Introduction to acoustic values

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In the ocean, acoustic energy consists of molecular vibrations that travel at the speed of sound. These vibrations occur in the direction of propagation (i.e., longitudinal waves) and in a direction perpendicular to the direction of propagation (i.e., transverse waves) leading to series of compression (increase in particle density) and rarefaction (decrease in particle density, Fig. 1) [1]. Therefore, sounds consist of two components: a scalar quantity named **sound pressure** and a vector quantity named **particle motion**. The ratio of pressure to particle motion varies with distance from the source, frequency, and other factors [2]. In the literature, sound pressure has been studied much more extensively than particle motion.

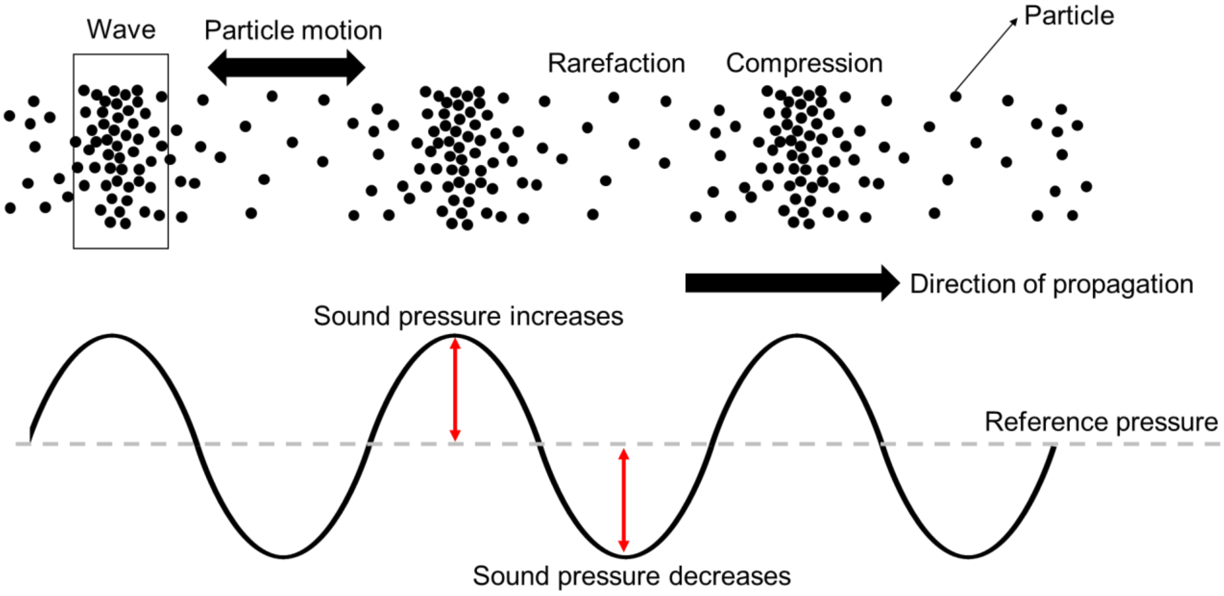

Fig. 1 Schematization of sound pressure and particle motion.

The louder a sound is, the larger the pressure change. Sound pressure, measured in (micro)pascals (1 Pa = 1 N m^{-2}), can be used to quantify the pressure level of a sound. However, the unit commonly used for **sound pressure level** (SPL) is the **decibel** (dB). SPL is a logarithmic measure of the ratio between the measured pressure (p) and a reference pressure (p_0). In air, p_0 is egal to 20 µPa, while in the water, it is egal to 1 µPa. Thus, SPL is expressed as dB re 20 µPa in terrestrial environments and as **dB re 1 µPa** in aquatic environments, requiring a transformation for comparison purposes. Two[1] types of SPL can be measured depending on the signal type (Fig. 2). The peak-to-peak SPL (**SPL_{pp}**) is calculated as the difference between the maximum and minimum values within a given time period T (Fig. 2). It is used to characterize broadband transient sounds, for example [3]. On the other hand, the root-mean-square SPL (**SPL_{rms}**) calculates the square root of the mean square of the signal (Fig. 2). It is used for narrowband sounds such as buzzing sounds [3].

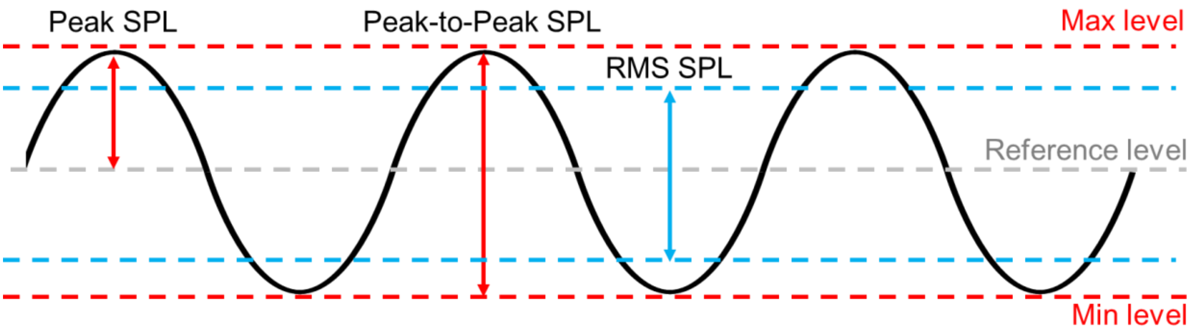

Fig. 2 Schematization of the different types of Sound Pressure Level (SPL): Peak SPL, Peak-to-Peak SPL, and RMS SPL. RMS stands for root-mean-squared.

The temporal acoustic signal can be transformed into the frequency domain using a Fourier transform. The Fourier transform determines the spectra of a signal. The **power spectral density** (PSD = γ) represents the proportion of the total signal power contributed by each frequency [4]. To achieve this, it is necessary to integrate values according to a specific integration step, which involved dividing the entire frequency range into frequency bands. Two commonly used frequency bands are one-thord octave bands and 1 Hz bands. An **octave** has an upper frequency equal to twice the lower frequency (Fig. 3). Consequently, a **one-third octave band** has an upper frequency equal to the lower frequency multiplied by the cube root of two. Octave analysis is associated with human hearing (and by extension, to marine mammals' audition, see Appendix III). Therefore, in soundscape ecology and fish bioacoustics, integration over a 1 Hz band is commonly used (Fig. 3). In this case, the PSD is measured in **dB re 1 μPa^2 Hz^{-1}**, and its SPL is referred to as **γSPL**, sometimes simply called SPL. The PSD can be measured for different **percentiles** (Q). For example, $Q_{0.05}$ represents the 5% faintest sounds; $Q_{0.90}$ represents the 10% loudest sounds, $Q_{0.95}$ represents the 5% loudest sounds, and so on. The median level (**$Q_{0.50}$**) is commonly used to describe soundscapes. Modeling lower percentiles (typically with a χ^2 distribution on $Q_{0.20}$) is carried out to obtain a value for the **ambient noise level** (ANL) [5][6]. The ANL represents the overall energy of distant sounds without the

[1] A third value known as "peak SPL" also exists, but it is less commonly used.

discriminable near sources of high-energetic sounds, while the SPL is the sum of both discriminable near sources of sounds and the ANL. Both ANL and SPL can be calculated broad band. Consequently, they are logically expressed in dB re 1 µPa and not in dB re 1 $\mu Pa^2\ Hz^{-1}$.

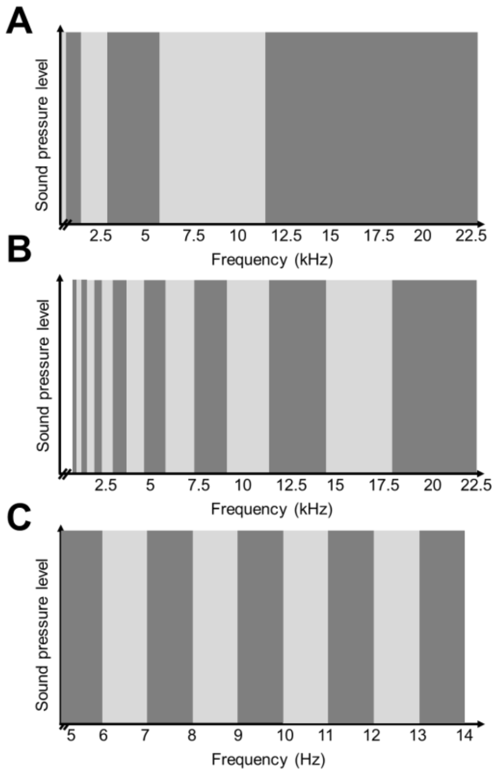

Fig. 3 Division of a theoretical power-spectrum into (A) octave bands, (B) one-third octave bands, and (C) 1 Hz bands.

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