A Century of Sonar: Planetary Oceanography, Underwater Noise Monitoring, and the Terminology of Underwater Sound

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No self-respecting science – or scientist – would tolerate a factor of four uncertainty in the interpretation of a reported measurement or model prediction, arising from poorly defined terminology alone, so why do we?

Introduction

The current terminology of underwater sound, as documented, for example, by (Urick, 1983), was developed during and after the Second World War (ASA, 1951; Urick, 1967), and has evolved little since then (Jensen et al., 2011). When examined against a modern requirement, with particular attention to the needs of planetary oceanography and underwater noise, this 60-year old terminology is found wanting.

The Sonar Equations and "Noise Level"

The development of passive and active sonar during the first half of the 20th century, motivated by the loss of RMS *Titanic* in April 1912 and by two world wars (Wood, 1965; Hackmann, 1984), was directed almost exclusively towards the detection and localization of objects in seawater. In order to understand the performance of underwater detection systems, a theoretical framework (known today as the 'sonar equations' (Urick, 1983)) was developed for quantifying that performance in terms of the signal-to-noise ratio (Horton, 1959).

The traditional meaning of the term "noise level," in the sonar equations, is the level of the masking background against which a signal is to be detected. In the 21st century, underwater sound is increasingly seen as a potential pollutant, for which "noise level" is then taken to mean the amount of that pollutant. For the bulk of this article, I focus on the sonar equation, and return in the final section to the possible impact of noise on aquatic life.

The sonar equations are in widespread use on Earth (Urick, 1983), and are starting to find application in space (Arvelo and Lorenz, 2013). Whether in search of signs of extra-terrestrial life in subsurface water oceans (Hussmann et al., 2006) or of vast hydrocarbon resources on distant moons (Stofan et al., 2007), these new uses encounter harsh conditions that are very different to those on Earth. These extreme conditions serve to expose a fundamental ambiguity in the way the individual terms in the sonar equations are expressed as levels. Although the ambiguity is minor for the range of conditions usually encountered in water on Earth, it becomes important in some situations, and is seen on closer inspection to be a symptom of a deeper malaise, namely a dearth of widely accepted definitions for even the most basic terminology used in undersea acoustics. My main purpose is to demonstrate the need to adopt a more rigorous terminology if we wish our science to be taken seriously as it enters its second century of existence.

By convention, the sonar equations are written in a logarithmic form by converting ratios of acoustic intensities to differences between the corresponding levels in decibels. The "intensity" is usually not the true intensity of the sound in question, but its equivalent plane wave intensity (EPWI), defined as the magnitude of the time-averaged intensity of a propagating plane wave with the same root-mean-square (RMS) sound pressure as that sound (Urick, 1983). Denoting the time-mean-square sound pressure (MSP) by $\overline{p^2}$, and characteristic impedance (Morfey, 2000) by Z, intensity ratios are therefore formed by dividing the noise EPWI, $N_{\mathrm{EPWI}}(\boldsymbol{x})=\overline{p_N^2(\boldsymbol{x})}/Z(\boldsymbol{x})$, where p_N is the noise sound pressure, by a reference intensity I_0. In equation form, the noise level according to these conventions, using $\boldsymbol{x}$ to denote the receiver position, is

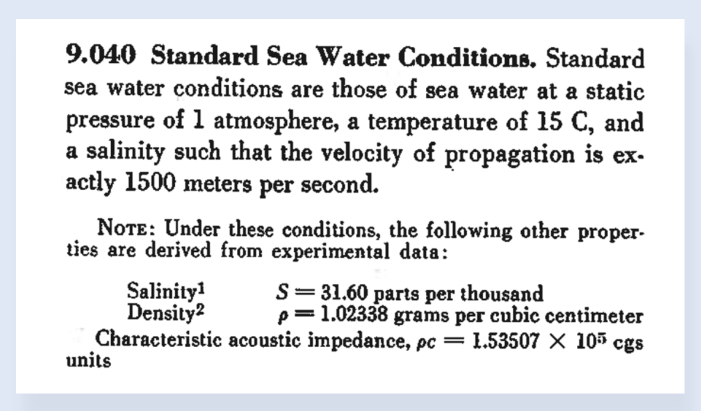
$$L_N(\boldsymbol{x}) = 10\log_{10}\left[\frac{N_{\mathrm{EPWI}}(\boldsymbol{x})}{I_0}\right]\mathrm{dB}. \tag{1}$$

A similar equation can be written for the signal level, and the difference between these two levels is a logarithmic measure of signal-to-noise ratio.

While the value of I_0 in **Equation (1)** is not needed for the signal-to-noise ratio (because it cancels), when either of signal or noise level is reported separately, the correct reporting and interpretation of that level requires a shared understanding of the value of I_0. By a convention that dates to the Second World War (Horton, 1959), the reference intensity in underwater acoustics is understood to be the magnitude of the time-averaged intensity of a propagating plane wave in seawater whose RMS sound pressure is equal to an agreed reference pressure (p_0) (Urick 1967, 1983). For example, with $p_0 = 1$ µPa, the level would be reported in units of "dB re 1 µPa" (or, equivalently, "dB // 1 µPa"), a shorthand used to mean that the level expressed in decibels is that of the EPWI, relative to the magnitude of the time-averaged intensity of a plane wave whose RMS sound pressure is 1 µPa (Urick 1967). The reference intensity according to this convention is $I_0 = p_0^2/Z_0$, where Z_0 is the characteristic impedance of seawater. If the local impedance is $Z(\boldsymbol{x})$ it follows that

$$\frac{N_{\mathrm{EPWI}}(\boldsymbol{x})}{I_0} = \frac{\overline{p_N^2(\boldsymbol{x})}}{p_0^2}\frac{Z_0}{Z(\boldsymbol{x})}, \tag{2}$$

and the pertinent question, given the need to define I_0 unambiguously, becomes "what are p_0 and Z_0?" During the period 1951-1960 one could have answered this question with some confidence. The then current US acoustical terminology standard ASA Z24.1-1951 (ASA, 1951), published by the American Standards Association (ASA) – now the American National Standards Institute (ANSI), permitted both $p_0 = 20$ µPa and $p_0 = 10^5$ µPa. Further, Z24.1-1951 specified a standard reference sound speed of $c_0 = 1500$ m/s, with the reference density ($\rho_0 \approx 1023.38$ kg/m^3) inferred from specified conditions of temperature and pressure. The corresponding reference impedance is $Z_0 = \rho_0\, c_0 \approx 1.53507$ MPa s/m (see **Figure 1**), from which the reference intensity can be calculated as either $I_0 \approx 260.57$ aW/m^2 (using $p_0 = 20$ µPa) or 6.5144x10^9 aW/m^2 ($p_0 = 10^5$ µPa), where 1 aW (one attowatt) = 10^{-18} W.



9.040 Standard Sea Water Conditions. Standard sea water conditions are those of sea water at a static pressure of 1 atmosphere, a temperature of 15 C, and a salinity such that the velocity of propagation is exactly 1500 meters per second.

NOTE: Under these conditions, the following other properties are derived from experimental data:

Salinity[1]	$S = 31.60$ parts per thousand
Density[2]	$\rho = 1.02338$ grams per cubic centimeter

Characteristic acoustic impedance, $\rho c = 1.53507 \times 10^5$ cgs units

***Figure 1**. Extract from withdrawn American Standard Acoustical Terminology Z24.1-1951, entry 9.040 Standard Sea Water Conditions (ASA, 1951). The value inferred for the impedance of seawater under these standard conditions was 1.53507 MPa s/m. The CGS unit of impedance is 1 dyn s/cm^3 = 10 Pa s/m. © ASA. This extract, reproduced with permission of ANSI and the Acoustical Society of America, is not part of an approved American National Standard, nor may it be referred to as such. All rights reserved.*

In 1960, ASA Z24.1-1951 was superseded by ANSI S1.1-1960 (ANSI, 1960), which made no mention of a standard reference impedance for use in water, and introduced in its place the standard reference *intensity* of 1 pW/m^2, where 1 pW (one picowatt) = 10^{-12} W. In 1969 the modern reference value of sound pressure $p_0 = 1$ µPa was adopted by ANSI S1.8-1969 (ANSI, 1969) for sound in liquids. Today these standard values for sound pressure and sound intensity in liquids are recognized by both the International Electrotechnical Commission (IEC) (IEC, 1994) and the International Organization for Standardization (ISO) (ISO, 2013). The situation is summarized in **Table 1.**

Table 1: Evolution of American national and international standard reference values of acoustical quantities in liquids since 1951. The SI prefixes μ, n, and p represent the numbers 10^{-6} (micro-), 10^{-9} (nano-) and 10^{-12} (pico-), respectively. For example the modern reference value for sound particle velocity is 1 nm/s (one nanometer per second) = 10^{-9} m/s.

		Reference value (q_0)					
Quantity (q)	**Field (F) or Power (P)**	**ASA Z24.1-1951**	**ANSI S1.1-1960**	**ANSI S1.8-1969**	**ANSI S1.8-1989**	**IEC 60050-801:1994**	**ISO/DIS 1683:2013**
sound pressure	F	20 μPa or 10^5 μPa	20 μPa or 10^5 μPa	1 μPa	1 μPa	1 μPa	1 μPa
sound exposure	P						1 μPa^2 s
sound power	P			1 pW	1 pW	1 pW	1 pW
sound intensity	P		1 pW/m^2	1 pW/m^2	1 pW/m^2	1 pW/m^2	1 pW/m^2
sound energy	P			1 pJ			1 pJ
sound energy density	P			1 pJ/m^3			
sound particle displacement	F						1 pm
sound particle velocity	F			10 nm/s		1 nm/s	1 nm/s
sound particle acceleration	F			10 μm/s^2			1 μm/s^2
frequency					1 Hz		
distance							1 m

None of the applicable modern standards (ANSI 1989, 2013; IEC, 1994; ISO, 2013) specifies or mentions a standard value of impedance for use in **Equation (2)**. Despite the resulting ambiguity in the value of I_0, the convention to report levels in "dB re 1 μPa" is still in widespread use today. For the range of representative conditions listed in S1.1-1960, all at atmospheric pressure, the corresponding reference intensity would be between 0.64 aW/m^2 and 0.71 aW/m^2, and in the examples that follow I adopt 0.65 aW/m^2 precisely, which to two significant figures is equal to the value that would be implied by the standard impedance value from Z24.1-1951.

Planetary Oceanography

With the surfaces of many planets thoroughly mapped using radar, planetary scientists are becoming curious about what lies beneath those surfaces. In order to satisfy this curiosity, they turn to sound for much the same reasons as oceanographers and seismologists do on Earth. Several of Jupiter's moons are thought to contain liquid water (Hussmann et al., 2006; NASA, 2014) (see also **Figure 2**), and the methane-rich atmosphere of Saturn's moon Titan gives rise to a unique hydrocarbon precipitation and evaporation cycle (Lunine and Atreya, 2008). Both Europa (Kovach and Chyba, 2001; Lee et al., 2003; Leighton et al., 2008) and Titan (Leighton et al., 2004; Arvelo and Lorenz, 2013) have been the subject of acoustical oceanography, so far of a theoretical nature only, but the issues apply as much to model predictions as to measurements.

The sonar equations were developed for conditions involving a source and receiver in seawater at Earth's atmospheric pressure. What happens when we take our receiver out of these benign conditions on Earth and put it instead on Titan, Europa, or Ganymede? This seemingly hypothetical question is increasingly becoming a reality as sound is proposed to probe bodies other than Earth in our solar system (Lee et al., 2003; Leighton et al., 2004; Arvelo and Lorenz, 2013).

The presence of hydrocarbon seas on its surface makes Titan a particularly suitable example to examine the consequences of different choices of Z and Z_0 in **Equation 2**. (Arvelo and Lorenz, 2013) examined the potential for sonar to map the depths of *Ligeia Mare*, a hydrocarbon-rich sea on Titan comprising a mixture of ethane and methane in their liquid forms. The principle they investigated is the same as used in conventional echo sounders fitted to ships on Earth, whereby a pulse transmitted downwards from a surface vessel is reflected by the seabed and received at the same surface vessel. For a known sound speed, the depth of the liquid (usually seawater) is then inferred from the two-way travel time. Thus, for the hypothetical *Ligeia* echo sounder, both source and receiver were immersed in liquid methane, liquid ethane, or some mixture of the two. Associated sonar performance calculations require concepts of signal level and noise level in *Ligeia*, and I focus here on the noise level at the receiver position. This noise level was expressed by (Arvelo and Lorenz, 2013) as a spectral density level, presumably of the EPWI (the convention when not stated otherwise), de-

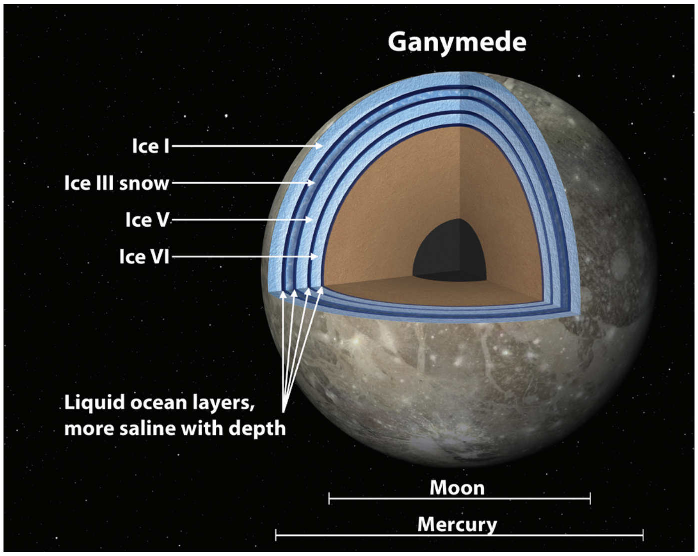


***Figure 2**. Ganymede, Jupiter's largest satellite, is one of several moons in the Solar System thought to contain liquid water. Source: NASA [NASA, 2014], Image credit: NASA/JPL-Caltech*

noted in the following by $N_{\mathrm{EPWI},f}$, with corresponding level $L_{N,f} = 10 \log_{10}[N_{\mathrm{EPWI},f}/(I_0/f_0)]$ dB, where f_0 is a suitable reference frequency. Although the quantity $L_{N,f}$, defined in this way, has a reference value of I_0 / f_0 (i.e., 0.65 aW/(m^2 Hz) on Earth, with f_0 = 1 Hz), its value is widely reported in units of "dB re 1 μPa^2/Hz", consistent with the reference values of sound pressure and frequency from **Table 1**, but raising questions about the appropriate choice of Z, Z_0 in **Equation 2**. The definition of $L_{N,f}$ leads to several different interpretations of the stated noise value ($L_{N,f}$ = 40 dB re 1 μPa^2/Hz), depending on this choice. For a receiver in *Ligeia, Z* must be the impedance of the local medium (e.g., Z ≈ 1.2 MPa s/m for a measurement in liquid ethane, or Z ≈ 0.67 MPa s/m for liquid methane), but what is Z_0? On Titan there is no established convention, but one possible interpretation is that the reference intensity is a universal constant, i.e., that the value for seawater (I_0 = 0.65 aW/m^2) is used as a universal standard reference intensity. In this interpretation, the 40 dB corresponds to EPWI = 6500 aW/(m^{2}Hz), leading to an MSP spectral density of precisely 7800 μPa^2/Hz for a receiver in ethane or 4355 μPa^2/Hz in methane. Four further values are obtained if the reference intensity is based instead on the impedance of either liquid ethane (I_0 = 0.83 aW/m^2) or liquid methane (I_0 = 1.49 aW/m^2), making six combinations in all. These six possibilities are summarized in **Table 2**, illustrating a maximum difference in MSP exceeding a factor of four.

It is not the hydrocarbon nature of *Ligeia Mare* that results in the ambiguity illustrated by **Table 2**, but the contrast between the impedance of *Ligeia's* (liquid) hydrocarbons and that of seawater under standard conditions on Earth. Pointed out originally by (Horton, 1959) (Horton's proposed solution at the time was the adoption of a standard reference intensity of 1 W/cm^2), it is also not a new problem, but Horton's warning has gone unheeded for more than half a century.

The ambiguity exists in any medium whose impedance differs from Z_0 ≈ 1.5 MPa s/m, including water subject to high pressure. The impedance of liquid water increases with increasing pressure, up to about 1.7 MPa s/m in a deep ocean trench on Earth (Leroy et al., 2008). Even higher pressures are to be found at the bottom of the oceans thought to exist in the Jovian moons Europa and Ganymede and other ocean planets (Hussmann et al., 2006), with sound speeds in liquid water of up to 1750 m/s estimated for Europa (Leighton et al., 2008) and 2500 m/s measured for conditions similar to those expected on Ganymede (Vance and Brown, 2010), compared to 1500 m/s in seawater at atmospheric temperature and pressure. Taking into account expected variations in density with pressure (Vance, 2007), the estimated impedance values corresponding to these sound speeds are Z ≈ 1.7 MPa s/m (ocean trench), 1.9 MPa s/m (Europa) and 2.9 MPa s/m (Ganymede). The resulting uncertainty in any reported noise level, estimated as 10 $\log_{10}(Z/Z_0)$ dB, is between 0.5 dB (ocean trench) and 2.8 dB (Ganymede).

Table 2: Possible values of the spectral density of EPWI and MSP, all consistent with the noise level in *Ligeia Mare* of 40 dB re 1 μPa^2/Hz, depending only on the choice of Z and Z_0.

	EPWI spectral density / aW m^{-2} Hz^{-1}	**MSP**	**Spectral Density / μPa^2 Hz^{-1}**
case	$Z^{-1}\mathrm{d}\overline{p^2}/\mathrm{d}f$	receiver in liquid ethane (Z = 1.2 MPa s/m) $\mathrm{d}\overline{p^2}/\mathrm{d}f$	receiver in liquid methane (Z = 0.67 MPa s/m) $\mathrm{d}\overline{p^2}/\mathrm{d}f$
universal standard (seawater: I_0 = 0.65 aW/ m^2)	6500	7800.00	4355.00
local *Ligeia* standard (liquid ethane: I_0 = 0.83 aW/ m^2)	8300	9960.00	5561.00
alternative local *Ligeia* standard (liquid methane: I_0 = 1.49 aW/ m^2)	14900	17880.00	9983.00

Even without considering extremes of high pressure, circumstances occasionally arise on Earth that lead to the deployment of a hydrophone or modeling of sound propagation in a medium of abnormally high or low impedance (Lamarre and Melville, 1994; Beaudoin et al., 2011). Transmission of sound across a boundary with a large impedance contrast then gives rise to a further ambiguity depending on whether the associated transfer function (transmission loss or propagation loss) is corrected for the impedance ratio (Ainslie and Morfey, 2005; Ainslie, 2008).

What Exactly is a Level?

Given that the ambiguity illustrated by **Table 2** stems from the reporting of a level in decibels, the only way to resolve it, short of discarding the decibel altogether (Horton 1952, 1954, 1959; Chapman and Ellis, 1998; Clay, 1999; Hickling, 1999; Chapman, 2000), is to be more precise in our use of the decibel as a unit of level. To achieve this we first need to understand what a level is. According to ISO 80000-1:2009 'Quantities and Units Part 1: General' (ISO, 2009), and ANSI S1.1-2013 'Acoustical Terminology' (ANSI, 2013), a level, L, is the logarithm of the ratio of a quantity q to a reference value of that quantity q_0. In equation form, $L = \log_r q/q_0$, from which it is clear that the value of q (the nature of which must also be specified) can only be recovered unambiguously from that of L if the base of the logarithm (r) and the reference value (q_0) are both known precisely.

The convention to use $[1\ \mu\mathrm{Pa}]^2/\rho_0 c_0$ as a reference intensity… is neither an American national standard nor an international standard, nor has it ever been.

Q1 What is the base of the logarithm?

ISO 80000-3:2006 (ISO, 2006) distinguishes between the *level of a field quantity* on the one hand and *level of a power quantity* on the other. In **Table 1**, field quantities (e.g., sound pressure) and power quantities (e.g., sound power) are identified by an 'F' or 'P', respectively, in the second column. The level of a field quantity F, with reference value F_0, is $L_F = \log_e F/F_0$, implying that, for the level of a field quantity, the base r = e. Similarly, the level of a power quantity P (reference value P_0) is $L_p = (1/2)\log_e P/P_0$, from which it follows that $L_p = \log_{e^2}(P/P_0)$ and therefore, for the level of a power quantity, $r = e^2$.

For every real, positive power quantity P there exists a field quantity $F = P^{1/2}$, in which case that field quantity may be referred to as a root-power quantity (ISO, 2009), and for which (assuming also that $F_0 = P_0^{1/2}$) the level L_F as defined above is equal to the level L_P. Further, the term "field quantity" is deprecated by ISO 80000-1:2009. For these reasons, attention is restricted in the following to real, positive power quantities and to their corresponding root-power quantities.

Q2 What is the reference value?

International standard reference values for selected power quantities, indicated by a 'P' in column 2 of **Table 1**, are given in column 7(q_0) of that Table, and the reference value of each corresponding root-power quantity is $q_0^{1/2}$. For example, the reference value of sound exposure, E, is $q_0 = 1\ \mu\mathrm{Pa}^2\ \mathrm{s}$; the corresponding root-power quantity is $\mathrm{E}^{1/2}$, whose reference value is therefore $q_0^{1/2} = 1\ \mu\mathrm{Pa\ s}^{1/2.}$

International standard reference values for selected root-power quantities, indicated by an 'F' in column 2 of **Table 1**, are given in column 7(q_0) (remember that root-power quantities are also field quantities), and the reference value of each corresponding power quantity is q_0^2. For example, the reference value of RMS sound pressure, ρ_{RMS}, is $q_0 = 1\ \mu\mathrm{Pa}$; the corresponding power quantity is $\overline{p^2} = \rho_{\mathrm{RMS}}{}^2$, whose reference value is $q_0^2 = 1\ \mu\mathrm{Pa}^2$.

Corollary: how large is a decibel?

Although correct (by definition), the equation $L_P = (1/2)\log_e P/P_0$ is rarely used in that form. Instead the decibel (dB) is introduced, defined in such a way that $L_P = 10 \log_{10} P/P_0$ dB. It follows by equating these two expressions for L_P that the decibel is a dimensionless constant, equal to $(1/20)\log_e 10 \approx 0.115\ 129$.

International Harmonization

Don't write so that you can be understood, write so that you can't be misunderstood. – William Howard Taft (1857-1930)

The effective communication of precise information and ideas requires a precise language. Our ability to communicate effectively is compromised by the ambiguity inherent in conventional reporting of levels in decibels.

The convention to use $(1\ \mu\mathrm{Pa})^2/Z_0$ as a reference intensity is widely used, primarily due to its adoption and promulgation by (Urick 1967, 1983), but it is neither an American national standard nor an international standard, nor has it ever been, and the absence of a standard value of Z_0 leads to widespread ambiguity. Under normal conditions on Earth, the effects

Table 3: Who polices the police? ANSI and ISO define "sound pressure" to mean $p(t)$, the difference between instantaneous pressure and static pressure, whereas IEC defines the same term to mean ρ_{RMS}, the RMS value of $p(t)$. Similar differences arise for the definition of "sound pressure level."

Organization	Sound Pressure	Sound Pressure Level (SPL)	Reference
American National Standards Institute (ANSI)	$p(t)$	$10\log_{10}[p_{\mathrm{RMS}}^2/p_0^2]$ dB	(ANSI, 2013)
International Organization for Standardization (ISO)	$p(t)$	$10\log_{10}[p(t)^2/p_0^2]$ dB	(ISO, 2007)
International Electrotechnical Commission (IEC)	p_{RMS}	$20\log_{10}[p_{\mathrm{RMS}}/p_0]$ dB	(IEC, 1994)

of this ambiguity are small, and we don't notice them. For some applications, however (e.g., calibration of transducers in fresh water (Horton, 1959), even small ambiguities lead to significant errors, while for others we depart sufficiently from the standard seawater conditions that the effects are no longer small. Even if we never put a hydrophone in Ganymede's oceans, the question "what is the reference intensity?" will still arise for model predictions reported in decibels.

The "obvious" way to remove the ambiguity is to follow a national or (better) international standard instead of the convention. After all, the whole purpose of standardized terminology is to facilitate unambiguous communication, and if there existed a single unambiguous standard terminology, the adoption of that standard would indeed be the solution. Unfortunately, while there is international agreement on reference values for sound pressure (1 μPa) and sound intensity (1 pW/m^2), different national and international standards bodies have chosen different definitions even for basic terminology such as "sound pressure" and "sound pressure level," pointed out below and summarized by **Table 3**, so there remains some harmonization work to be done.

Why it Matters, Here on Earth

The examples considered so far involve exotic conditions on distant moons, but there is no need to look so far for examples of the need for national and international harmonization. Sound (or "noise") in water is increasingly seen as a potential pollutant, and offshore contractors are required by regulators to assess or mitigate the risk of exposing marine animals to noise (Lucke et al., 2014). For example, the National Marine Fisheries Service (NMFS) in the US (NMFS, 2013), and the *Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit* (BMU) in Germany (BMU, 2013) specify thresholds of levels (e.g., of sound pressure or of sound exposure) that are either not to be exceeded at all or only by permit. While it is up to each national authority to define the terms used in its national regulations or guidelines, underwater sound, like salmon and dolphins, shows scant regard for national boundaries, creating regulatory confusion if the nationally adopted terminologies differ from one another, and highlighting the need for international harmonization. In Europe, the Marine Strategy Framework Directive (EC, 2008) requires EU Member States to co-operate at a regional level to achieve good environmental status. Specifically, EU Member States are required to monitor trends in underwater noise levels (EC, 2010), and associated monitoring programs can only yield comparable results if the Member States are measuring the same quantity (Dekeling et al., 2014).

Recent advances in scientific knowledge about risks of underwater sound have been reviewed by (Southall et al., 2007) (for marine mammals) and (Popper et al., 2014) (for fishes and sea turtles). These expert reviews provide stakeholders with sorely needed risk criteria, and insights into the latest scientific findings. In the absence of widely accepted international standard terminology, the onus is on the authors of such reviews related to underwater sound to provide a complete list of acoustical terms used, and their definitions. To the extent that neither review defines all the terms used, the onus is then placed on the reader (who is unlikely to have the same in-depth expertise as the authors) to refer to the original research literature to find the missing definitions, increasing both the reader's effort and risk of misunderstanding.

The International System of Quantities

We are witnessing the birth of a new science, planetary oceanography, and a new societal concern, underwater noise pollution. Before reaching maturity, both will need a more precise terminology than is presently available.

Help is on its way in the form of a long-standing collaboration between ISO and IEC that has borne as fruit the 14-

part standard ISO/IEC 80000 'Quantities and Units' (Jensen and Thor, 1995; IEC, 2012). This joint ISO/IEC Standard describes the International System of Units (SI), other standardized units intended for use alongside the SI such as the decibel and the neper, and the corresponding system of quantities, known as the International System of Quantities (ISQ) (BIPM, 2006).

In 2011, an ISO technical sub-committee (ISO/TC 43/SC 3) dedicated exclusively to underwater acoustics was established (ISO, 2012). The need for an unambiguous underwater acoustics terminology was identified in June 2012, at the inaugural meeting of that sub-committee. The new standard ISO 18405 Underwater Acoustics - Terminology, under development by ISO Working Group ISO/TC 43/SC 3/WG 2, is based on Parts 3 and 8 of ISO/IEC 80000, and is scheduled for publication as an International Standard in 2016. This new standard will include definitions, reached by international consensus, not only of basic terminology already mentioned ("sound pressure," "sound pressure level," "sound exposure"), but also of more advanced terminology such as "source level" (a measure of source power,) "temporary hearing threshold shift" (a measure of change in hearing sensitivity,) and "detection threshold" (a measure of the minimum signal-to-noise ratio required for a sonar to correctly identify a signal in the presence of noise.)

A Parting Plea

Underwater acousticians, myself included, have a responsibility to provide a clear, concise, and unambiguous language with which to communicate results and ideas about our science. The sooner we provide that language, the sooner industry, governments, and scientists will start to benefit from its use. We must not let them wait a minute longer than is necessary.

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Biosketch

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