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THE ELUSIVE DECIBEL: THOUGHTS ON SONARS AND MARINE MAMMALS

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INTRODUCTION

A few years ago, there was considerable controversy over the effects of a proposed global acoustic experiment designed to measure the temperature of the world's oceans[1]. The focus of concern was the possible effect of the acoustic signals on whales and other marine life. There is continued interest in the effects of underwater sound on marine animals, according to a recent news item in *The Economist*[2] based on related scientific correspondence in *Nature*[3]. The thesis is that loud signals from experimental sonars harm marine mammals, or at least harass them enough to unacceptably alter their behaviour patterns. In the various discussions of this important issue that can be found in the press and on the internet, one often sees questionable comparisons being made, such as the acoustic output of a naval sonar being compared with the noise from a jet aircraft. Some misunderstandings between professionals in different fields can be traced to the multiple uses of the term "decibel". Acoustical terms can be confusing, even for experts. It is not at all surprising that well-intentioned articles sometimes fail to present situations clearly. By definition, the decibel is a relative unit, not an absolute unit with a physical dimension; unless the standard of comparison is cited, the term "decibel" is to all intents and purposes useless. The confusion is not helped by the use of the decibel to specify distinctly different physical quantities, or the same physical quantity with different reference levels. Some reporters—and even some scientists—are getting their "apple" decibels mixed up with their "orange" decibels, as it were.

The decibel (abbreviated dB) is simply a numerical scale used to compare the values of like quantities, usually power or intensity. Acousticians introduced the decibel to devise a compressed scale to represent the large dynamic range of sounds experienced by people from day to day, and also to acknowledge that humans—and presumably other animals—perceive loudness increases in a logarithmic, not linear, fashion. An intensity ratio of 10 translates into a level difference of 10 decibels[4]; a ratio of 100 translates into a level difference of 20 dB; 1000 into 30 dB; and so on. (The term "level" usually implies a decibel scale.) In a uniform acoustic medium, the magnitude of the acoustic intensity is proportional to the square of the pressure for a freely-propagating sound wave. Accordingly, the level difference in

decibels associated with two sound pressure values (measured in the same medium) is determined by calculating the ratio of the pressures, squaring this number, taking the logarithm (base 10), and multiplying by 10.[5] If one chooses a standard reference pressure value, then sound pressure levels can be specified in decibels relative to that reference, but this should be stated along with the number, for clarity[6].

The following is a typical erroneous statement found in the press, on radio, on television, and on internet discussion groups. Referring to an experimental sonar source that produces very loud low-frequency sound, *The Economist* wrote: "It has a maximum output of 230 decibels, compared with 100 decibels for a jumbo jet." Regardless of the author's intention, the implication is that a whale would experience an auditory effect from the sonar that would be substantially greater than that of a person exposed to the jet aircraft. However, this type of comparison is misleading for at least three reasons: (1) the reference sound pressures used in underwater acoustics and in-air acoustics are not the same; (2) it compares a source level with a received level; and (3) there is no obvious connection between an annoying or harmful sound level for a human in air and an annoying or harmful sound level for a marine animal in water. In the remainder of this note, we will expand on these topics somewhat, attempt to correct the mistaken impression, and try to direct attention to the real issue at the heart of the controversy.

1. STANDARD REFERENCE SOUND PRESSURES IN AIR AND IN WATER

The standard reference pressures used in underwater acoustics and in-air acoustics are not the same. In water, acousticians use a standard reference sound pressure of 1 micropascal (i.e. 10^{-6} newtons per square metre), abbreviated μPa. In air, acousticians use a higher standard reference sound pressure of 20 μPa. The in-air standard was chosen so that the threshold of hearing for a person with normal hearing would correspond to 0 dB at a frequency of 1000 Hz. Adopting different standards for air and water inevitably leads to a confusing consequence: the same sound pressure that acousticians label 0 decibels in air would be labelled 26 decibels in water. Presumably, both factions of acousticians had equally good reasons for proposing their respective standards, and this dichotomy is now entrenched in an ANSI standard[6], which is unlikely to change. Accordingly, the following dictum should always be observed, especially when dealing with cross-disciplinary issues: *It is essential that sound levels stated in decibels include the reference pressure.*

2. SOURCE LEVEL AND RECEIVED LEVEL

The erroneous statement compares a *source* level with a *received* level. In underwater acoustics, a source level usually represents the sound level at a distance of one metre from the source, while a received level is the sound level at the listener's actual position, which could be considerably more distant with a correspondingly reduced sound level. In an unbounded uniform medium, loudness decreases rapidly with increasing source-receiver distance, 6 dB less per doubling of distance. For example, *The Economist* (and even *Nature*), in referring to the 230 dB sonar source level, neglected to mention the reference distance of 1 metre. In contrast, the 100 dB number that *The Economist* associated with a jumbo jet is not a source level at all, but is typical of a received noise level measured during jet airplane take-off, averaged over several microphones situated several hundred to some thousands of metres from the runway[7]. *It is incorrect to compare a source level at 1 metre with a received noise level at an unspecified (and probably much larger) distance.*

Combining these two remarks, the output of the sonar source should have been written as 230 dB re 1 μPa at 1 m, while the jumbo jet noise level should have been written as 100 dB re 20 μPa. The inclusion of the reference values shows that these are not like quantities, and that the numbers are not directly comparable. *The Encyclopedia of Acoustics*[8] offers 120 dB re 20 μPa as a typical noise level associated with jet aircraft take-off measured at 500 m distance (although there is sure to be a wide variation about this number, depending on the type of aircraft, etc.). With the assumption of spherical spreading, referencing this level back to 1 metre distance adds 54 dB. Switching to the 1 μPa standard reference adds another 26 dB. Accordingly, the source level of a large jet looks more like 120 + 54 + 26 = 200 dB re 1 μPa at 1 m, compared with 230 dB re 1 μPa at 1 m for the sonar. Both of these are loud sources, but now at least the comparison is sensible. The ratio of sound pressures is around 32, rather than over 3 million, as some commenters would have you believe!

There are other minor issues that could be discussed. The signal from the sonar source is narrowband, and the concentration of all the signal at one frequency may be particularly troublesome for an animal who has a cavity that resonates at that frequency. On the other hand, the jet noise is broadband, and the acoustic signal was probably passed through a filter that approximately matches the sensitivity of the human ear before the measurement was made, so this measurement would be meaningless for an animal with a different hearing sensitivity curve. Much more could be said about these issues, but the principal reason for raising them is to underscore the message that the sonar / jet plane comparison has little validity.

3. WHAT HURTS?

There is no clear connection between a harmful sound level for a human in air and that for an animal in water. All creatures have evolved and adapted to their respective environments and there is no reason why human hearing characteristics should apply to any other animal, including whales. If a given sound pressure hurts a human, would the same sound pressure level in water hurt a whale (or a fish, or a shrimp)? Is the threshold of pain higher? Is it lower? Particularly when comparing acoustic effects in media of widely different impedance, is acoustic pressure the relevant acoustic quantity, or is it acoustic intensity?[9] In the end, it is the answers to these and related questions that really matter, not juggling decibels. To properly answer these questions and to determine the “community” noise standards for marine animals, scientific research is necessary—just as it was for humans. Some of this work has already been done, and an excellent review[10] of the state of knowledge up to 1995 is a good starting point for acousticians and biologists interested in deepening their understanding. A single example cannot represent the whole range of species under consideration, but is typical: The response threshold (determined through behavioural studies) of a Beluga at 1000 Hz is just over 100 dB re 1 μPa. Of course, this says nothing about the Beluga’s threshold of pain, and says nothing about what sound level would unacceptably alter its behaviour. *It is unwise to assume that the auditory experience of any animal would be the same as that of a human exposed to the same sound level.*

CONCLUSION

As sonar engineers, marine biologists, and environmentally conscious citizens continue to discuss these important issues, we should at least agree to use the same acoustical units to convey our points of view, to avoid confusion and misrepresentation. Some sensible acousticians have advocated abandoning the use of the decibel—which is partly to blame for our woes—in favour of good old SI (i.e., metric) units for sound pressure, acoustic intensity, power, etc. Until that happy day dawns, let us include reference values with our decibels, so we don't end up with fruit salad dBs. Ultimately, what is important is to determine what underwater sound levels are harmful to marine life. We must develop mitigation measures to allow underwater acoustic systems to be operated while ensuring the protection of the marine environment with due diligence.

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[2] "Quiet, please. Whales navigating", *The Economist*, 1998 March 7, page 85.

[3] R. Frantzis, "Does acoustic testing strand whales?", *Nature* **392**, 1998 March 5, page 29.

[4] In fact, this defines 1 bel, named after Alexander Graham Bell. The bel turned out to be too large for practical purposes and the decibel—which is 1/10 of a bel—is the preferred unit. Also, one decibel is about the smallest incremental change of sound pressure level a person can sense.

[5] Mathematically, this is equivalent to taking the logarithm of the pressure ratio and multiplying by 20, but knowing when to multiply by 10 or 20 in such calculations is an endless source of confusion to the neophyte, so we advocate the definition in the main text.

[6] *American National Standard Preferred Reference Quantities for Acoustical Levels*, ANSI S1.8-1969, page 8.

[7] Malcolm J. Crocker, editor, *The Encyclopedia of Acoustics* (John Wiley and Sons, Inc., New York, 1997), page 1095.

[8] Malcolm J. Crocker, editor, *The Encyclopedia of Acoustics* (John Wiley and Sons, Inc., New York, 1997), page 11.

[9] The suggestion that acoustic intensity has more bearing than sound pressure in this context has been seriously proposed by some acousticians; however, the available evidence gives the nod to sound pressure, not intensity.

[10] W. John Richardson *et al*., *Marine Mammals and Noise* (Academic Press, New York, 1995).