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Baseline

Ambient noise dynamics in a heavy shipping area

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ABSTRACT

The management of underwater noise within the European Union's waters is a significant component (Descriptor 11) of the Marine Strategy Framework Directive (MSFD). The indicator related to continuous noise, is the noise levels in two one-third octave bands centered at 63 Hz and 125 Hz. This paper presents an analysis of underwater noise in the Celtic Sea, a heavy shipping area which also hosts the seasonal Ushant thermal front. In addition to the MSFD recommended frequency bands, the analysis was extended to lower and upper frequency bands. Temporal and spatial variations as well as the influence of the properties of the water column on the noise levels were assessed. The noise levels in the area had a high dynamic range and generally exceeded 100 dB re 1 μPa. Finally, the results highlighted that oceanic mooring must be designed to minimize the pseudo-noise and consider the water column physical properties.

Man-made noise has become a major international concern in mid-latitudes oceans (Boyd et al., 2011; Tasker et al., 2010). Its level seems to increase, particularly in coastal areas with the development of marine renewable energy sites (e.g., wind farm, tidal farm, etc.) (Lindeboom et al., 2011; Slabbekoorn et al., 2010). However, in such areas, the low-frequency ambient noise (10 Hz–1 kHz) appears to be mainly generated by shipping (Gervaise et al., 2012; Merchant et al., 2012). Measurements in the Northeast Pacific open ocean indicated a general increase of the low-frequency 10–100 Hz ocean noise level since the 1960s early measurements (Wenz, 1962, 1969). Andrew et al. (2002) showed an increase of 10 dB of the ambient noise level in the predominant shipping noise frequency band (20–80 Hz) over 30 years (from 1963 to 2001). Several other results in the Pacific open ocean support the idea that the ambient noise level resulting from shipping may have doubled (i.e. increase by dB) every decade since the 1960s (Andrew et al., 2011; Hildebrand, 2009; McDonald et al., 2006, 2008).

Sound is essential for most of marine animals, from invertebrates to mammals. Many species (as bivalves for example) use the surrounding soundscape to select their habitat (Lillis et al., 2013, 2015); while others use sounds for foraging, communication, reproduction and other social interactions (Au, 2012; Au and Hastings, 2008; Clark et al., 2009). The impacts of man-made noise on these critical processes has undergone several scientific research topics for the past decade (Bagočius, 2015; McCauley et al., 2003; Richardson et al., 2013; Southall et al., 2007). Taking advantage of the growing knowledge on the noise impacts on marine species, several international rules and guidelines have been set up to tackle the potential disturbance of anthropogenic noise on marine organisms (Compton et al., 2008; Erbe, 2013). Thus, the Marine Strategy Framework Directive (2008/56/CE) (MSFD) requires the European Union member states to guarantee a good environmental status (GES) by 2020 (Directive E. C., 2008) in their waters. The GES encompasses the introduction of energy, including underwater sound sources, through the Descriptor 11. The aim of this Descriptor is to ensure that both impulse and continuous sounds from anthropogenic sources do not exceed levels that adversely affect populations of marine animals. An attention is paid to the shipping noise which must be monitored in two one-third octave bands, namely centered on 63 Hz and 125 Hz. These frequencies were chosen by the MSFD according to their clear relationships with shipping noise, and must be monitored by mean of measurements or modelling following initial recommendations from Tasker et al. (2010).

Long-term monitoring of underwater noise levels is a challenging research field, mainly because both anthropogenic and natural sound sources may share the same frequency bands (Wenz, 1962), whether being impulsive or continuous. The initial frequency bands recommendations by TG Noise (Tasker et al., 2010) stems from the fact that shipping noise is expected to be predominant around 100 Hz and as such is a good proxy of the anthropogenic ambient noise. In addition, the main concern addressed by the traffic noise was the potential impact on communication ranges of deep diving marine mammals. In shallow water regions, sound propagation may be drastically affected by cut-off frequency effects (Jensen et al., 2011). Therefore, monitoring at higher frequencies, as proposed in other initiatives (Folegot et al., 2016), is tempting but it needs to be able to separate natural noise from

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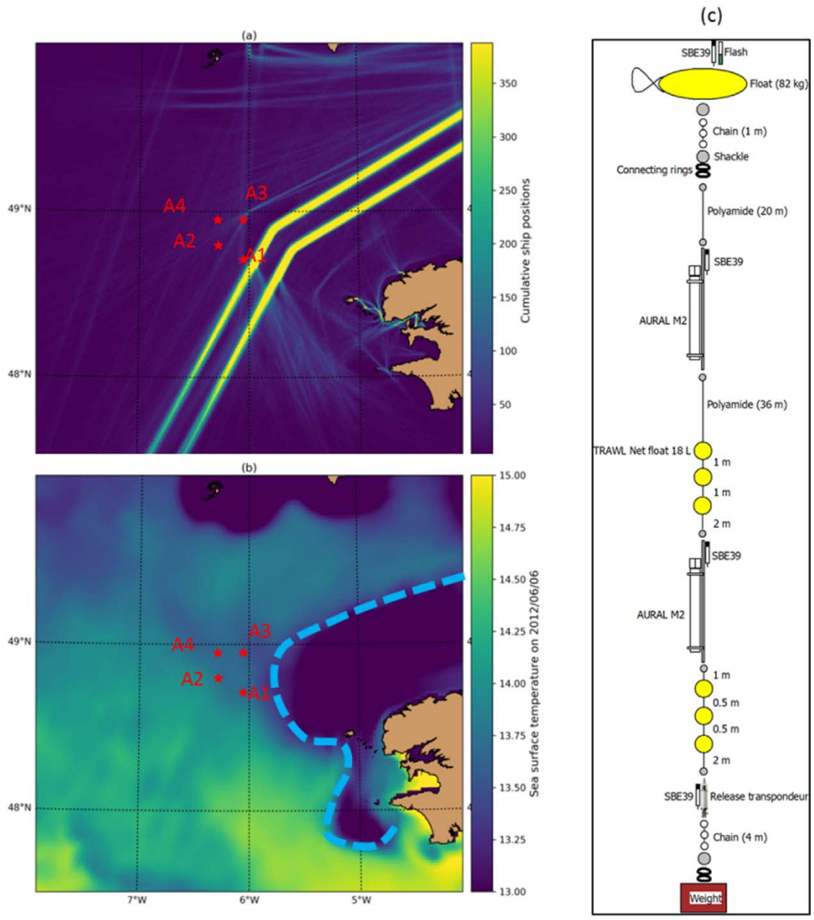

Fig. 1. Celtic Sea map showing: (a) the shipping routes from six months cumulative AIS (Lloyd's List Intelligence) data and (b) the sea surface temperature on June 6th 2012 (HYCOM3D (Hybrid Coordinate Ocean Model) operated by Shom). Blue line in (b) virtually separates thermally stratified open sea waters from mixed coastal waters. The mooring positions are labeled A1–A4. (c): Example of the subsurface mooring used in 2012. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

anthropic noise, which is not straightforward and likely makes the monitoring more complex. It requires also an accurate understanding of the acoustic propagation since the oceanographic variability (surface duct effect, fronts, internal waves, etc.) is more impacting at a few hundred Hz than a few tens of Hz. At last, from a practical point of view, long-term monitoring of underwater noise levels is also challenging for technical reasons. A lot of pseudo-noise may affect the observations as flow noise due to currents or mooring mechanic self-noise (Bassett et al., 2014; Kinda et al., 2013; Strasberg, 1979).

In this paper, ocean noise time-series from several recording sessions in a heavy shipping area west of France was analyzed. The main aim was to estimate the main characteristics of the ambient noise in a high anthropogenic pressure area which is also a highly dynamical oceanographic area. The purpose of this paper was twofold. On the one hand, the first goal was to test the relevancy of the two one-third octave bands as efficient proxies of the shipping noise in this area. Especially, statistical analyses of the noise time series were focused on frequencies and temporal dependences following the distance of mooring positions to the main shipping lane. On the other hand, it investigated the influence of (i) possible parasitic noises or pseudo-noise inherent to the mooring technology and, (ii) the effects of the oceanographic dynamics on the measured noise levels. The results of this study aim to contribute to design a future long-term monitoring strategy in the Celtic Sea.

The paper is organized as follows. A short description of the at-sea experience is presented first, followed by the data processing and some statistical essentials results are then presented. Afterward, the results are discussed and compared to similar studies in others geographical areas. Finally, conclusion remarks are given.

The data under consideration were recorded in the South-East of the Celtic Sea, which is part of the North Atlantic Ocean, at the western end of Brittany (France). The Celtic Sea hosts one of the world busiest waterways, the Ushant shipping lane (Fig. 1(a)), whereby more than one hundred commercial vessels pass *per* day since 2000.[a] This commercial shipping is organized as two main sea waterways, clearly established thank to the mean vessel positions obtained from the Automatic Identification System (AIS) along a 6-month period (Fig. 1(a)). In parallel to this permanent and well established commercial shipping is superimposed a more complex and local traffic including fishing and recreational activities, mainly inshore (Fig. 1(a)). The Celtic Sea is also a site hosting an important seasonal hydrological structure, the Ushant thermal front (Fig. 1(b)), appearing during summer every year. The Ushant thermal front is known to separate tidally mixed coastal waters from thermally stratified open sea waters (e.g. Le Boyer et al., 2009).

The acoustic data are summarized in Table 1. They extended over three years (2009, 2010, and 2012) and each recording session lasted at least 1 month. The recorders (AURAL-M2,[b] 16-bits resolution) were attached to subsurface bottom mounted mooring lines (Fig. 1c), where the connections between the line and the recorders have been isolated with rubber. The recorders were configured to record continuously or over predefined duty cycle (Table 1). The data was stored in wav format for later processing. The position of the moorings has been chosen to sample different ranges from the main shipping lane (Fig. 1(a)). In September 2009, two moorings were simultaneously deployed at distinct positions (Fig. 1 and Table 1, A1 & A2) both consisting in a single acoustic recorder placed in the middle of the water column (~84 m). A similar single mooring was used in May 2010 but at one position (Fig. 1 and Table 1, A3). The 2012 mooring consisted in two recorders placed

[a] http://www.dirm.nord-atlantique-manche-ouest.developpement-durable.gouv.fr/IMG/pdf/CORSEN_cle1759fb.pdf (last viewed 2017/02/08).

[b] http://www.multi-electronique.com/ (last viewed 217/03/02).