A Comparison of Underwater Noise at two High Energy Sites

MR Willis[#], M Broudic[#1], T.N Croft[#], I Masters[#]

[#]*College of Engineering, Swansea University*
Singleton Park
Swansea SA2 8PP
Wales, UK

[1]M.Broudic@swansea.ac.uk

***Abstract*— The amount of noise associated with the installation, operation and decommissioning of tidal stream devices and the effect that this noise has on the resident and transient marine wildlife populations is a prime concern of the marine energy stakeholder community.**

Before assessing the potential impact that a marine energy device may have on the environment, it is crucial to characterise underwater background noise as a baseline of a marine energy project.

This paper considers the ambient noise associated with anthropogenic noise at two sites typical of hosting tidal stream turbines in the future. The first site is an open channel measuring approximately 2.5 km long by 1 km wide, varying in depth between 25 and 70 m referring to the Lowest Astronomic Tides (LAT) and subject to tidal streams in excess of 3 $m.s^{-1}$. The second site is an inlet channel, 1.5 km long by 200 m wide, between 2 and 10 m LAT and again experiencing flows of around 3 $m.s^{-1}$ during spring tides. Anthropogenic noise occurred during the recordings: intense boat traffic (first site), pile driving and vibro-drilling (second site). The impact that these anthropogenic noises may have on ambient noise in shallow water are quantified and discussed.

***Keywords*— underwater ambient noise, anthropogenic sound, pile driving, vibro-drilling**

I. Introduction

The installation and operation of a marine renewable energy device into the marine environment will change that environment. The nature of that change and the risks associated with the change has been discussed in a number of studies [1], [2]. In most cases the quantification of the risk is little better than a best guess estimate due to the lack of installations from which to gather data. One of the most important concerns relates to underwater noise. However, there is a knowledge gap regarding the potential impact of anthropogenic noise on marine life [3].

Underwater noise emitted during a project phases (installation, operation, decommission) potentially presents a risk to fish and marine mammal populations. These risks may result in behavioural changes, such as marine life leaving the affected area or injuries. The potential effect of anthropogenic noise on marine life depends partly on whether the sound emitted is continuous or transient. Transient sound such as pile driving or underwater explosive is defined as pressure increase that starts and ends in a relatively short time [4]. Transient can cause temporary threshold shift (TTS), permanent threshold shift (PTS), physical injuries, or even fatalities to marine animals depending on the noise level exposure and other factors [5]. Continuous noise is defined as sound whose waveform continuous with time, such as vibro-drilling or boat noise. This sound can cause permanent threshold shift (PTS) [4]. Transient noise is often expressed in "peak to peak" or "0-peak" due to the short duration of the sound. Continuous sound is usually expressed using "root mean square" due to the long time duration of the sound. Thomsen [3] reported that "Peak-to-peak sound pressure levels (SPLs) are usually used to describe short, high intensity sounds where the rms-sound pressure value could underestimate the risk of acoustic trauma". This emphasises the importance of using the appropriate unit to express anthropogenic noise, depending on the noise studied. It also highlights the difficulty of making comparisons between different types of anthropogenic noises.

The Low Carbon Research Institute Marine (LCRI Marine) recorded underwater background noise in two different high energy flow areas. During the recordings, anthropogenic noise occurred such as vibro-drilling, pile driving and boat traffic. An analysis of the background noise will be made by quantifying the distribution of underwater ambient noise. Then, an analysis of the anthropogenic noise contribution to the ambient noise will be assessed and the importance of units to express anthropogenic noise (transient and continuous) will be discussed. This will allow the characterisation of the influence of anthropogenic noise on ambient noise in shallow and high energy flow environment.

II. Experimental Techniques

A. Study Areas

This paper contains a comparison of two underwater noise surveys. The first survey site was located in Ramsey Sound, Wales, UK and will be referred to as "site A" in this contribution. A first measurement period at this site carried out on the 22th of April 2009 and a second on the 6th of August 2009.

Fig 1 Location of Ramsey Sound, South Wales, UK

Ramsey Sound is considered a high tidal flow area. Ramsey channel is 2.5 km long by 1 km wide varying in depth between 25 and 70 m LAT. In this area, current flow can reach up to 3 $m.s^{-1}$ during spring tides [6]. It is also subject to semi diurnal tides (two high waters and two low waters per day). The north flowing (flood) tide changes to south flowing (ebb) tide between 2.5 to 3 hours after high water at Milford Haven. The changing from the ebb to the flood occurs 8.75 to 9.5 hours after high water at Milford Haven. Water height fluctuation during spring tide can fluctuate between about 5.1 m and 0.7 m.

Ramsey Sound is designated as a marine special area of conservation (Marine SAC), a special protection area (SPA), a site of specific interest and a national nature reserve. It has a resident population of harbour porpoise and it hosts the largest colony of grey seals in southern Britain. The main recreational activity in Ramsey Sound is wildlife/nature tour boat trips which operate from May to October. No commercial shipping or trawling activities operate the Ramsey Sound.

The second survey site refers to an inlet channel. This measurement site is named "site B". This channel is 5 km long by 200 m wide between 2 and 10 m LAT. During spring tide, water height in the channel can reach 0.5 m at low water and 5.5 m at high water. Industrial firms are located on the banks of the channel, and the area is subject to anthropogenic noise: boat generator, pile driving and vibro-drilling. The inlet is not considered as a protected area nevertheless, seals and bird colony have been seen in the channel.

B. Noise measurements

The British Oceanographic Data Centre defines ambient noise as the environmental background noise not of direct interest during a measurement or observation [6]. It may initiate from sources near and far, distributed and discrete, but excludes sound produced by measurement equipment.

During underwater measurements in the two sites, anthropogenic noise occurred. This noise is not of direct interest in the measurement of background noise. Thus, it will be included in the underwater background noise analysis and then isolated to quantify its contribution to the ambient noise.

Underwater noise measurements were recorded with a C54XRS hydrophone from Cetacean Research Technology. This hydrophone is able to record sound from 4 to 22000 Hz.

Recording underwater noise in a high energy flow area is complex. From Kim & al. [7], measuring underwater noise in a high energy flow area by holding the hydrophone in the fixed position induces noise at low frequency due to flow noise and cable strumming noise. Thus, the methodology used to undertake measurements was to turn off the research vessel engine, immerse the hydrophone and let the boat drift with the current. This methodology reduced the turbulence created around the hydrophone and the cable. and consequently it reduced the noise associated with these sources. Underwater noise measurements were recorded from 4 Hz to 20 kHz. After each recording, the engine was turned on and the boat navigated back to the start position.

With respect site A (Ramsey Sound), the recording was undertaken from a Rigid Inflatable Boat (RIB). The hydrophone was immersed to around a depth of 10 m below the water surface. Recordings were made throughout the entire tidal cycle from the ebb to the flood. Recording lengths varied between 15 min and 45 min depending on the speed of the current.

Underwater noise was gathered during two periods. The first period was the 22nd of April 2009 and the second the 6th of August. In April, there was very little boat traffic in Ramsey Sound and the weather was calm with variable light wind. In August, Ramsey Sound traffic was busy with pleasure and recreational boats and the weather was sunny with light variable wind.

With regard to the site B, recordings were undertaken from a 4 m aluminium boat including an isolated 12 V DC power supply for acoustic recording equipment to avoid the potential electric perturbations. Noise data was recorded in January. The hydrophone was immersed to around 4-7 m below the surface and underwater background noise was recorded from the beginning of the flood to the middle of the ebb tide.

There were pile driving and vibration drilling activities at times during the underwater measurements, at approximately 200/500 m from the hydrophone. Table 1 provides a résumé of the anthropogenic noise recorded for each run.

TABLE I
NOISE SOURCES THROUGHOUT MEASUREMENT PERIOD (SITE B)

Time Run	Time run relative to Low Water	Vibro-drilling	Pile driving
1423	0658		X
1434	0708	X	X
1455	0729		X
1516	0751		X
1536	0811		X
1552	0826		X
1605	0839		X

C. Noise analysis

Data were processed via Spectra Pro software. Measurements of frequency and amplitude (dB re 1μPa) were taken every second. The sampling rate used was 44100 Hz with a sampling precision of 16 bits defined during the recordings. The sound pressure levels (SPL) in dB re 1μPa were expressed in 1/3rd Octave. In fact, this technique allows the display of smoother underwater background noise. In addition, for some animals, the effective bandwidth of the hearing system is roughly 1/3rd Octave [4], [8]. The output can also be used to assess the potential disturbance on marine mammals [8].

III. RESULTS

A. *Underwater background noise characterisation in high energy areas*

1) *Power Level (PL)*: The Power Level displays the total root mean square (RMS) power level for a specific spectrum. For each survey, the data has been processed from 1Hz to 22 kHz. Then the PL values are average through time to obtain mean PL for each recording.

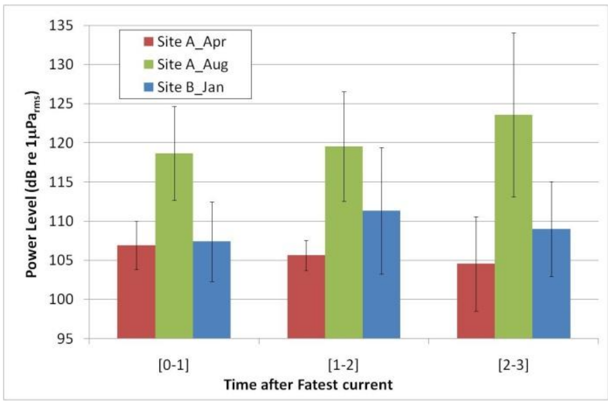

Fig 2 Background noise evolution (in terms of Power Levelrms for 1 to 22 000Hz) after fastest current for three data set: site A_Apr, site A_Aug and site B

Figure 2 represents the PL results from 1 Hz to 22 kHz as a function of time after the fastest current. Standard deviations have also been represented.

From Figure 2, it appears that site A_Aug has the highest PL across all time ranges. This can be directly linked with anthropogenic noise. As noted previously, the site A_Aug was constantly populated with pleasure boats.

For both site A_Aug and site B_Jan, no link can be made with the current flow. Current noise has almost certainly been hidden by anthropogenic noise, such as intense traffic boat or pile drilling activities. In contrast, it appears that noise at site A_Apr PL decreases with increase in time after the fastest current. This proves that turbulence created by the current speed has an impact on the background noise.

Regarding error bars, it can be seen that site A_Aug error bars and site B_Jan error bars are much longer than site A_Apr due to the anthropogenic noise that occurred in the studied areas.

In addition, it may be thought that boat traffic noise (site A_Aug) is much noisier than pile driving activities (site B_Jan). However, caution is advised due to the fact that the comparison is of underwater background noise at two different locations. Moreover, anthropogenic noise at the sites arises from every different sources which emit noise over different time scales.

Subsequently, it was decided to study the two noisier data sets: site A_Aug and site B_Jan. The aim was to assess the impact anthropogenic noise has on the background noise.

2) *Sound Pressure Level (SPL)*: SPL has been displayed in dB re 1µPa$_{rms}$. SPL is a Decibel measure of sound pressure. The SPL is a common unit used to express noise intensity. SPL level can be expressed in several ways [8]. In this paper, the SPL is expressed as a log ratio:

$$\mathrm{SPL} = 20\,\log_{10}\left(\frac{P}{P_0}\right) \qquad (1)$$

where P_0 in (1) represents the reference pressure (1 µPa for underwater acoustic) and P is the measured pressure. This formula gives a measurement in dB re 1µPa.

Figure 3 and 4 show the distribution and amplitude in RMS of frequencies from 4 to 20 kHz in 1/3rd Octave bands at site A_Aug and site B_Jan. Results have been obtained by averaging values through the time run. Underwater background noise without anthropogenic activities has also been represented.

For both sites A and B, the SPL distributions without anthropogenic activities (black curves in figures 3 and 4) were obtained by processing data during the period where no anthropogenic noise occurred in the area. The SPL distributions for the sites A and B are approximately the same. For site A the values range between 67 and 78 dB re 1µP$_{rms}$ and for site B the values range from 70 to 81 dB re 1µP$_{rms}$. This underwater background noise similarity allows comparison of ambient noise for the two sites.

As previously stated, the site A_Aug was populated with pleasure boat trips during the recording. Pile driving and vibro-drilling occurred during site B_Jan recordings.

From Figure 3, it can be seen that ambient noise in the presence of intensive pleasure boat traffic can reach up to 108 dB re 1µPa$_{rms}$ with higher amplitude response between 4 Hz and 300 Hz. Two strong increases appear around 7 Hz and 100 Hz where the amplitude can reach up to 108 dB re 1µPa$_{rms}$. Moreover, peaks appear at 315 Hz, 700 Hz and 1,000 Hz. The origins of these peaks are difficult to determine. It could be generated from electrical devices being employed by pleasure boats or even their engine.

Regarding site B, in Figure 4 it can be seen that ambient noise distribution involves in a wider range of amplitudes as functions of frequency and time than site A. This can be explained by the occurrence of anthropogenic noises (pile driving, vibro-drilling) during the recordings. Ambient noise ranges between 68 dB re 1µPa$_{rms}$ and 100 dB re 1µPa$_{rms}$. Two increases appear around 10-20 Hz and 200-1,000 Hz and the amplitude can reach up to 100 dB re 1µPa$_{rms}$.

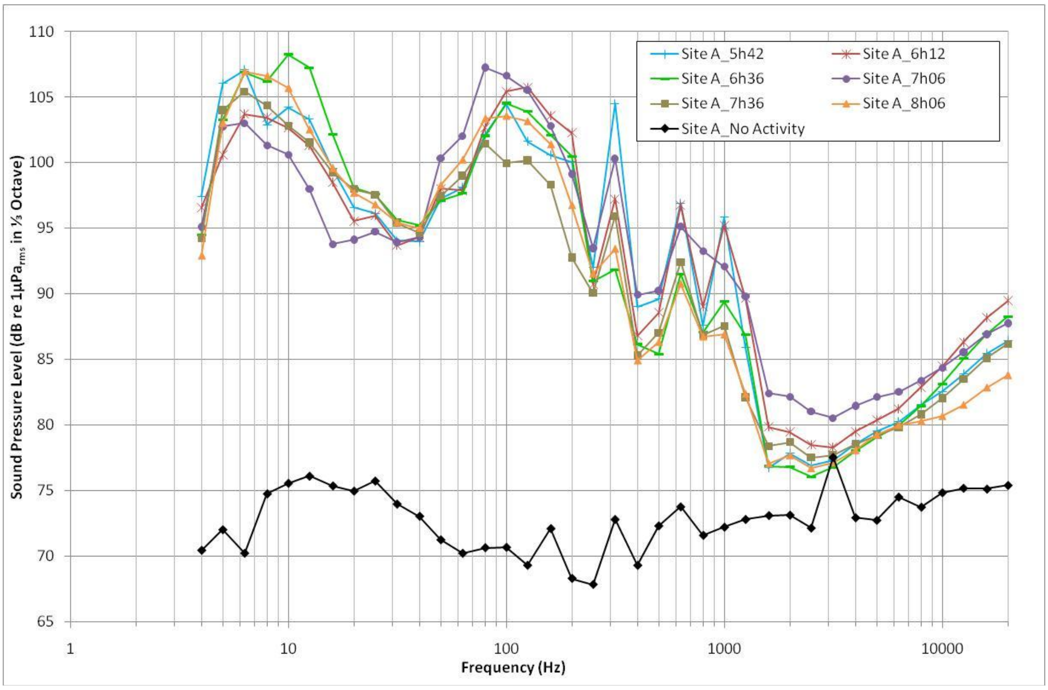

Fig 3 The variation of underwater noise levels (SPLrms) in 1/3rd Octave frequency bands during anthropogenic noise (boat traffic) for site A_Aug

Caution must be taken when considering the comparison of site A and site B. These results do not prove that boat traffic noise is louder than pile driving or vibro-drilling noise, as it can be thought from Figure 2-4-5. The results have been processed in RMS and obtained by averaging the results throughout the recording time for each run. Regarding site A, boat traffic was continuously present in the area with small variation of quantity of boats over time. For site B, anthropogenic noise such as pile driving or vibro-drilling was sometimes interrupted during recording time.

Underwater background noise depends strongly on anthropogenic activities present in the studied area. The following part will now focus on the analysis of anthropogenic noise that occurred in the areas.

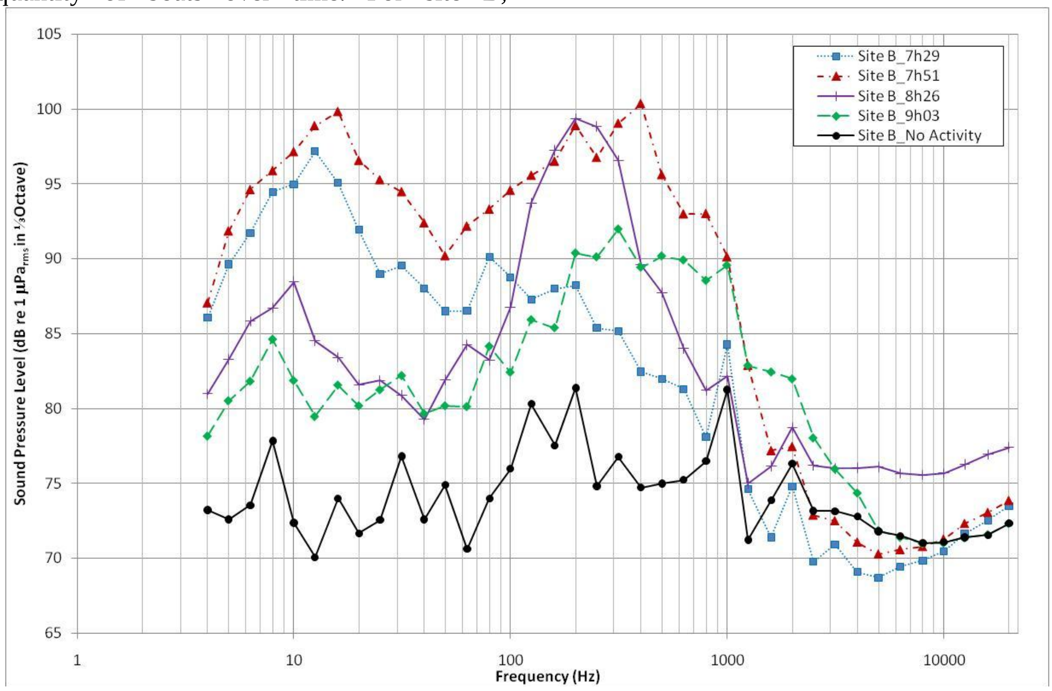

Fig 4 The variation of background noise levels (SPLrms) in 1/3rd Octave frequency bands during anthropogenic noise (pile driving and vibro-drilling) for site B_Jan

B. Anthropogenic Noise Analysis

Underwater noise units analysis depends strongly on the sound studied. Boat noise, pile driving and vibro-drilling differ by their time scale and their intensity and thus cannot be displayed in the same unit. This part focuses on the anthropogenic noise

1) *Boat and Vibro-drilling noise*: Boat noise and vibro-drilling consists on a continuous and steady sound. In this case, it is common to express this noise in rms values (dB re $1\mu Pa_{rms}$) which is defined as the 'root -mean-square' pressures divided by the duration of the signal. This unit is often used in hearing studies [8]. Values were taken every second and then they were averaged and displayed on Figure 6.

Figure 6 shows the signature of boat sound recorded 150-200 m from the source (site A) and vibro-drilling noise recorded 200 m from the source (site B). Underwater background noise without activities for each site has also been represented.

From Figure 5, underwater background noise without activity are similar for both site A and B.

Boat noise signatures taken at 150-200 m are very similar to the results display in Figure 3 and ranges between 85 and 108 dB re $1\mu Pa_{rms}$ below 1 kHz. With regard to vibro-drilling, SPL ranges between 87 and 103 dB re $1\mu Pa_{rms}$ below 1 kHz at 200 m from the source. At higher frequencies, pile driving SPL decreases rapidly to reach the same level as underwater background noise without activity at 5 kHz.

With regard to Figure 5, boat traffic noise is concentrated below 300 Hz and can reach 108 dB re $1\mu Pa_{rms}$. Vibro-drilling signature emits noise in a wider frequency band, from 4 Hz to 1 kHz with higher energy concentrated around 7 Hz and 400 Hz.

2) *Pile driving noise*: Pile driving consists on a short and intense pulse and is an erratic function of time (Figure 6). This anthropogenic noise is usually characterised through peak-to-peak, pressure changes, which is the difference in pressure from the lowest to the highest point of the waveform.

Figure 7 shows the signature of pile driving that occurred during underwater noise measurements at the site B. The hydrophone was located at 200 m from the pile driver.

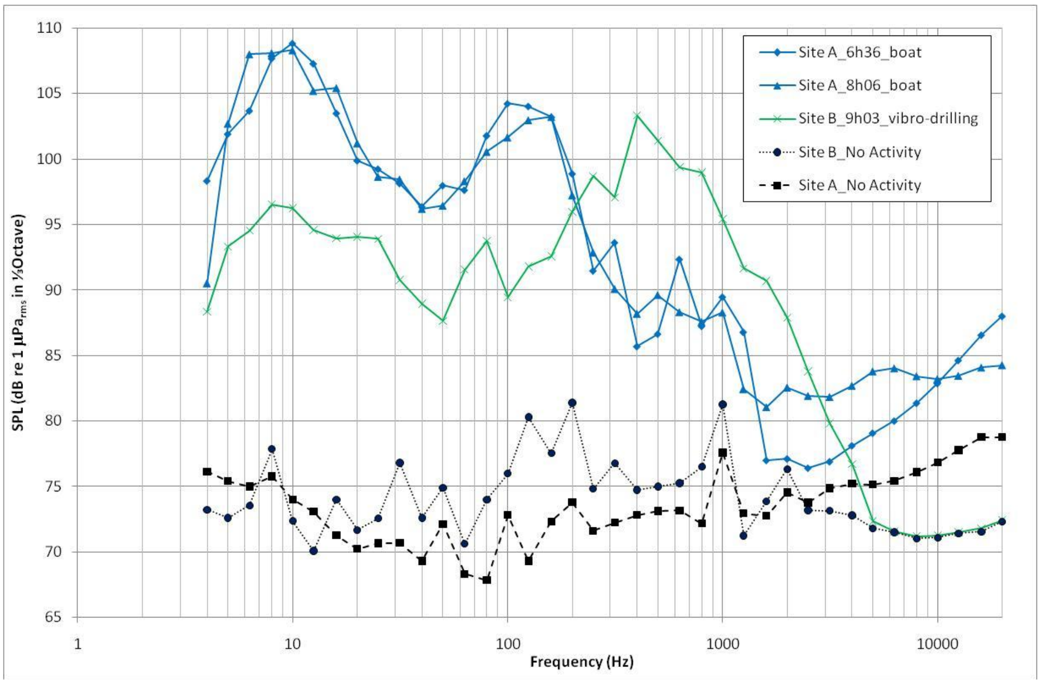

Fig 5 Boat (150-200m site A) and vibro-drilling (200m, site B) noise spectra in 1/3rd Octave levels with their respective underwater noise without activity

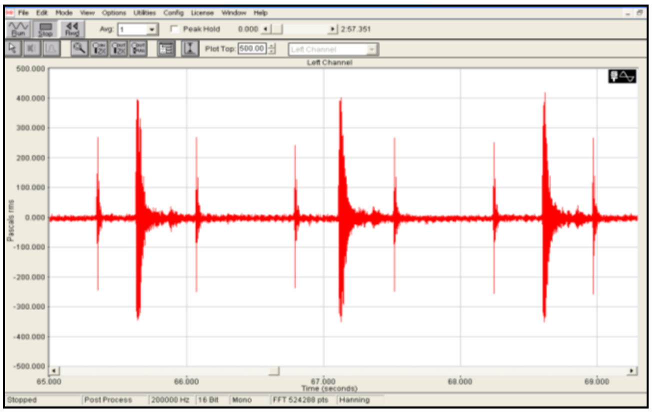

Fig 6 Times series of pile driving occurring at the site B (pressure in function as a function of time

From Figure 7, it appears that pile driving impact underwater background noise on a wide range of frequency. Below 100 Hz, SPL ranges between 92 to 120 dB re 1μPa$_{p-p}$. Between 100 Hz to 20 kHz, SPL ranges between 120 and 135 dB re 1μPa$_{p-p}$.

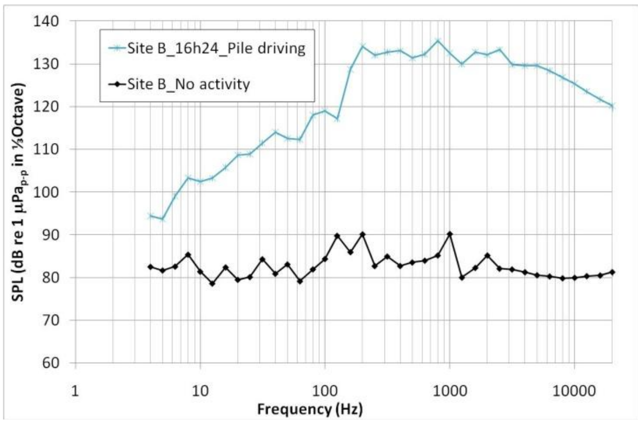

Fig 7 Pile drilling (300m, site B) noise spectra in 1/3rd Octave levels with its respective underwater background noise without activity

IV. Conclusion

Underwater ambient noise depends strongly on the anthropogenic activities that occur in these high energy flow areas. This study focused on three type of anthropogenic noise: boat traffic, vibro-drilling and pile driving.

Due to the different nature of anthropogenic sound and their units associated, it is not possible to compare numerically pile driving and boat/vibro-drilling noise. However, it can be noticed that anthropogenic noises in areas impact ambient noise from 4 Hz to 2 kHz. Regarding boat traffic noise, higher pressures are localised around 10 Hz and 150 Hz and can reach up to 110 dB re 1μPa$_{rms}$. This boat traffic noise present in the open channel induces an ambient noise increase of 10 to 35 dB re 1μPa$_{rms}$, depending of the 1/3rd Octave band considered. Concerning vibro-drilling, recorded in the site A, higher SPL emission is localised around 10 Hz and 400 Hz and reaches 104 dB re 1μPa$_{rms}$ at 400 Hz.

Pile driving noise has been processed in dB re 1μPa$_{p-p}$ due to its short time duration (pulse). This anthropogenic noise recorded 200 m away from the source emits sound throughout a wider frequencies range that boat traffic noise or vibro-drilling. The noise spectra shown that pile driving emits sound from 4 Hz to 20 kHz. Noise emission in this frequencies can reaches 130 dB re 1μPa$_{p-p}$. However, pulse sound (pile driving) usually should be measured in terms of their energy. They are difficult to interpret in terms of pressure or power because they depend on time averaging [4]. Unfortunately, the software used was not able to extract the energy distribution.

Before the installation of a marine energy device, underwater ambient noise needs to be assessed. The ambient noise might have the potential to mask or not the sound emitted by the device in the area which might have an impact on the risk of migration and collision.

Finally, it is necessary to specify that the results depend on the area considered. Geometrical specifications and proprieties of the environment influence strongly the propagation of waves. In future research, it will be interesting to study wave propagation in these two areas in order to compare wave propagation in two shallow water areas.

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