used to build OSW generates high-intensity impulsive sounds that have various impacts on marine fauna (Mooney et al. 2020). However, the impacts of associated substrate-borne vibrations on benthic invertebrates from PD are not known (Popper et al. 2022).

Bivalves can detect substrate-borne vibrations through their abdominal sense organs and statocysts (Roberts and Elliot 2017). A previous study showed mussels and scallops respond to low-frequency vibrations (i.e., $<$ 1 kHz) in tanks by closing their valves (Roberts et al. 2015; Jézéquel et al. 2023), which is a common anti-predatory response with likely energetic consequences (Robson et al. 2012). However, there are needs now to scale up these experimental studies into the field to better understand the impacts from OSW constructions.

Bivalves are both a key taxonomic group for many marine ecosystems and represent a commercially important taxon (Newell 2004; Wijsman et al. 2019). Given the rapid proliferation of planned OSW projects overlapping in vital bivalve habitats and fishing zones, it is necessary to quantify the construction impacts on these species. The purpose of this field-based study was to measure the behavioral responses of the giant scallop (*Placopecten magellanicus*) to real-time PD using biologging tags.

Materials and Methods

Data Collection

This study was performed using 14 scallops (8.2 ± 0.5 cm) that were acclimatized in tanks at the facilities of the Woods Hole Oceanographic Institution (WHOI). Before the PD experiment started, scallops were tagged with Axy 5 XS bio-loggers (Technosmart Europe Srl, www.technosmart.eu) using the same technic described in Jézéquel et al. (2022). Basically, these tags measured the valve angle of bivalves using the strength of the magnetic field (in mV; sampling frequency = 2 Hz) between a magnetometer placed on the dorsal valve and a magnet located on the ventral valve. In addition, this tag contains an accelerometer that was used to detect the substrate-borne vibrations (sampling frequency = 25 Hz) arising from PD exposure. Substrate-borne vibrations were also monitored using a calibrated geophone (model GS-11D from Geospace®; sampling frequency = 200 Hz) placed at 8 and 50 m from the PD. Overall, these data were recorded for a period of 2 weeks of PD exposure.

Experimental Procedure

Pile driving exposures occurred from the 14th to 29th of September 2021 in a shallow water area (41.52° N, 70.67° W; Fig. 1A). A cylindrical steel monopile (length, 10.0 m; diameter, 0.3 m; thickness, 0.02 m) was hammered into the seabed each day using an impact hammer (weight, 1500 kg; Fig. 1B) at a rate of 10 strikes per min, generating 16 kJ per strike. Tagged scallops were placed in cages located at a near (< 10 m) and far (50 m) site from the PD (Fig. 1A). Scallops were exposed daily to 2-hour-long PD events.

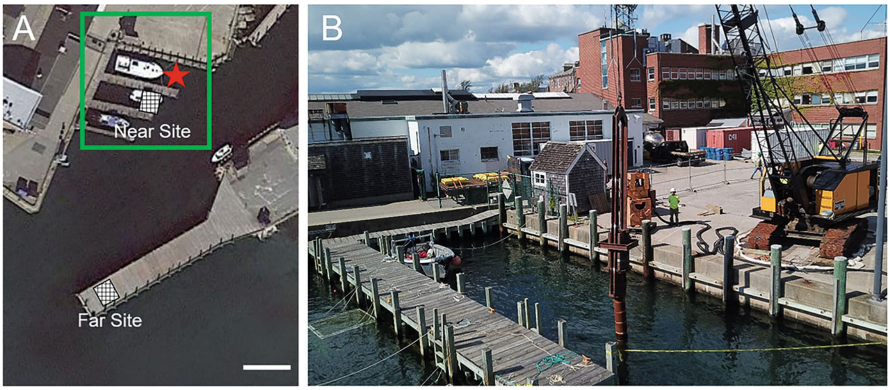

Fig. 1 A) Top view of the experiment site at Woods Hole harbor (Massachusetts, US). Near site is located within 10 m from PD while far site is at 50 m. White bar is 10 m and red star denotes PD location. B) Picture of the PD setup at the green square shown in A

Statistical Analyses

Linear mixed-effects analyses were conducted between scallop valve angle and different fixed effects. Individual and date were used as random effects, while fixed effects included exposure type (pre-exposure vs. exposure). Pairwise tests were also performed using post hoc Tukey tests.

Results

Substrate-borne vibrations recorded without PD were low at both distances (Fig. 2A, D). The PD generated transient substrate-borne vibrations with calculated peak-to-peak levels ranging from 87.08 ± 2.88 to 109.95 ± 1.25 dB re 1 μm.s^{-2} at 50 and 8 m, respectively (Fig. 2B, E). Single strike exposure levels were 94.39 ± 1.34 dB re (1 μm·s^{-2})^2.s at 8 m and 72.48 ± 2.51 dB re (1 μm·s^{-2})^2.s at 50 m. The spectra peaked at low frequencies around 10 Hz (Fig. 2C, F).

Scallops located within 10 m from the PD showed valve closures in synchronicity with PD substrate-borne vibrations (Fig. 3). This resulted in a significant diminution of 30% in valve angle during PD exposure compared to pre-exposure (Tukey test, $p < 0.001$, Fig. 4). Interestingly, no reactions were found in scallops placed at 50 m, and there were no significant differences in valve angles between pre- and PD exposure (Tukey test, $p = 0.864$, Fig. 4). These results show that scallops were not behaviorally affected by substrate-borne vibrations at 50 m from the PD.

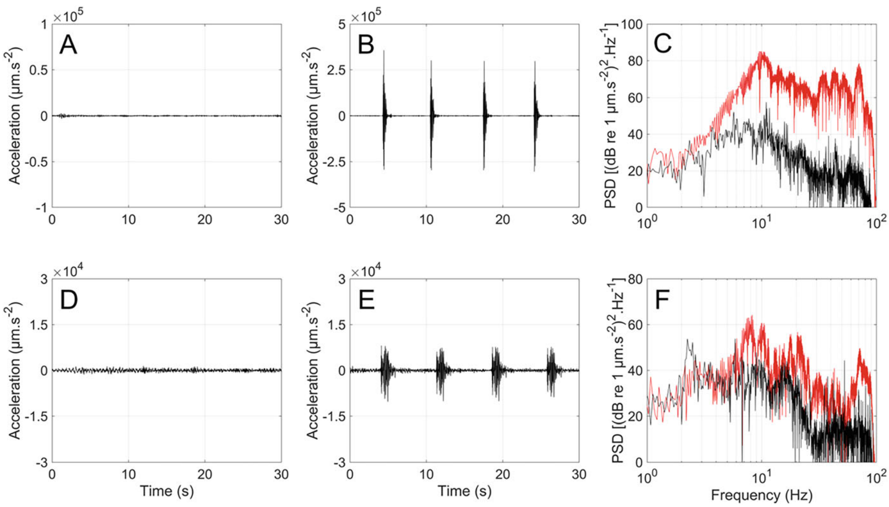

Fig. 2 Example of recorded substrate-borne vibrations recorded by the geophone (x-axis) at 8 m (top) and 50 m (bottom) without (A and D) and during PD (B and E). Power spectral densities (PSD) of the temporal signals are presented in C and F (red: PD; black: ambient)

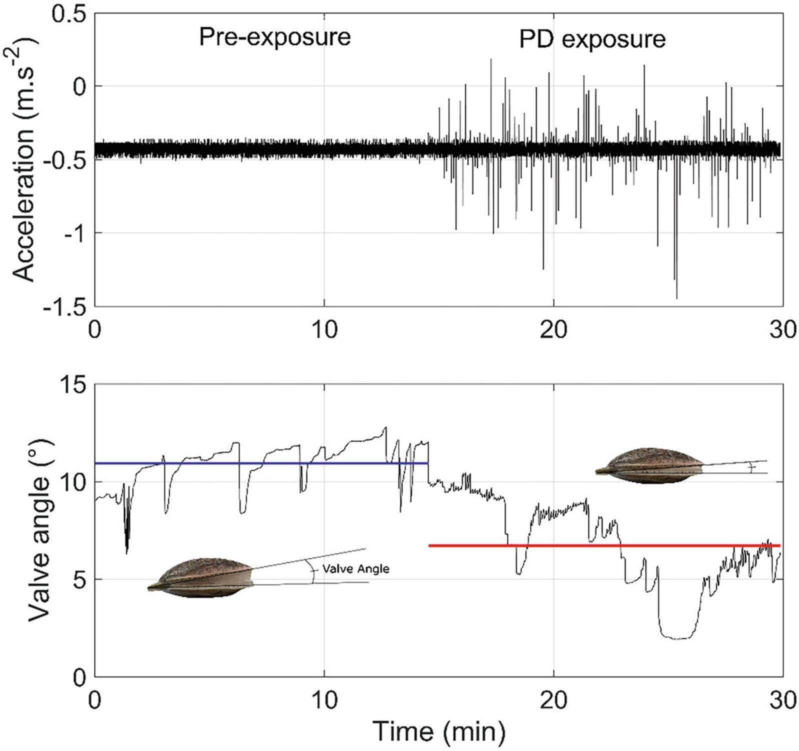

Fig. 3 Synchronized data from one tagged scallop located in the vicinity of the PD (< 10 m), with the accelerometer (top) and magnetometer (bottom). Substrate-borne vibrations from the PD (vertical bars) were detected by the scallop, which responded by closing its valves. Horizontal bars highlight mean valve angle measured before (blue) and during (red) pile driving

Discussion

This field-based study showed that substrate-borne vibrations arising from PD impacted scallop behaviors. While strong valve closures were found in the vicinity (< 10 m) of the PD, scallops showed no behavioral responses at 50 m despite PD substrate-borne vibrations were still detected. These data raise concerns about the potential impacts from OSW constructions on scallops.

Scallops exposed to PD responded to substrate-borne vibrations by closing their valves (Fig. 3), which is a common antipredatory response (Thomas and Gruffydd 1971). Similar results were found by Day et al. (2017) with scallops (*P. fumatus*) exposed to seismic air gun. The energy cost and ecological consequences associated with these behaviors are not known. Robson et al. (2012) showed that scallop valve closures result in large expenditures of energy, and an oxygen debt has to be paid off

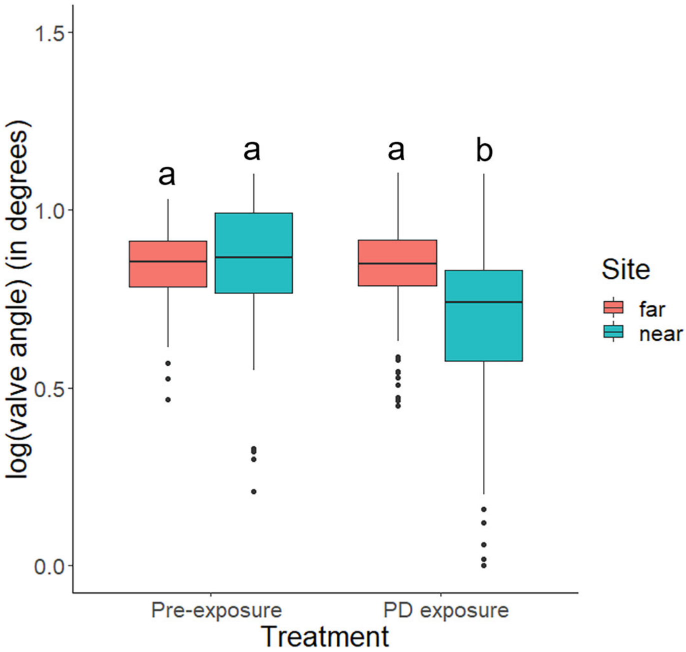

Fig. 4 Boxplot showing the mean valve angles (log transformed) measured from tagged scallops at the far (red) and near (green) sites before and during pile driving exposure. Results of the post hoc Tukey test are shown with the letters

over long periods of time that limit further movement, including predator escapes. Hence, scallops exposed to PD could be more vulnerable to predation.

Most previous studies with marine invertebrates exposed to PD occurred in tanks at unrealistic sound exposure levels, which rend these results difficult to translate to wild populations (Popper et al. 2022). To fill this gap, scallops in this study were exposed to substrate-borne vibrations from real-time PD in an open water environment (Fig. 1). While such study remains scarce, it is to note that OSW foundations are much larger compared to the PD setup used here (Kallehave et al. 2015). Physical parameters such as bottom type also need to be considered when assessing substrate-borne vibration impacts. Taken together, the spatial range of impacts found in this study is likely to increase during OSW constructions, potentially impacting scallops at the population level.

Conclusion

The efforts developed in this field study are an important step in understanding the impacts of substrate-borne vibrations from PD in marine benthic invertebrates. The results indicate that scallops behaviorally responded to PD with potential ecological consequences. Further studies are now required to measure the responses of wild scallop populations to OSW constructions (Popper et al. 2022).

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