Ambient Underwater Noise in High and Low Energy Flow Conditions

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Abstract

The planned order-of-magnitude expansion of the UK offshore wind industry coupled with ambitious wave, tidal stream and tidal range projects over the next 20-30 years will undoubtedly lead to an increase in noise associated with the installation, operation and decommissioning of these devices. Before these potential effects can be quantified, the background noise needs to be characterised with regard to its constituent frequency bands and the anthropogenic/natural origins of the noise source.

This paper presents the results of background noise measurements at two near-shore sites along the Welsh Coast. One site is subject to tidal currents up to 2 $m.s^{-1}$ during spring tides and has a resident population of harbour porpoise in close proximity. The other is relatively sheltered with tidal flows around 1 $m.s^{-1}$ and is close to a transient population of harbour porpoise. The problems associated with taking hydrophone readings in high tidal, turbulent currents are discussed. The influences that tidal environment and shipping activity have on background noise are also discussed.

This paper presents the underwater background noise difference (levels, frequencies) between offshore wind site (low energy flow) and tidal/wave energy site (high energy flow).

Using the Power Level (PL) in dB re 1 μPa and sound pressure level (SPL) in root mean square (dB re 1 μPa_{rms} in 1/3rd Octave band), this paper establishes the underwater background noise comparison of two different energy sites as a function of the tide, boat traffic and current speed.

It has been found that the low frequency response of underwater background noise at high and low energy sites were similar. Both sites showed increases in sound pressure levels (SPL) around 1-20 Hz although the extent of the increase varied with tidal speed and weather conditions.

The importance of characterising background noise (and subsequent operational noise) across the spectra of frequencies is emphasised. Background noise levels are normally reported as root mean squared values whereas operational noise is measured as zero-to-peak or peak-to-peak. The authors stress that whenever noise measurements are presented that the methodology and units should be stated to avoid misunderstanding.

Introduction

U.K marine energy market is going to move from the offshore wind energy to tidal stream and wave energy market. Underwater noise emitted by wave and tidal energy devices is likely to induce temporary or permanent hearing losses of marine mammals and fish species (Richards et al, 2007). It is therefore necessary to assess through measurement and analysis the amplitude and frequency distribution of noise emitted during installation, operational and decommissioning phases. This assessment must begin by underwater background noise characterisation, to define the distribution of the "natural noise" of the studied area. Underwater background noise or underwater ambient noise is defined as a mixture of natural, biological and anthropogenic noise.

In 2004, Nedwell & Howell defined underwater background noise as the sound that is measured in the environment not originating from the sensor, or from an identifiable localised source. Underwater background noise depends of several factors, such as the natural environment, biological and anthropogenic factors.

Underwater ambient noise monitoring and analysing in water flow environment is less well understood that from a low energy flow area. Thus, the Marine Energy Research Group (MERG) of Swansea University has carried out underwater ambient noise measurements in low and high energy flow area to assess the main difference that these two sites may have.

Study Areas

This study has been built on two underwater noise surveys: Mumbles Head and Ramsey Sound.

Figure 1: Mumbles and Ramsey Sound sites, South Wales, UK

The first survey was located at Mumbles Head, Swansea Bay, Wales, UK (Figure 1). In August/September 2008, drilling operations have been carried out in this area. The MERG gathered some data from the ambient and drilling noise to study noise emitted and propagated. In this study, only underwater background noise will be taken into account. Swansea Bay is characterized by a tidal range in excess of 10 m during spring tide. At low tide, the area exposes sand and mud. The current regime is unusual, in that water follows in an anticlockwise gyre, following in the same direction

throughout the tidal cycle (Heathershaw, 1979). Out into the Bristol Channel currents may reach 3 $m.s^{-1}$, but remain below 1 $m.s^{-1}$ in the sheltered waters of the bay. Swansea Bay is a protected area as a site of special scientific interest (SSSI) because it is a species-rich, biologically-diverse area. The bathymetry of Swansea Bay is quiet flat and the sea depth at the study area is around 15-20 m.

The second area concerns Ramsey Sound, Pembrokeshire (Figure 2). Underwater background noise measurements were taken in late spring and midsummer 2009. Ramsey Sound is designated as a marine special area of conservation (Marine SAC), a special protection area (SPA), a site of special scientific interest (SSSI) 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.

Ramsey Sound is subject to semi diurnal tides (two high water and two low water events per day). Highest high water is around 5.1 m whilst lowest low water is 0.7 m. Ramsey is subject to tidal flows in excess of 3 m s^{-1} on spring tides (United Kingdom Hydrographic Office, 1999). The north flowing (flood) tide changes to south flowing (ebb) tide between 2.5 to 3 hours after high water at Milford Haven (Figure 1). The change from ebb to flood occurs between 8.75 to 9.5 hours after high water at Milford Haven. The bathymetry in Ramsey Sound is diverse, containing a steep sided trench up to 66 m deep LAT and several rocky outcrops. Consequently, parts of the Sound experience extreme turbulence and upwelling.

Figure 2: Ramsey Sound site map, South Wales, UK

Noise Measurement

Underwater noise was recorded with a C54XRS hydrophone, able to records sound from 1 to up 22 050 Hz. Sound measurements were taken with the engine turned off so that the rigid inflatable boat (RIB) was allowed to drift with the current. This reduced the turbulence around the hydrophone and consequently removed the associated with noise. Underwater noise was recorded in the range of 1.2 up to 22 000 Hz. After each run the hydrophone was turn off and the boat was motored back up to the start position.

Concerning the Mumbles Head study, each recording was carried out from the University Research Vessel *Noctiluca* over a 2 minutes period and at a depth of 2 m below the sea surface. The ambient noise was recorded only at the end of August

and the beginning of September 2008. The weather during the recordings was calm with light variable winds.

The Ramsey sound recordings have been gathered from a RIB. The hydrophone was immersed at around a depth of 10 m below the sea surface. The boat drifted during all of the Ramsey sound recordings. Measurements were made in the ebb and flood directions throughout the tidal cycle. The lengths of the recordings vary from 15 min to 40 min depending on the speed of the current (neap or spring tides). Data was gathered at two separate occasions: April 2009 and August 2009. In April, there was very little boat traffic in Ramsey Channel. In August, Ramsey-Sound was busy with recreational and tourist boats around Ramsey Island. The weather for both seasons was light variable wind and a calm sea (Sea State 1). For April and August, the surveys were conducted during tides between neap and spring.

Noise Analysis

Sound recording have been analysed with Spectra Pro software. Measurements of frequency (Hz) and amplitude (dB re 1μPa_{rms}) were taken every 2 seconds. The sampling rate used was 44100 Hz with a sampling precision of 16 bits defined during the recordings. The sound pressure levels were expressed in root mean square (dB re 1 μPa_{rms}) in 1/3 Octave band. In fact, this unit matches well to express underwater background noise because it is a constant noise and it can be used to assess the potential disturbance on marine mammals. The Power Level (PL) was calculated by using the root mean square (RMS) value for the frequency band from 1 to 20 Hz.

Anthropogenic noise influence

Mumbles Head is considered as the low energy flow area due to its low current speeds. Ramsey Sound is considered as the high energy flow area due to its fast current speeds. The Power Level (PL) of the sound has been used to determine the influence of tide on the ambient noise (Wenz, 1962).

The PL displays the total RMS power level for a specified spectrum. For each run, the data has been processed from 1 Hz to 20,000 Hz. Then, the PL values are averaged to obtain mean PL for each recording.

Figure 3 represents the PL results from 1 Hz to 22,000 Hz in function of time after fastest tide current. Standard deviations have also been represented.

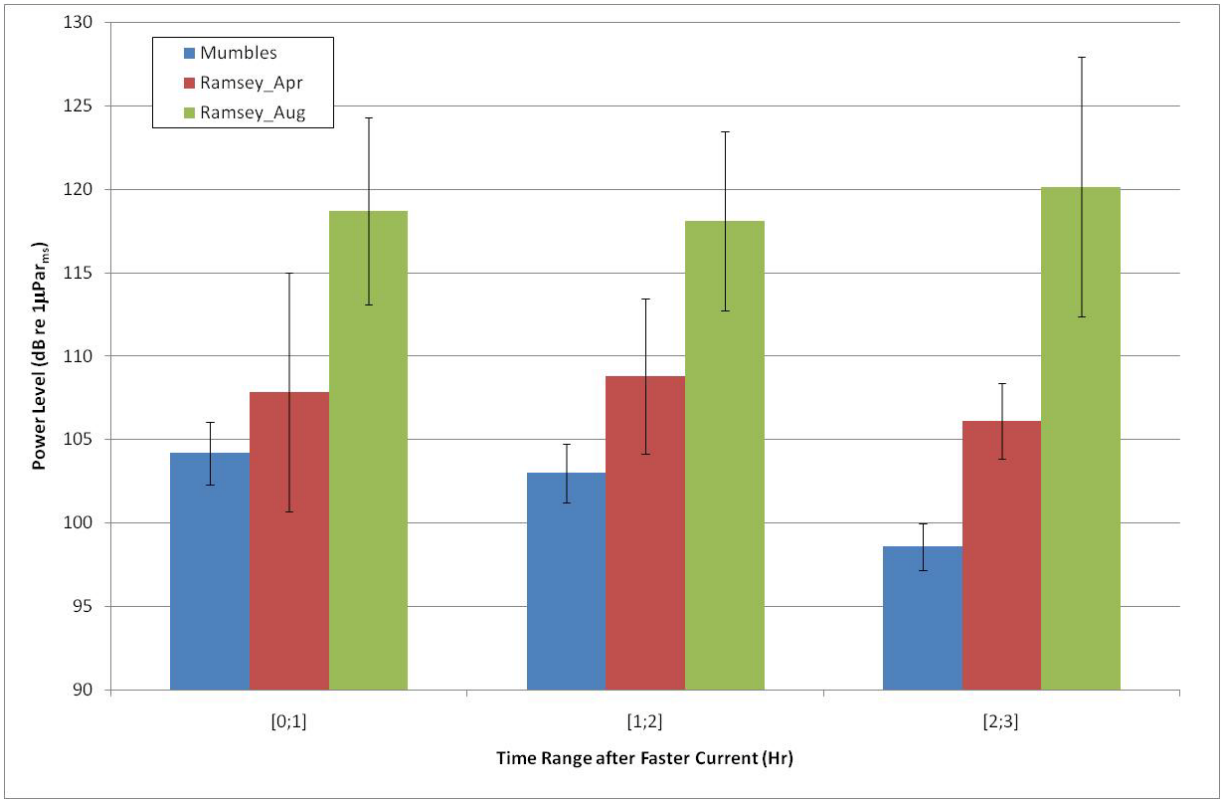

Figure 3: Background Noise evolution (in terms of Power Level$_{rms}$ for 1 Hz to 22,000 Hz) after fastest tide current for three data set: Mumbles, Ramsey in April and Ramsey in August

From Figure 3, it appears that Ramsey in August has the highest PL across all time ranges. Mumbles and Ramsey in April have much lower values. This first comment can be directly linked to anthropogenic noise. As noted previously, Ramsey Sound area in August was busy by several sort of pleasure boat. Boat noise has affected the recording on these frequencies.

Regarding the errors bars, it can be seen that Ramsey error bars are much diffuse than Mumbles error bars for all the time range displayed. This is due to higher waters motion and more pressure fluctuation in Ramsey, where the current speed can reach 2/3 m.s^{-1} in a rough environment, than in Mumbles where the current is much still in a flat environment.

Wenz (1962) states that underwater ambient noise is generally a composite of at least three overlapping components. From 1 Hz to 10 Hz turbulent-pressure fluctuation such as current or water motion dominates. From 10 Hz to 1,000 Hz, the noise generally comes from the traffic noise and can also be affected by very low frequency noise (below 10 Hz) or higher frequency noise (above 1,000 Hz). High frequency noise above 1,000 Hz results from wind-dependent noise. This type of noise is generated by the interaction of sea with bubbles and spray, created by the sea state and wave height.

Thus, it has now been chosen to focus the results on the frequency range. Figure 4 shows the PL processed through the frequency range 1-10 Hz.

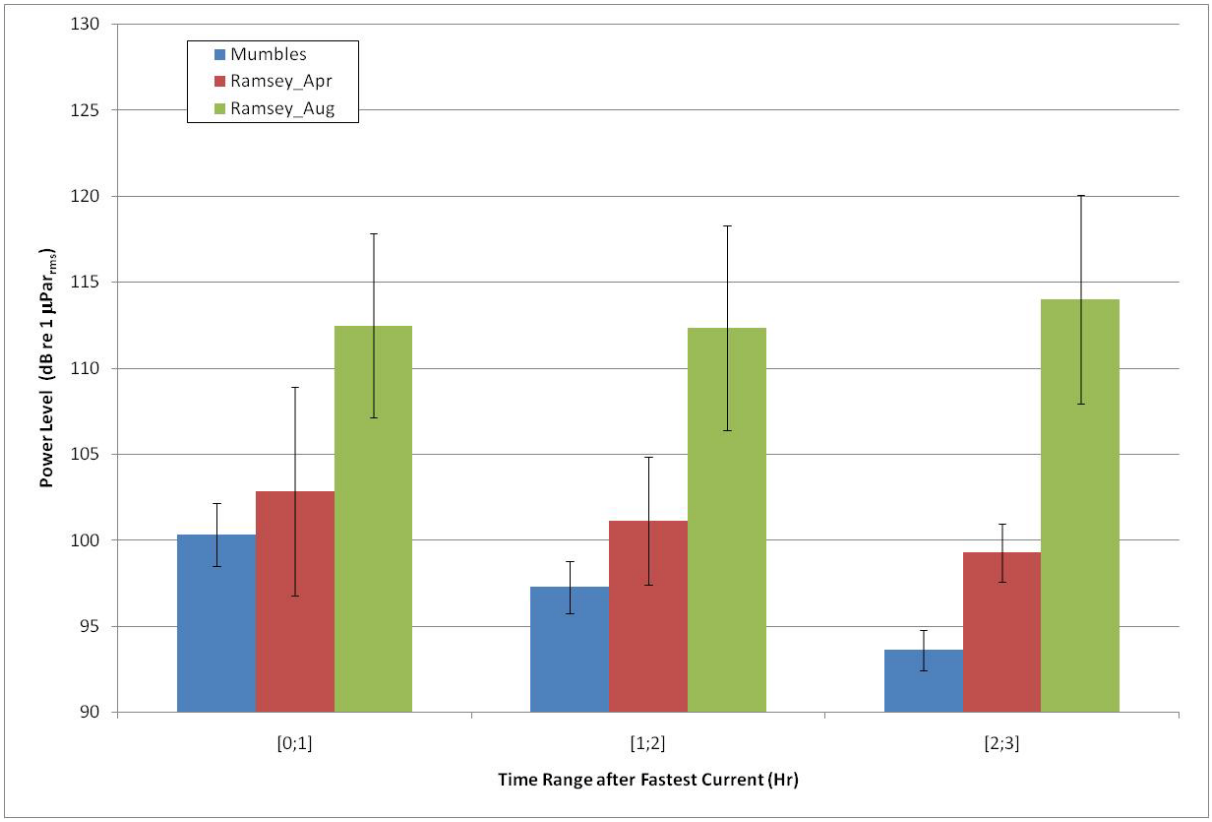

Figure 4: Background Noise evolution (in terms of Power Level$_{rms}$ for 1 Hz to 10 Hz) after fastest tide current for three data set: Mumbles, Ramsey in April and Ramsey in August

Figure 4 (PL from 1 to 10 Hz) shows that the PL distribution seems to have the same shape than for the PL from 1 to 22 000 Hz. In fact, Ramsey August PL values are still higher than Ramsey April and Mumbles. However, tide characteristics and current speeds for Ramsey April and August were very similar. This important PL difference between Ramsey April and August is due to the noise from pleasure boat. In fact, noise from any source usually contributes to a number of frequency ranges and is not strictly and clearly defined in a single frequency range. Current noise has surely been hidden by anthropogenic noise, such as intense traffic boat that occurred around Ramsey Sound during the recordings. In this case, boat traffic noise has a strong impact on the frequency range 1-10 Hz.

For Mumbles and Ramsey in April, PL decreases with increasing time after fastest current. This partly proves that turbulences created by the current speed has an impact on the PL from 1 to 10 Hz and consequently on the background noise.

Influence of the current speed

In Figure 5 Power Level for 1 Hz to 10 Hz has been plotted the two of the studied sites: Mumbles and Ramsey in April.

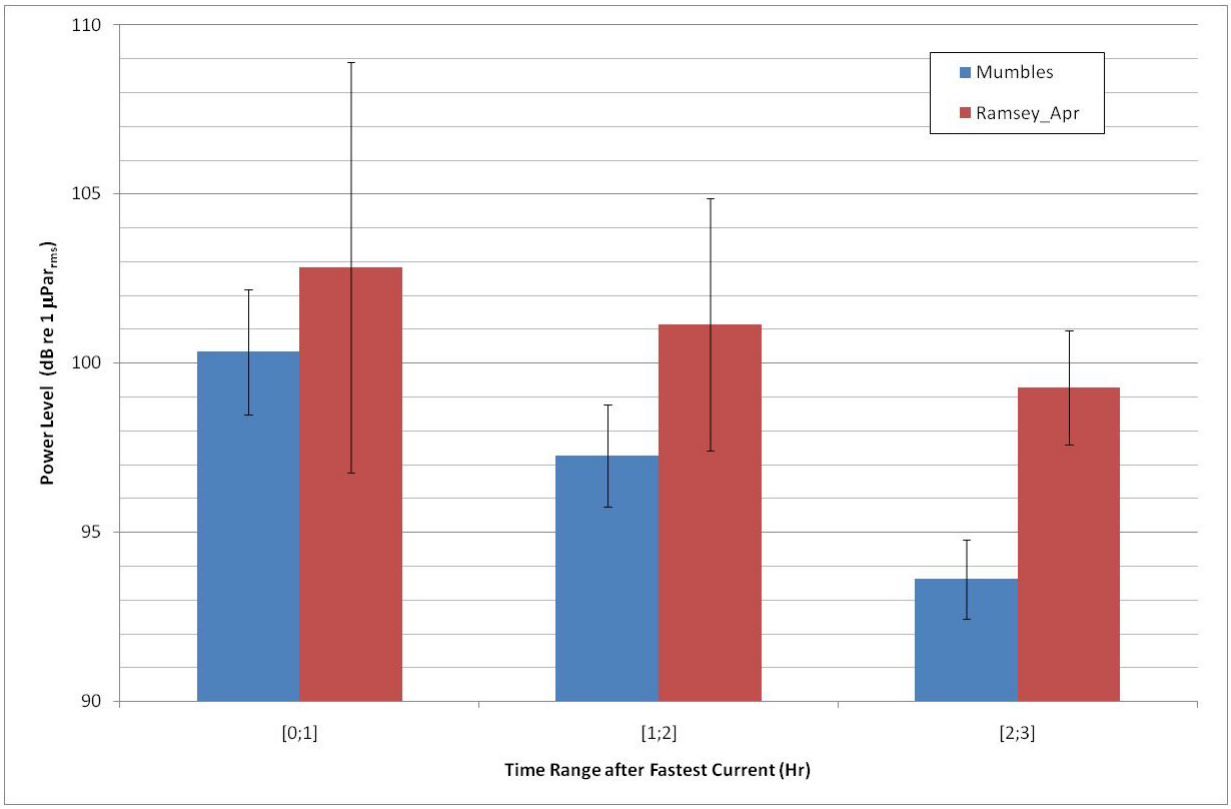

Figure 5: Background Noise evolution (in terms of Power Level$_{rms}$ for 1 Hz to 10 Hz) after fastest tide current for three data set: Mumbles, Ramsey in April

For both of the sites Mumbles and Ramsey, PL have the same shape evolution. Higher PL occurs during fastest current speed (around 0-1 hours) and decreases with increasing in time. In addition this PL can be linked to the current speed. Around 0-1 hours, PL for Ramsey April reaches 103 dB re 1 μPa_{rms} and 100 dB re 1 μPa_{rms} for Mumbles. In comparison, 2-3 hours after strong current, Ramsey April PL value is 99 dB re 1 μPa_{rms} and Mumbles PL reaches 94 dB re 1 μPa_{rms}. It can be noted that Ramsey PL is always higher than Mumbles PL. In fact, Ramsey Sound currents are much stronger than Mumbles because Ramsey Sound seabed is much rougher than Mumbles and the current in there are much faster than in Mumbles. This induces more turbulence in the middle and thus higher noise.

Sound Pressure Level Analysis

Figure 6 shows the distribution and amplitude in RMS of frequencies from 1 to 20 Hz in 1/3rd Octave bands at Mumbles and Ramsey April. Sound Pressure Level (SPL) has been displayed in dB re 1 μPa_{rms}. SPL is a Decibel measure of sound pressure. SPL is defined as:

$$SPL = 20\log\left(\frac{P}{P_{ref}}\right)$$

P_{ref} is the reference pressure (1 μPa_{rms} for underwater acoustic).

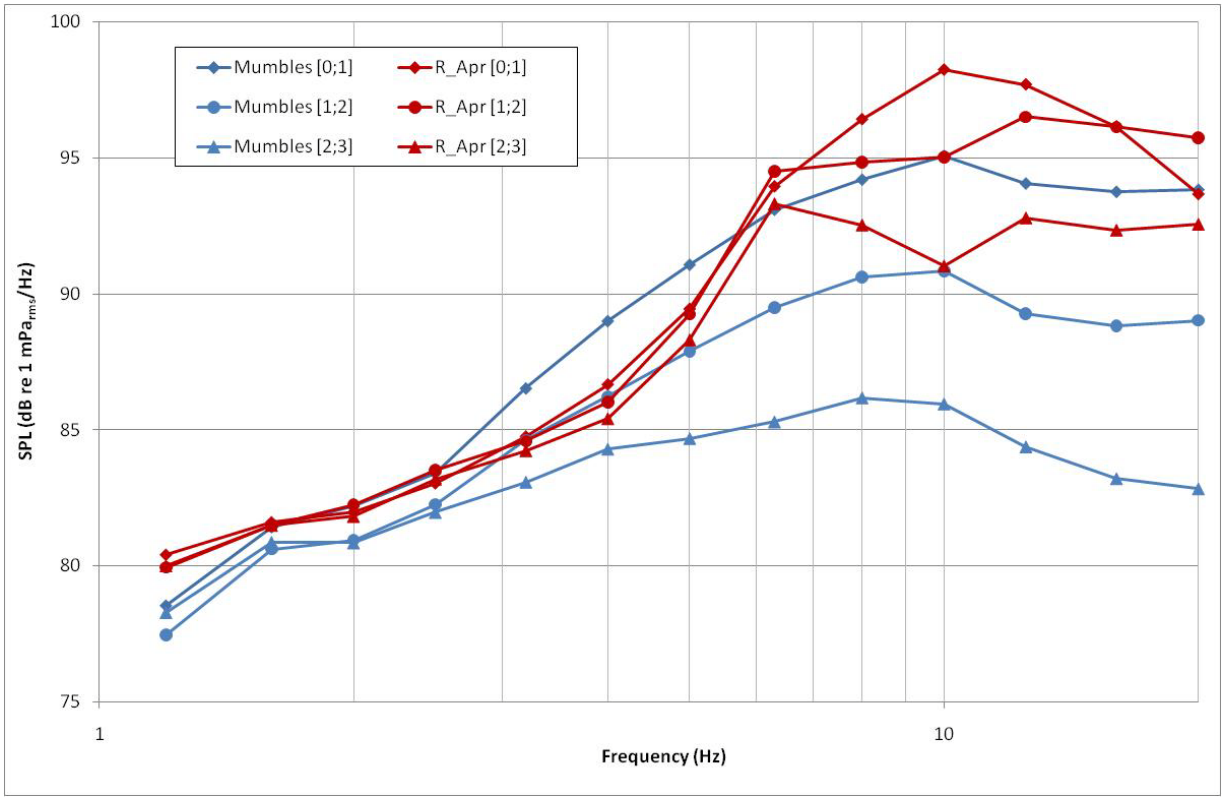

Figure 6: The variation of background noise levels (SPLrms) in 1/3 octave frequency bands with times after strong tide current for two site: Mumbles and Ramsey Sound in April

Ramsey background noise in April is quite similar to Mumbles background noise at very low frequencies. For Ramsey in April the values between 1.2 Hz and 20 Hz ranges between 80 and 98 dB re 1 μPa_{rms}. For Mumbles the value ranges between 78 and 95 dB re 1 μPa_{rms}.It can be added that Ramsey SPL and Mumbles SPL are not so different from each other. Ramsey SPL values are around 3-6 % higher than Mumbles SPL values. From Y.T. Chan (1988), "the noise as such radiated from turbulent region is not likely to be of significance due to its quadrupole character and thus its rapid fall-off with distance from the source region".

Conclusion

The underwater ambient noise monitoring and analysing is an essential process for all marine energy project. Monitoring and analysing underwater noise in high tidal flow environment is more complex than in low energy site as it is the case for offshore wind turbine because it is the current which induces turbulence.

Underwater background noise can be analysis in different ways. In this paper, it has been chosen to express underwater background noise in power level and in sound pressure level. Data has been processed in RMS. First of all, underwater background noise has been expressed in power level from 1 to 22,000 Hz. It has enabled the

study to show that anthropogenic noise has an important impact on the background noise, as it is the case for Ramsey in August.

Then, the study has been focused on the frequency range 1 to 10 Hz, frequency range identified by Wenz as current noise. It has been shown that Ramsey PL in August is higher than Ramsey Sound in April and Mumbles especially at low frequency. This is due to boat traffic noise that affected very low frequency. This study has shown that tide noise can be only identified in sites where anthropogenic noise is very low or even inexistent. Anthropogenic noise is in fact very low in comparison of current noise, and thus, current noise is most of the time hidden by anthropogenic noise.

In low anthropogenic noise cases (Ramsey in April and Mumbles) it has been possible to identify the impact of the current noise on the background noise. As expected, the current noise is higher in high energy flow sites than in low energy flow sites by about +3/6 dB re 1μPa_{rms}. For Ramsey Sound in April, underwater noise during strong tide reaches 104 dB re 1μPa_{rms} and 99 dB re 1μPa_{rms} at low current.

Sound Pressure Level show that current noise in the range of 1 to 20 Hz is very similar in low and high energy flows. The main difference appears in the range of 5 Hz to 20 Hz. SPL differences between the two sites can reach 5/7 dB re 1 μPa_{rms}.

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