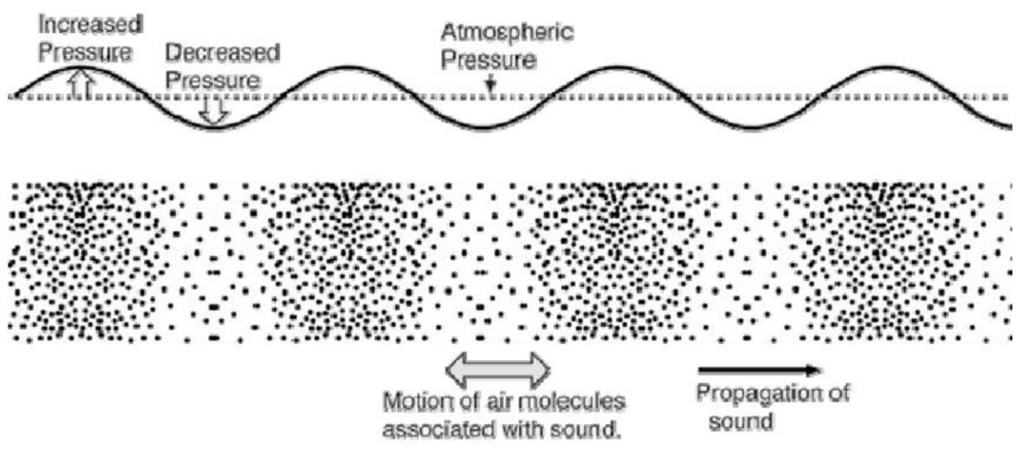
Man-made earthquakes
From field studies to laboratory exposure

Jordan Burgess[1,2], Sophie Al-Mudallal[2], Krysia Mazik[1], Katharine Clayton[1], Thomas Breithaupt[3]

[1]School of Environmental Sciences, University of Hull, Hull, UK, [2]Energy and Environment Institute, University of Hull, UK
[3]School of Natural Sciences, University of Hull, Hull, UK

There's more to sound than meets the ear...



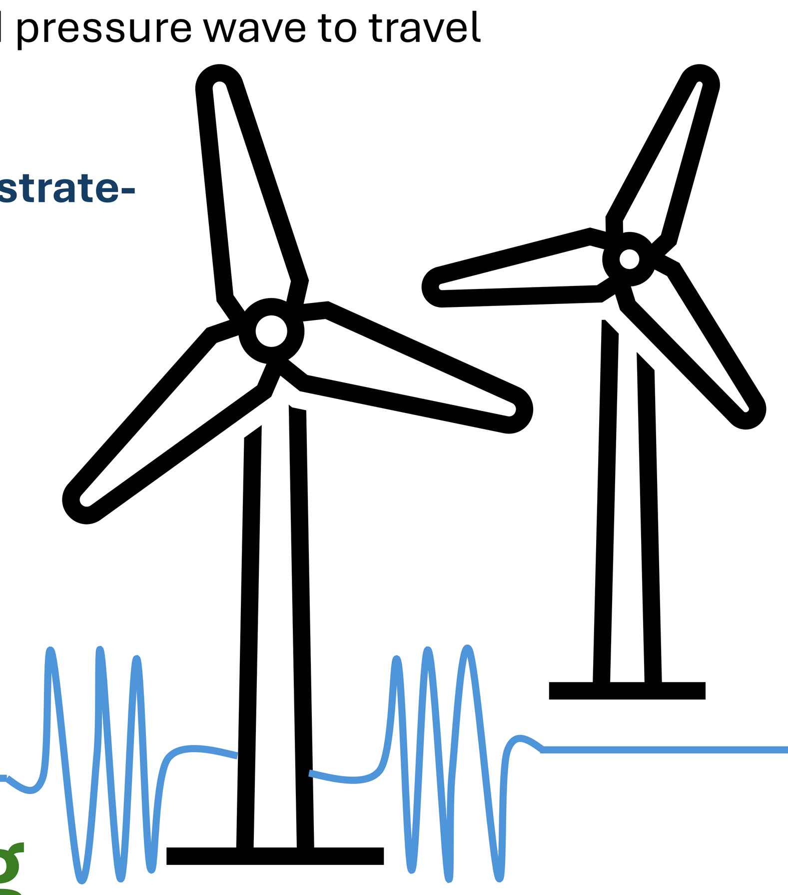
- 2 components to sound – **sound pressure** and **particle motion**
- Particles move **backwards** and **forwards** (compression and rarefaction) to allow a sound pressure wave to travel

- Particle motions may travel in the form of **air-borne**, **water-borne** or **substrate-borne**
- **Installation** and **operation** of turbines come into **direct contact** with the **seabed** → **substrate-borne particle motion**

Invertebrates **do not have** a **compressible**, air-filled space and **instead** show **sensitivity** to **particle motion** (and vibration) through:
- Surface receptors (sensory hairs), internal statocycts (fluid filled chamber) and chordontal organs

Turbines are fixed to the substrate, so vibration arising from installation or operational parts will produce vibrations that travel through the substrate, in the form of substrate-borne particle motion (seismic interface waves)

Existing data on substrate vibration from operational or impulsive vibration sources are scarce with no standardisation for measurements



Continuous – operational vibration

Field study (Burgess *et al.*, 2023)

Measured at an **onshore 2.0 MW turbine on the tower, foundation** and **soil** at varying wind speeds

Data compared to **sensitivities** of different **invertebrates** and **used to inform the lab study**

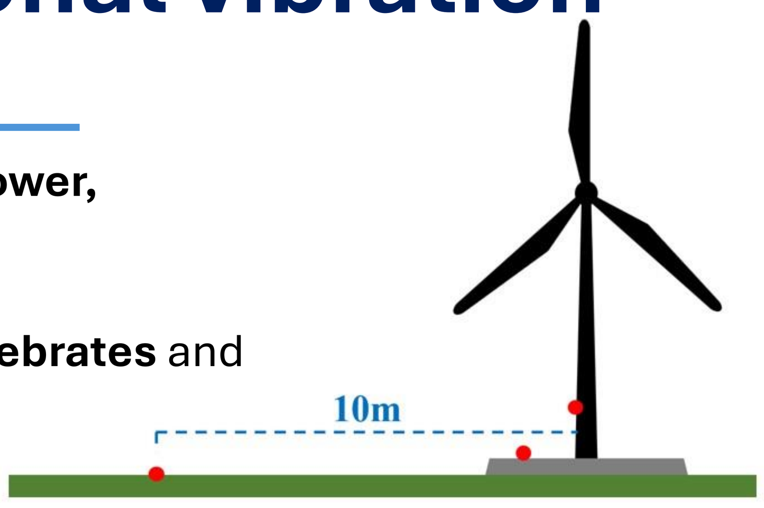


Fig 2. Accelerometer placement

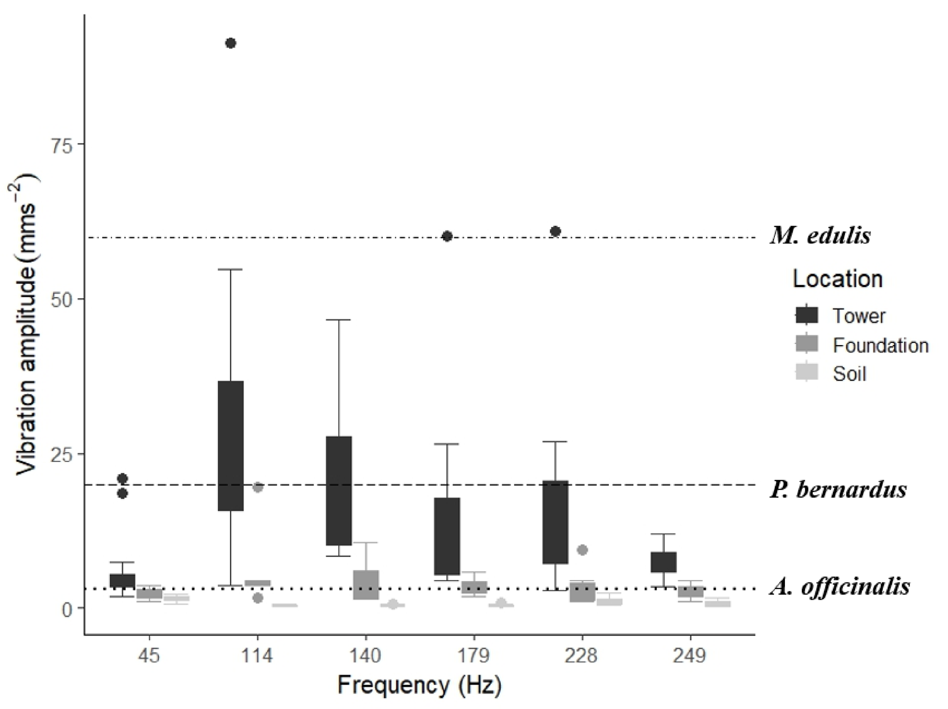


Fig 3. Amplitudes measured on turbine by frequency

At an onshore turbine, there are **overlaps with invertebrate sensitivities**

Overlaps may cause **behavioural** or **physiological** changes

The **amplitudes** and frequency will **change** with wind speed, which may **prevent acclimation**

Impulsive - pile-driving

Field study (Al-Mudallal *et al., in prep*)

Substrate-vibration measured with an **accelerometer** at a small pile driver in Cleethorpes, UK

Data collected at **increasing distances** to measure vibration through the substrate (0 - 300 metres from pile)

Substrate-vibration **decreasing** with **distance**, but still **recorded** up to **300 metres away**

Vibration recorded 30m from a small pile driver is:
- **300x the sensitivity** threshold of the **common hermit crab** (*Pagurus bernhardus*)
- **100x** the sensitivity threshold of the blue mussel (*Mytilus edulis*)

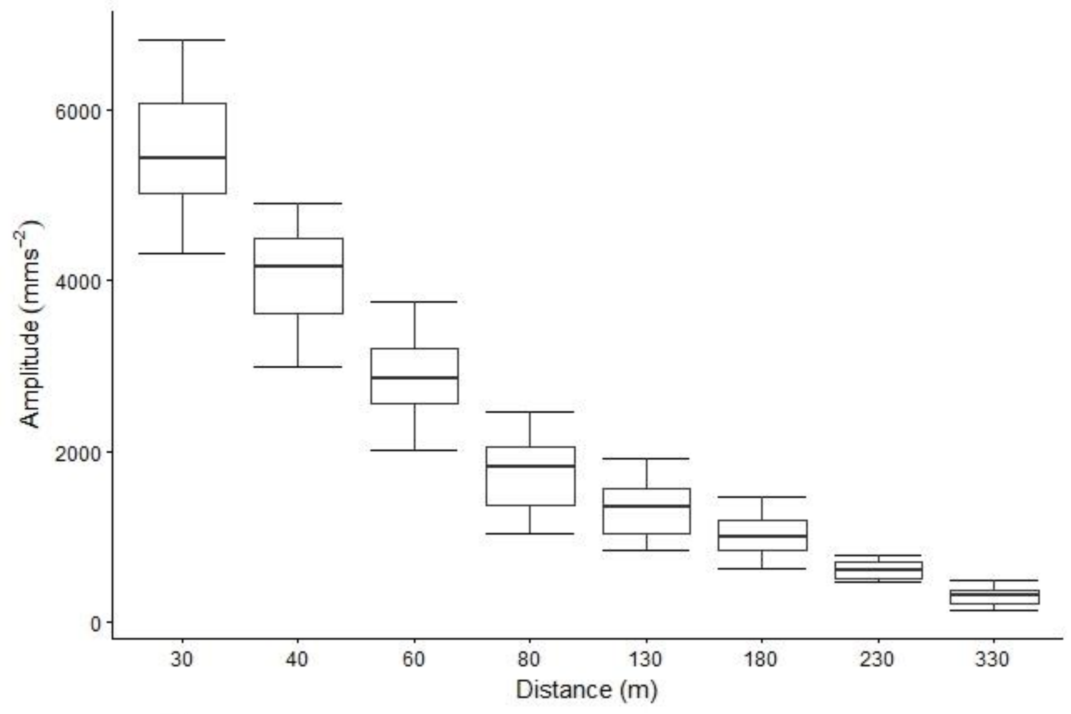


Fig 4. Amplitudes measured on turbine by frequency

Vibration at this level has been seen to cause irreversible damage (Day *et al*., 2019)

Continuous vibration – in the lab

Continuous (sinusoidal) **vibration** is produced using an **underwater speaker**
Speaker is fixed to a PVC sheet, where substrate vibrations will travel through

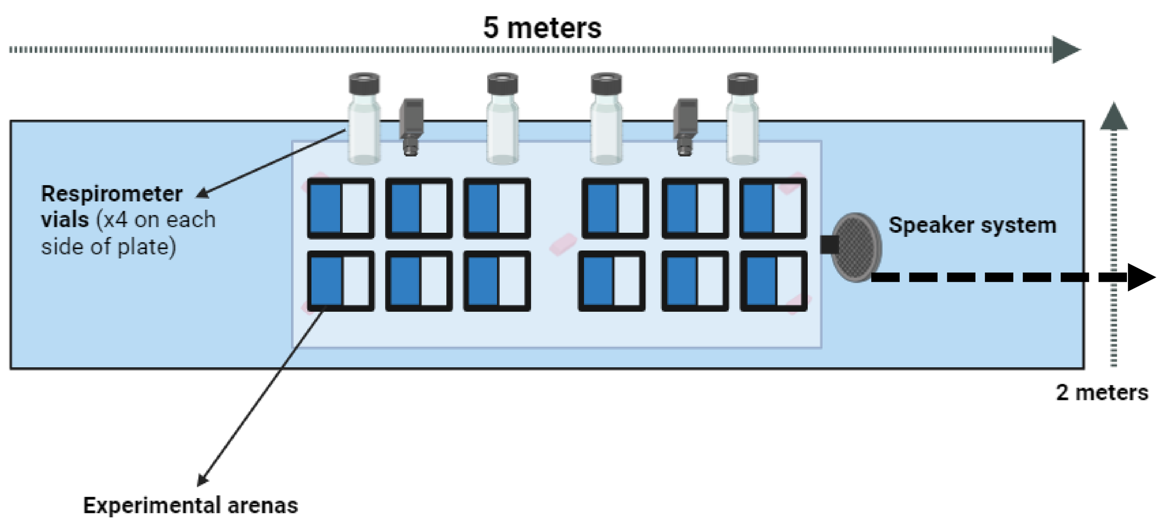


Fig 5. Vibration exposure experimental set up at University of Hull

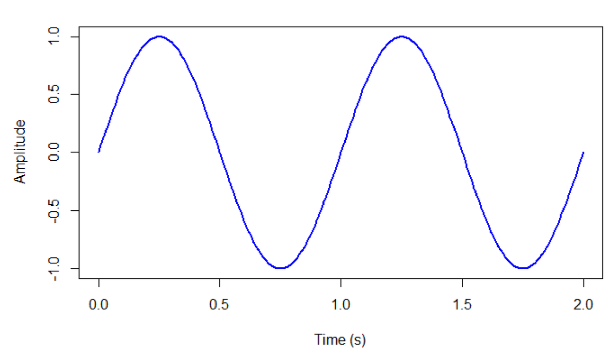


Fig 6. Example of sinusoidal waveform (continuous vibration)

The speaker can produce vibrations in line with field measurements (Fig 3) and existing data:
- Species sensitivity thresholds: **Blue mussel – 60 mms^{-2} (0.6 ms^{-2})** (Roberts *et al.*, 2015), **Common hermit crab – 20 mms^{-2} (0.02ms^{-2})** (Roberts et al., 2016)
- **Up to 100 mms^{-2} (0.1 ms^{-2})** (Fig 3) for a small wind turbine -> data is lacking for larger turbines
- Vibration at **5m distance from dredging** activity produces vibration at approximately **200 mms^{-2} (0.2ms^{-2})**

We use a **large flume** to make lab-based experiments more **reliable** (Fig 5)
- Many studies use tanks that are too small which can cause sound and vibration to behave differently (intensifying the signal)

Impulsive vibration – in the lab

Impulsive vibration produced using a purpose-built **pile driver**
Using a **dead-blow hammer,** pile driver strikes create **impulsive substrate-vibrations** through plywood resting on the table
The amplitude and frequency can be manipulated through adjusting the hammer arm and strike rate

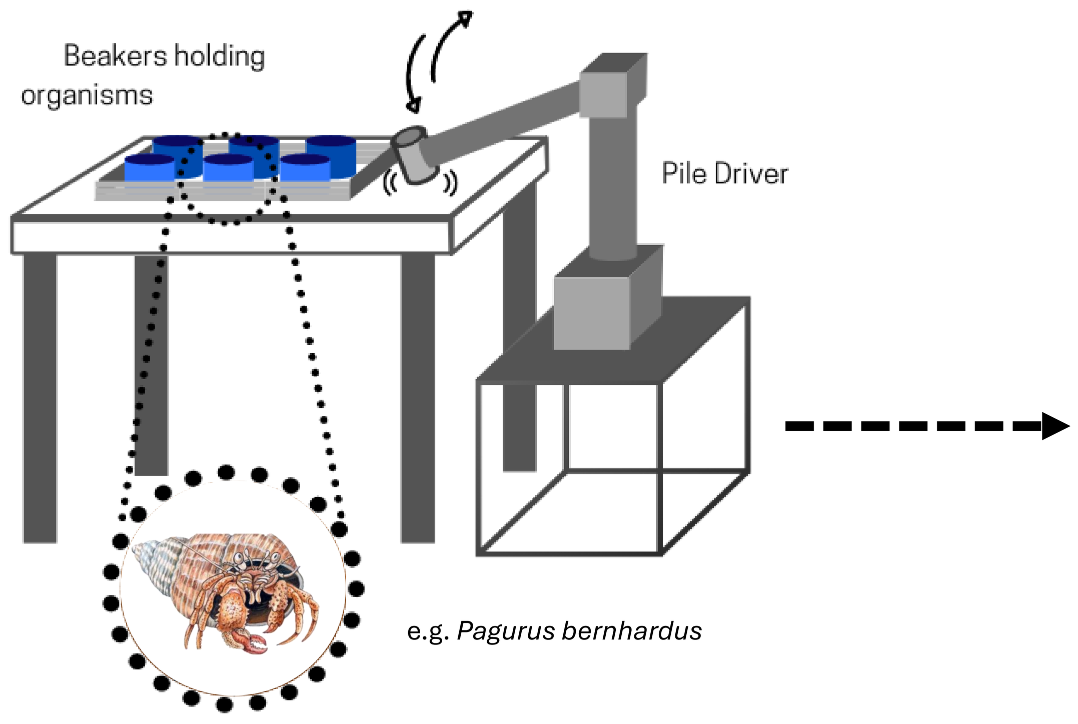


Fig 7. Pile driver experimental set up at University of Hull

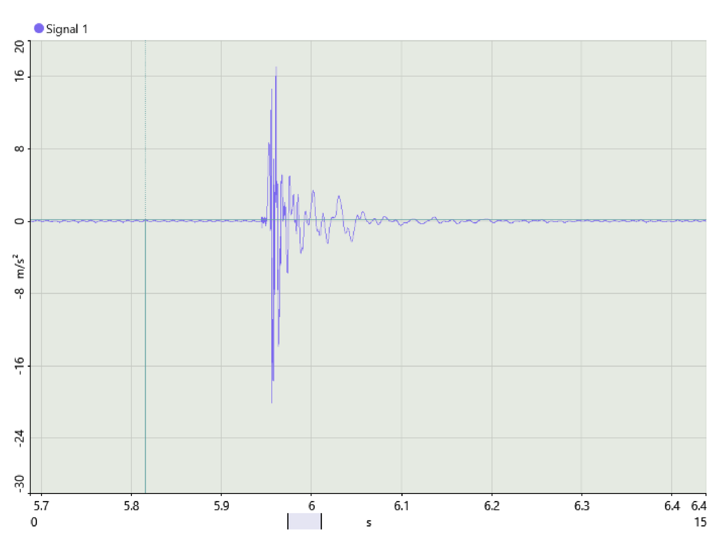


Fig 8. Example of impulsive waveform

The pile driver can produce impulsive vibrations in line with current literature and field measurements (Fig 4):
- **Up to 6 ms^{-2}** based on substrate-vibration recorded from a small pile driver (Fig 4)
- **10ms^{-2} recorded 8m from a vibratory hammer** (Jézéquel et al., 2023)

Conclusions

The set-ups can generate reproducible vibrations that are representative of operational and pile driving activities from offshore wind turbines. These vibrations fall within the sensitivity ranges of marine and benthic invertebrates

Burgess, J., Thomas, S., Mazik, K., Al-Mudallal, S., Tang, S.K., Breithaupt, T. (2023). Effect of Operational Wind-Turbine Vibration on Surface-Dwelling Invertebrates. In: Popper, A.N., Sisneros, J., Hawkins, A.D., Thomsen, F. (eds) The Effects of Noise on Aquatic Life. Springer, Cham. https://doi.org/10.1007/978-3-031-10417-6_21-, Jézéquel, Y., Cones, S., Jensen, F.H. *et al.* Pile driving repeatedly impacts the giant scallop (*Placopecten magellanicus*). *Sci Rep* **12**, 15380 (2022). https://doi.org/10.1038/s41598-022-19838-6, Roberts, L. *et al.* (2015) 'Sensitivity of the mussel mytilus edulis to substrate-borne vibration in relation to anthropogenically generated noise', *Marine Ecology Progress Series*, 538, pp. 185–195. doi:10.3354/meps11468. , Roberts, L. *et al.* (2016) 'Sensitivity of pagurus bernhardus (L.) to substrate-borne vibration and anthropogenic noise', *Journal of Experimental Marine Biology and Ecology*, 474, pp. 185–194. doi:10.1016/j.jembe.2015.09.014.