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Underwater operational noise level emitted by a tidal current turbine and its potential impact on marine fauna

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ABSTRACT

Marine renewable energy development raised concerns over the impact of underwater noise. Here we assess the acoustic impacts of an operating tidal current turbine (Paimpol-Bréhat site, France) on marine fauna. Its source level (SL) has been measured in situ using 19 drifting transects at distances between 100 m to 2400 m from the turbine. SL ranged from 118 to 152 dB re1 μPa@1 m in third-octave bands at frequencies between 40 and 8192 Hz. It is comparable to the SL of a 19 m boat travelling at 10kt speed. This SL was used to estimate the impact of this noise type based on acoustic propagation simulations. The acoustic footprint of the device corresponds to a 1.5 km radius disk. Our results show that within this area of greatest potential impact, physiological injury of the hearing apparatus of invertebrates, fishes and marine mammals is improbable. Behavioral disturbance may occur up to 1 km around the device for harbor porpoises only. This is of little concern for a single turbine. However, greater concern on turbine noise impact, particularly on behavioral reactions has to be granted for a farm with up to 100 turbine. The lack of consolidated knowledge on behavioral disturbances identifies the needs for specific research programs.

1. Introduction

In the near future, Marine Renewable Energies (MRE) will partly substitute fossil fuel energy resources, providing benefits to the environment by reducing carbon emissions (Pelc and Fujita, 2002). EU countries have agreed on a new 2030 framework for climate and energy that includes common objectives. More specifically, renewable energy will have to represent at least 27% of the energetic consumption (European Commission, 2014). Tidal current turbines generate one of the most reliable and predictable source of renewable energy (Rourke et al., 2010). Only a few large-scale tidal current operational sites exist worldwide,[1] as the technologies are less mature compared to fixed wind turbines.

The risks of impacts of such devices on marine ecosystems remain largely unknown, mainly because of their little number, the difficulties in studying their high energetic environments and the absence of a unique regulatory framework to measure its impact. Among the potential effects of these marine renewable energy devices, exposure to anthropogenic noise can cause detrimental effects to wildlife (Isaacman and Lee, 2010; Polagye et al., 2011). Many aquatic species, ranging from benthic invertebrates, fishes to marine mammals, can detect and generate sounds (Amorim, 2006; Popper et al., 2001; Richardson et al., 1995). These sounds are vital for communication, prey detection, orientation in the water column and habitat selection (Tolimieri et al., 2000; Wladichuk et al., 2011). Anthropogenic underwater noise may consequently be a threat to marine habitats and their inhabitants and is now seriously considered for environmental impact assessment (Andersson, 2011; Boehlert and Gill, 2010). These assessments involve among others, measuring or predicting the Source Level (SL) at 1 m of the sound source, propagating this SL to compute the Received Level (RL) at a potential receptor's distance r and comparing this RL to a given acoustics impact threshold. Until today, there is a lack of peer-reviewed articles describing in detail the noise and especially the SLs emitted by tidal turbines (Deveau et al., 2011; Parvin et al., 2005; Richards et al.,

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[1] The tidal current turbine that are or have been operational during the past few years are: 1) Openhydro, EMEC/Atlantis Resources Corporation AR1000 (UK), 2) Pulse Stream 100 (UK), 3) SeaGen/MTC turbines (UK), 4) Sabella (Fromveur, FR), 5) OpenHydro turbine “Arcouest” and others (Paimpol Bréhat, FR), 6) Openhydro (Fundy, Canada) (Observ'ER (FR) et al., 2013, 2014).

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2007; Robinson and Lepper, 2013; Thomsen et al., 2015).

Available data on the effects of noise on the marine fauna is quite variable in quantity and quality. Acoustic impacts have been classified for marine mammals into four zones of noise influence, which depend on the distance between the source and the receptor (Richardson et al., 1995). They are defined as footprint, zone of audibility, responsiveness (or behavior disturbance), masking and hearing damage (Temporary or Permanent Threshold Shifts, TTS or PTS). The existence of these zones depends on the SL of the source studied, the transmission losses and the sensitivity of the receptors. Some sound exposure guidelines (National Marine Fisheries Service, 2016; Southall et al., 2007) constitute a significant development in predicting how noise affects marine mammals. Knowledge on the effects of noise exposure in fishes and invertebrates is still sparse, especially with regard to behavioral disturbances (Popper et al., 2014). This represents a major issue since there are > 30,000 described species of fishes and at least ten times more species of marine invertebrates compared to about 130 species of marine mammals. Furthermore, several recent reviews showed that anthropogenic noises can impact critical life history phases of marine fishes and invertebrate larvae (Aguilar de Soto et al., 2013; Jolivet et al., 2016; Nedelec et al., 2014; Pine et al., 2012).

The objectives of this study were to i) characterize the operating noise produced by one of the world's largest tidal current turbines (Zhou et al., 2014), ii) estimate its SL, and iii) evaluate the potential acoustic impact on marine fauna based on the turbine's acoustic signature via a numerical simulation.

Throughout our study, we used the word “noise” in terms of an “potentially adverse sound”, meaning all individually identifiable anthropogenic sounds, including the one emitted by the tidal turbine. The “ambient noise” in comparison refers to a chorus of a myriad of distant natural biotic and abiotic as well as anthropogenic sources (Wenz 1962; Urick, 1967).

2. Materials and methods

2.1. Study site and tidal turbine “Arcouest”

The study was carried out in Northern Brittany (France), off the coast of Paimpol and Bréhat Island in the English Channel (48°54′33,46″ N, 2°53′25,875″ W), where EDF (Electricité De France) and DCNS Energies installed one of the first 2.2 MW ‘Arcouest’ tidal current turbine of France in December 2013 (from Dec. 2013 to Apr. 2014) at 40 m depth (Pham and Martin, 2009). It was built by Openhydro, a DCNS Energies company. The turbine installation site is characterized by a rocky substrate and water depths varying between 32 m at the south-western part and 50 m at the north-eastern edge of the 12 km^2 area (Fig. 1). The site is subject to semi-diurnal tides, with maximal tidal amplitudes of about 7.2 m and tidal current velocities up to 3 $m{\cdot}s^{-1}$.

This area hosts part of a resident bottlenose dolphins (*Tursiops truncatus*) population living in the Normano-Breton Gulf that comprises over 450 individuals (Louis et al., 2015). Common dolphins (*Delphinus delphis*), harbor porpoises (*Phocoena phocoena*) and grey seals (*Halichoerus grypus*) also inhabit these coastal waters (OBS MAM Report, 2014). They are all protected under the European Union's Habitats Directive (92/43/22C) and listed in Annex IV as “in need of strict protection”. Other marine mammal species can cross occasionally this site but are not considered in this study. This area also hosts a large number of fish and benthic invertebrate species of commercial interest such as the sea bass (*Dicentratchus labrax*), the European pollock (*Pollachius pollachius*), as well as mussels (*Mytilus edulis*), common prawns (*Palaemon serratus*) or spiny lobsters (*Palinurus* spp.). The Paimpol-Bréhat tidal turbine deployment area is located within a crustacean's no-take zone (created in 1966, 7000 ha) that ensures the presence of crustacean species.

2.2. Acoustic recordings

Acoustic surveys were performed on a 12 km^2 area around the tidal turbine (Fig. 1). During two days (3 and 4 April 2014), we performed 19 line drifting transects of 10 to 30 min duration each using a drifting hydrophone deployed from a 6-m long inflatable vessel, at distances between 100 m to 2400 m from the turbine. Altogether 2 h 51′ 45″ of acoustic raw data were recorded representing 14.5 km of drift. Engine and depth sounder were switched off during the recording drift-transects. The advantages of using drifting methods over fixed bottom moorings are multiple. First, they are poorly affected by flow-noise, which may be important in tidal channels (Wilson et al., 2013, 2014). Second, drifts produce measurements of the radiated noise as a function of the range across kilometers and can therefore be used to assess local TL models. This allows reducing the impact of Transmission Loss (TL) errors on the estimation of the tidal turbine's SL. We took care to sample on- and off-axis of the tidal turbine's main direction. A GPS (Garmin® 600 Montana) was used to sample the position at a rate of 1 position every 10 s. A Brüel & Kjaer® 8106 hydrophone (sensitivity: −173 dB re1V/1 µPa, flat frequency response range between 7 Hz and 80 kHz) was attached to an anti-heave buoy and suspended at 10 m depth to avoid sea-surface noise and to decouple the hydrophone from the vessel movements. Measurements were amplified by a Brüel & Kjaer® 2692-C charge amplifier NEXUS (Gain: −31.6 V/Pa) and digitized at 192 kHz sampling frequency with a resolution of 24bit and a dynamic of 12 V using a DR-680 TASCAM® digital recorder. The acquisition chain was fully calibrated, at our laboratory for the TASCAM® digital recorder and at Brüel & Kjaer laboratory for the hydrophone and the amplifier NEXUS.

All recordings were carried out under sea state conditions below 2 on a Beaufort scale. During the study, tidal current speed[2] ranged between 0.7 and 1.7 m/s (Fig. 1). Table 1 exposes the precise terms of tide and wind for the 19 transects.

2.3. Sound analysis and SL estimation

Raw data were processed using custom-made Matlab® routines. To analyze the time-frequency patterns produced by the operating tidal current turbine noise, we computed and visually inspected the spectrograms of the data (L_{FFT} = 32,768, Kaiser window, overlap = 50%) (Hlawatsch and Boudreaux-Bartels, 1992). We represented the Narrow Band Sound Pressure Level (NB_SPL, dB re 1 µPa^2/Hz) not only as a function of time and frequency but also as a function of range and frequency.

Sound propagation is described by the equation:

$$SPL(r,f) = SL(f) - TL(r,f) \quad (1)$$

where SPL (r, f) is the one-third-octave Sound Pressure Level (dB re 1 µPa) at distance r from the source and frequency f, SL(f) is the one-third-octave Source Level at 1 m from the source (dB re 1 µPa@1 m) at frequency f, and TL (r, f) is the Transmission Loss (TL in dB re 1 µPa).

To investigate range-dependence, the 19 transects with ranges from 100 to 1400 m were divided into 100 m non-overlapping segments. For each one-second bin of measurements belonging to a given 100 m segment, we computed 33 third-octave band SPLs (L_{FFT} = 32,768, Kaiser window, overlap = 50%) for central frequencies ranging from 20 Hz to 32,768 Hz. Third-octave bands were chosen according to international recommendations on noise impact measurement (Dekeling et al., 2016). For each 100 m segment, the median third-octave band SPL (SPL_{med}) was computed. Drift measurements have been recorded at short ranges and emanate from a source propagating along a range-dependent environment as the depths are variable, extending from 30

[2] Data were extrapolated from an ADCP campaign conducted by France Energies Marines in 2013 during the spring and days with the same tidal coefficient.

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