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Issues relating to the use of a 61.5 dB conversion factor when comparing airborne and underwater anthroprogenic noise levels

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Abstract

Although a considerable amount of the current underwater acoustics literature deals with the proper documentation and analysis of underwater anthropogenic noise levels, mistakes and misconceptions can occur when attempts are made (often by non-experts) to make these data accessible for legislators, journalists and the public. This is because it is difficult for humans to assess qualitatively underwater sound level and quality. It can even be difficult for researchers to judge whether a given underwater sound should be classified as "loud" or "soft". Many practitioners have suggested that the difference between airborne and underwater sound can be accounted for by applying a 61.5 dB comparison factor (in an attempt to compensate for the different acoustic impedances, and dB reference level conventions, which characterize acoustics in air and water). Whilst use of such a factor is preferable to use of none (which has led to misleading comparisons between levels in-air and water) nevertheless its existence could confer a false sense of security that the comparison is sound, whereas in fact, depending on the details of the comparison, a range of other issues would have to be rigorously taken in to account. Those issues include the perception of sound and annoyance underwater, and the problematic issue of making comparisons across species. This paper does not offer solutions to those issues, but rather outlines the thinking behind the 61.5 dB comparison factor, and shows the intriguing results of it blind application in some interesting example scenarios.

Keywords: Underwater acoustics; Sonar; Decibel; Anthropogenic noise; Snapping shrimp; Bearded seal; Bottlenose whale; Strandings; Marine mammals; Cavitation in cetaceans

1. Introduction

Media coverage of cetacean activity, including the stranding of a beaked whale in the Thames River [1,2] and the occurrence of several mass strandings off Cape Cod during winter 2005–2006 [3], often highlight for the public the importance for the scientific community to continue to research and document the relationship between marine mammals and sound [4]. However, despite advances in instrumentation for measuring sound in water, and progress in understanding how marine animals perceive sound, it still remains difficult to answer a basic question: How loud is "loud"? This paper will not seek to address this question, nor that of how underwater sound is perceived by marine life. Rather it will explain the most common form of correction factor used in converting from airborne to underwater sound levels, and use example situations to show how blind calculations using this correction factor can generate intriguing results.

The last decade has seen an explosion in research which has the primary motivation of studying anthropogenic noise in an attempt to understand how marine fauna perceive and extract meaningful acoustic information from their environment. Of particular particular concern are the harmful effects of anthropogenic noise on cetaceans; especially the interruption of acoustic transmissions by cetaceans, or the inadvertent production of acoustic trauma in marine mammals [5]. Whilst underestimation of the potential effects of anthropogenic noise carries

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obvious risk, so too does overestimation. This is because, whilst the elimination of anthropogenic noise would be an unrealistic goal, a cooperative strategy for minimising the risks must be based on realistic and trusted procedures for assessing the effects of the noise. It is essential to be accurate with the facts if the community of those ‘stakeholders’ with an interest in sonar (both those who use sonar and those who seek to minimise any deleterious effects) are to work together to prevent harm by sonar, whilst preserving the considerable benefits that can accrue from safe use of sonar. Similar comments apply to other applications associated with the generation of underwater sound, such as the operation of off-shore wind-farms, refineries, shipping, piling, dredging and quarrying activity.

Unsafe comparisons using dB-scales are prevalent, and misleading to legislators, journalists, and the public (see Section 2). Avoiding the errors inherent in such poor comparisons, some researchers and practitioners [6–8] have recommended a 61.5 dB conversion factor to convert between underwater and airborne sound levels. In this paper, the concepts behind the 61.5 dB conversion factor are considered (Section 3). Then, a series of examples are introduced to illustrate for the reader ways in which even this conversion factor can bring about counterintuitive comparisons (Section 4). It is, of course, important to appreciate that intuition forms no rigorous basis for judging how sound is perceived underwater by non-humans, and so the counterintuitive nature of the outcomes to the examples in this paper should not be taken as proof of concern. However, counterintuitive outcomes to the 61.5 dB comparison factor are important since (i) by far the overwhelming number of judgements made by the public on the issue of marine mammal welfare with respect to noise are erroneously based on intuition; and (ii) one of these counterintuitive outcomes is not the result of any cross-species comparisons, but rather between sound perception by humans in air, and humans in water (Section 4.2.1).

2. Confusion regarding the decibel

Much of the misreporting of anthropogenic noise stems from a misunderstanding of the differing traditions and practices for applying it in air and water, and the difficulty of relating the physical measures to subjective effects across species [9,10]. The simplest and commonest error is the poor practice of implying that the decibel scale is an absolute measure, which becomes undeniably erroneous when transferred from air to water. The sources of other misunderstandings are less transparent, as this paper will outline.

The unfortunate side-effect resulting from the publication of misleading statements regarding the decibel is the potential for the public to misperceive the effects of sonar on marine life. Pressure from an ill-informed public can then be placed on government, advisors and legislators. In the case of the links between common sonar practices and marine mammal stranding, comparisons between the sounds heard by cetaceans in the presence of sonar, and the sounds heard by humans in the presence of turbomachinery and/or space rockets, are not uncommon. Consider for instance a statement in a press release published by the National Resources Defence Council (NRDC) [11] (a US-based environmental lobby group) in October 2005: “Mid-frequency sonar can emit continuous sound well above 235 dB, an intensity roughly comparable to a Saturn V rocket at blastoff”. In an excellent critique, Chapman and Ellis [10] analyse a 1998 quote from *The Economist* [12] which arose following scientific correspondence in *Nature* [13]. Referring to a sonar source designed to produce low-frequency sound, *The Economist* stated that “It has a maximum output of 230 dB, compared with 100 dB for a jumbo jet”.

Just as it is beholden on users of the dB scale always to cite their reference pressures and the location of the measurement with respect to the source, so too should it be obligatory for those who make comparisons between levels in water and those in air to state the procedure used for the conversion. Whilst the differing reference pressures and acoustic impedances of air and water make nonsense of a direct uncorrected transcription of dB levels from water to air, the 61.5 dB correction factor recommended by many [6–8] cannot be seen as the sole requirement in comparing, for example, annoyance levels between species. Indeed, its use even within a single species can lead to unexpected predictions (Section 4.2.1). Section 3 will outline the logic used to justify the 61.5 dB correction factor.

3. Deriving the 61.5 dB conversion factor

Generally, underwater acoustic data are expressed in decibels with reference to 1 μPa, whilst air borne noise data are referenced to 20 μPa (rms levels will be used throughout this paper). The transfer from dB re 1 μPa to dB re 20 μPa is straightforward, by letting the rms pressures P_2 and P_1 in Eq. (1) take their respective values:

$$10\log_{10}\left(\frac{P_2}{P_1}\right)^2 = 20\log_{10}\left(\frac{1\ \mu\text{Pa}}{20\ \mu\text{Pa}}\right) = -25.5\ \text{dB} \quad (1)$$

where P_1 is the reference pressure in air, and P_2 is the reference pressure in water. However, it is not sufficient simply to subtract 26 dB from an underwater level to make a viable comparison to an airborne sound. The specific acoustic impedance of water (given by the product $\rho_w c_w$, where ρ_w and c_w are respectively the density and sound speed in water) is some 3600 times greater than that of air. If the critical physical quantity which must be compared between air and water is based on the acoustic intensity[1] (see Section 4.2), then a further correction factor of 36 dB is required, because:

$$10\log_{10}\left(\frac{\rho_w c_w}{\rho_a c_a}\right) = 10\log_{10}(3600) \approx -36\ \text{dB} \quad (2)$$

[1] For the purposes of such calculations, the acoustic pressure falls into this category.