Measurements of underwater conductor hammering noise: compliance with the German UBA limit and relevance to the harbour porpoise (*Phocoena phocoena*)

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Summary
Cetaceans (whales, dolphins and porpoises) rely heavily on sound for communication, foraging, predator avoidance, orientation, and navigation. Noise generated by offshore construction work, such as piling during wind-farm construction and conductor hammering during exploration-drilling operations, has the potential to cause behavioural changes, masking of communication signals or, in extreme cases, a temporary loss of hearing in marine mammals. Numerous countries have issued individual standards for offshore noise monitoring before, during and after construction, but few standards specify actual noise thresholds, due to the complexity of underwater environments. Underwater noise measurements were taken from an offshore support vessel, stationed at distances of 750 m, 1 km, and 2 km away from a drilling-rig conductor hammering site in the North Sea. Results were then compared with the only official threshold value, which was issued by the German Federal Environment Agency (UBA). Sound Pressure Level (SPL) at various measurement locations, and beyond was predicted. The Sound Exposure Level for conductor hammering noise was monitored in real time, and did not reach 160 dB re 1 µPa at a distance of 750 m, in accordance with the UBA. Given the known behaviour of porpoises around offshore installations, it is unlikely that animals were exposed to levels of sound that might be potentially detrimental in the single and brief 2 h period that conductor hammering occurred.

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1. Introduction

Offshore construction work, such as piling during wind farm construction, and conductor hammering during Oil & Gas (O&G) exploration drilling operations produces high-amplitude, low frequency and impulsive sound [1]. Noise levels produced depend upon a number of factors such as pile size, hammer strike energy, and nature of the seabed, but field measurements of piling undertaken previously show that source levels are ca. 210–250 dB re 1 µPa @ 1 m [2-4] and frequency is predominantly <1 kHz [1, 5-7], although can extend to at least 100 kHz [7]. Unlike piling for multiple turbine installations associated with the development of a windfarm over a typical 30-60 d period, conductor hammering (to create a single foundation for O&G drilling) has a typical, one-off duration of only a few hours.

Marine mammals (whales, dolphins, and porpoises) rely on sound to undergo everyday activities, such as feeding, mate finding or predator avoidance. Introduction of noise into the marine environment therefore has the potential to cause an impact, either negative [8-11] or positive [12].

Harbour porpoises, which are the most common cetacean species in the central North Sea [13], produce Narrow Band High Frequency (NBHF) echolocation clicks, and are most sensitive to noises at 130 kHz [14, 15]. Noise from pile driving operations produces minimal sound in the high frequency range used by porpoises [16], but effects are still possible, as evidenced in the literature [7, 17-19]. Despite this, the decision to

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return to an area following noise exposure depends upon the importance of that habitat to the animals; motivation will be higher if rewards are greater. For example, past research has shown that porpoises forage regularly in the vicinity of routine-installation activities, such as drilling, cementing and casing, supply boat operations, etc. [20]. These installations are well established in the environment, many having been *in situ* for the entire life cycle of porpoises in the region; thus, drilling/production and conductor hammering noise forms a part of everyday life for a North Sea porpoise. Moreover, many well-placed O&G installations act as an 'artificial reef', providing a plentiful and reliable food source to any species, so incentive to remain close is considerable, especially if prey species are scarce in the surrounding habitat. This 'recolonisation' effect has been shown to some extent for porpoises during seismic surveys [21].

This is supported by on-going Passive Acoustic Monitoring (PAM) studies by Ocean Science Consulting Ltd. (OSC) [20, 22], which have shown porpoises may either move away temporarily from installations or cease vocalising for short periods associated with jack-up rig-platform-joining operations. Therefore, given that conductor hammering usually occurs shortly after rig arrival, porpoise density in the vicinity of rigs is probably lower compared with more typical operations, such as drilling. Consequently, assuming porpoises have learned to recognise typical noise signature associated with the various stages of O&G drilling activities – and are aware which are likely to interfere with their ability to forage and communicate – fewer animals are likely to be exposed to conductor hammering noise compared to routine drilling and/or production operations. Once these rig-arrival and set-up operations have been completed and routine drilling resumes, porpoises return to continue foraging around the supporting structures of the installations, eventually reaching 'baseline' levels [23].

Potential impacts of noise on marine mammals has led to numerous countries issuing individual standards for offshore noise monitoring before, during and after construction; however, due to the complexity of underwater environments, few standards specify actual underwater noise thresholds. The only official threshold value has been issued by the German Federal Environment Agency (UBA), and specifies that a value of 160 dB (re 1 $\mu Pa^2 s$) in Sound Exposure Level (SEL) and 190 dB (re 1 μPa^2) in peak-to-peak SPL should not be exceeded at a distance of 750 m around the piling site [24]. This value is based on a single research study carried out by Lucke, et al. [10], which found a TTS in a single harbour porpoise at 164 dB re 1 $\mu Pa^2 s$ SEL and 199 dB re 1 μPa^2 (peak-to-peak SPL) and suggested the chosen values include some safety adjustment. This study could be criticised for several reasons not discussed here (but not least on account of sample size and study design), but legislation has now been set on the basis of this research, and is being followed rigorously by industry. Thus, in German waters, the threshold now precludes certain activities that introduce sound deliberately into the marine environment, such as seismic exploration using airguns and military sonar operations. This is because noise reduction measures are difficult and impractical to implement and/or, in the case of military sonar, defeat the object, as defence exercises involve the use of intentionally loud active sonar for target detection. For more information on sound exposure criteria, see Tougaard, et al. [25].

This study presents noise measurements taken in the central North Sea, near an exploration jack-up rig attached to a gas production platform, during routine conductor hammering procedures. The noise measurements were compared with the UBA's threshold. SPLs at further locations were predicted with modelling.

2. Methodology

Underwater noise measurements were conducted from an offshore support vessel, stationed at distances of 750 m, 1 km, and 2 km away from the conductor hammering operation site. The noise monitoring system diagram is shown in Figure 1, and relevant equipment specifications are listed in Table I. Two Reson hydrophones were used: 1) TC4014, covering a bandwidth of 15 Hz to 470 kHz, and 2) TC4034 covering a bandwidth of 1 Hz to 470 kHz. The TC4014 hydrophone included a pre-amplifier, and both hydrophones were configured with voltage amplifiers, band pass filters, and a Data AcQuisition (DAQ) sound card (NI USB-6251). The DAQ sound card was connected to, and controlled by, a PC (laptop), and data were saved onto hard drives. To determine whether surface wave contributions were relevant, three measurements were carried out at ¼, ½ and ¾ of the 48 m water depth corresponding to depths of 12 m, 24 m and 36 m respectively. For background noise measurements, signals were taken in 5 s batches for 30–60 s in total, at each measurement point. For transient conductor hammering noise, signals were taken for long enough to cover at least ten transient periods.

Three noise level indicators were chosen, including SPL (5 s averaging time) and un-weighted zero-to-peak SPL and single transient SEL in the ⅓ octave band.

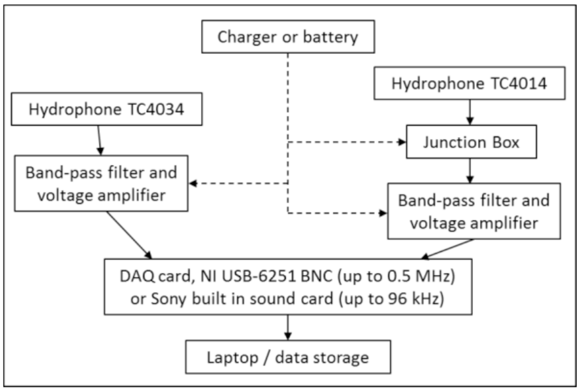

Figure 1. Noise measurement system.

Table I. Specifications of the noise measurement system.

Item	Specifications
Hydrophone TC4034	Receiving sensitivity: -211 dB re 1 V/µPa; linear frequency range: 1 Hz to 470 kHz
Hydrophone TC4014	Receiving sensitivity: -186 dB re 1 V/µPa; linear frequency range: 15 Hz to 470 kHz
Voltage amplifier and band-pass filter	Amplifier gain: 0 to 50 dB; band-pass frequency range: 1 Hz to 1 MHz
Junction box	Input connector: Jupiter Output connector: BNC
Battery charger	Input: 110/220 VAC Output: 15 V / 0.12 A
Battery	Output: 12 V / 0.12 A
NI DAQ card USB-6251 BNC	16-Bit, 1.25 Ms/s, 8 BNC analogue input; 2 BNC analogue output
Laptop computer	Sony Vaio VPCF11X5E

Noise measurements (including background) were carried out before and during piling operations. Simultaneous sound profile measurements of Conductivity, Temperature, and Depth (CTD) were undertaken at a sampling rate of 5 Hz. Simulation was then conducted by using a ray-tracing-based Bellhop numerical model to predict transmission loss away from the source.

3. Results and discussion

In the winter of 2012, conductor hammering commenced with a 15 min soft-start that used power levels below 80 kNm. Hammering then increased gradually to a stable power level of 85 (±5) kNm, which was maintained for *ca.* 2 h.

Figure 2 shows SPL and SEL of single hammer strikes at three different locations (750 m, 1 km and 2 km from the fully operated sound source) with three hydrophone depths (12 m, 24 m and 36 m) at each location. Background noise measured prior to conductor hammering is also presented in Figure 2 for comparison. Zero-to-peak SPL (Lz-p) for these measurements are listed in Table II.

Table II. Zero-to-peak Sound Pressure Level (Lz-p) for measurements carried out at 750 m, 1 km and 2 km away from the hammering sound source.

Depth	750 m	1 km	2 km
12m	152.5 dB	133.6 dB	130.6 dB
24m	150.9 dB	137.7 dB	131.5 dB
36m	156.0 dB	135.7 dB	134.5 dB

From the measurements, the SPL of hammering noise was about 10–20 dB larger than background noise, which confirmed the accuracy of the noise hammering measurements. Water-column depth did not reveal any obvious difference in SEL at 750 m distance. Maximum SEL for single strikes did not reach the permitted 160 dB limit. Highest energy appeared at the frequency band from 100 Hz to *ca.* 2 kHz.

At 1 km, SEL fell slightly compared with 750 m; however, at 2 km, SEL decreased noticeably due to sound propagation attenuation. These additional measurements were not enough to give an equivalent source level, but show that sound signal propagation generated by conductor hammering was stable, with a reasonable decrease at increasing distances from the source. Despite the energy decrease, measurements at different distances gave similar spectrum shapes, which confirmed the reliability of measurements conducted at 750 m.

Simulation was carried out to predict the sound field beyond measurement locations. Sound source level was set to match the SPL with measurement data. One example of Transmission Loss (TL) for a 250 Hz signal is shown in Figure 3. Predicted SPL at a horizontal level in a 24 m water depth, is shown in Figure 4.

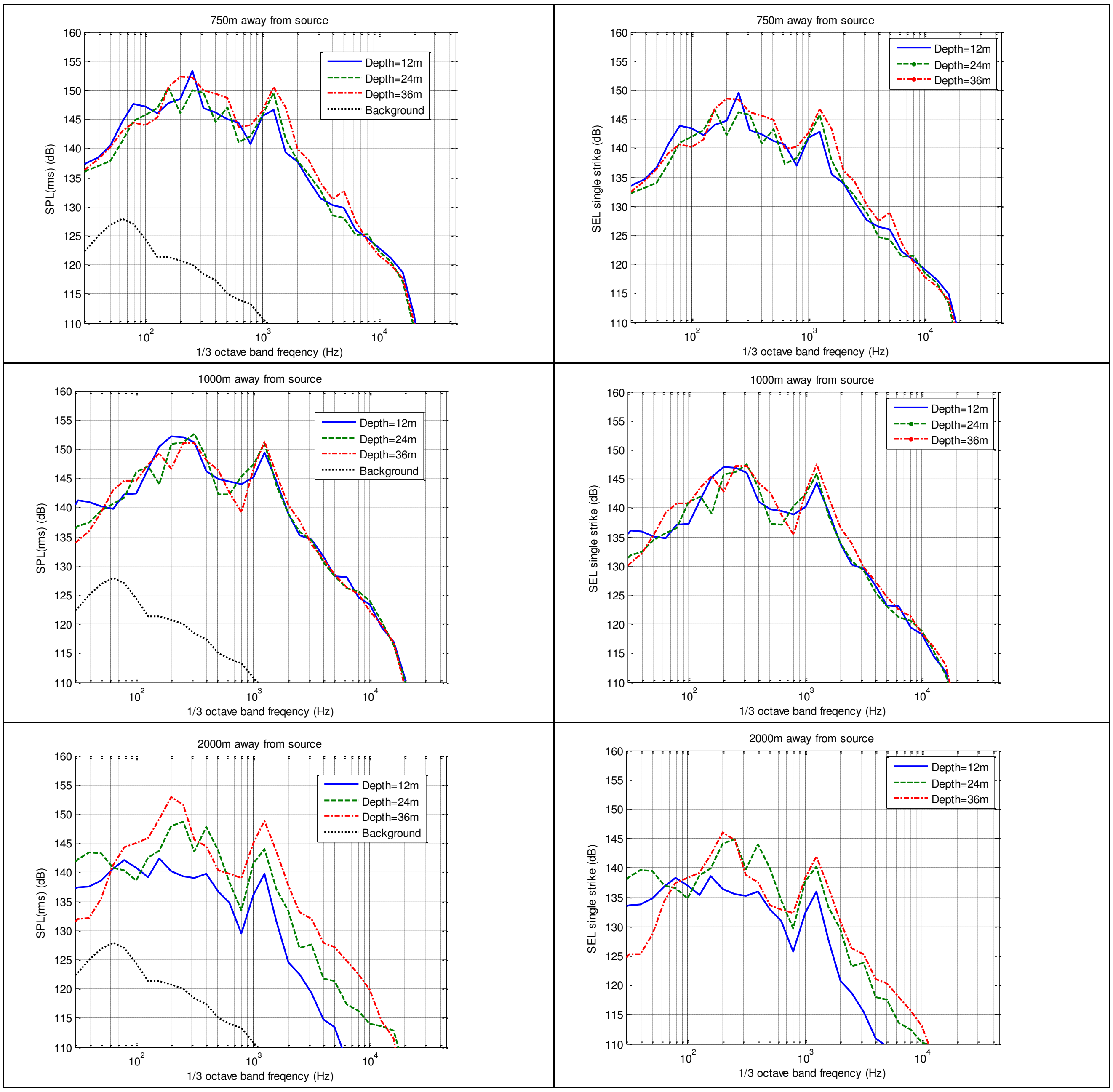

Figure 2. Sound Pressure Level (SPL) of conductor hammering and Sound Exposure Level (SEL) of single hammer strike at ranges of 750 m, 1 km and 2 km from the sound source.

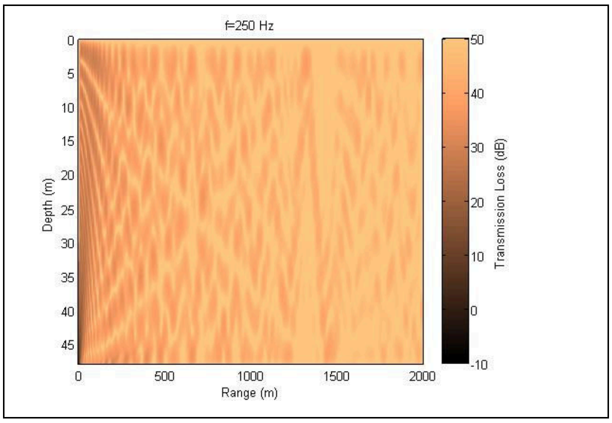

Figure 3. Transmission Loss of 250 Hz, at different depths and distances away from a point source which was placed at 47 m water depth (1 m above the sea bed).

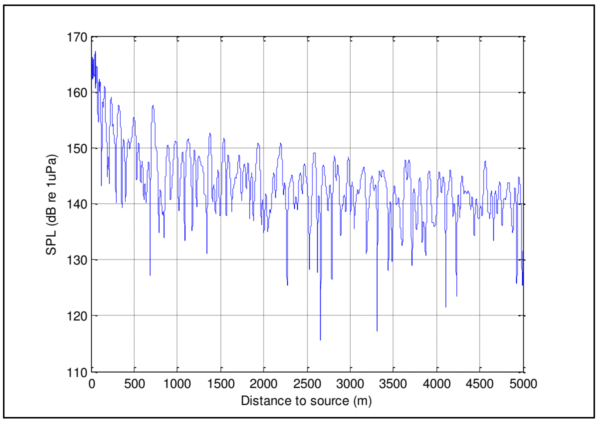

Figure 4. Sound Pressure Level at 24 m water depth, changing with distance from the piling source.

4. Conclusions

Background noise and transient conductor hammering noise was measured at 750 m from the noise source. The SEL for hammering noise was monitored in real time, and did not reach 160 dB, in accordance with the UBA's threshold. Noise measurements at further locations confirmed that the measurements at 750 m were reliable. Simulations were carried out to predict the SPL beyond the measurement locations, which confirmed a stable reduction with distance. Therefore, the UBA's limit appears practical for conductor hammering in an exploration-drilling-rig context. Moreover, conductor hammering is very brief and prior research indicates that animals are familiar with these short-term operations, probably vacate the area prior to conductor hammering, and are therefore less likely to be exposed to associated noise, compared with other pile-driving activities, such as wind-turbine construction.

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