IQOE – Inventory of existing standards and guidelines relevant to marine bioacoustics

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List of abbreviations

ADEON	Atlantic Deepwater Ecosystem Observatory Network
AEP	auditory evoked potential
ANSI	American National Standards Institute
ASA	Acoustical Society of America
EPWI	equivalent plane wave intensity
IEC	International Electrotechnical Commission
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
MSP	mean square pressure
NMFS	(US) National Marine Fisheries Service
SMRU	Sea Mammal Research Unit at University of St. Andrews
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
WHOI	Woods Hole Oceanographic Institute

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Introduction

This inventory includes a list of standards or other documents relevant to standardization in marine bioacoustics. For a similar inventory of standards relevant to the observation of ocean sound (excluding bioacoustics), see https://iqoe.org/groups/standardization. Documents are listed in the following categories:

- sound production;
- sound absorption and scattering;
- sound reception;
- soundscapes;
- effects on marine life (methodology);
- effects on marine life (metrics, including frequency weighting functions);
- bioacoustical terminology.

The International Organization for Standardization (ISO) explains the relevance of international standardization at its web page 'Using and referencing ISO and IEC standards to support public policy', see https://www.iso.org/sites/policy/index.html.

The focus is on international standards from ISO[1], IEC[2] and national standards relevant to marine bioacoustics. Also considered are documents relevant to standardization in the categories:

- peer reviewed publications with direct relevance to marine bioacoustical standardization;
- other publications with direct relevance to marine bioacoustical standardization, including project standards, technical reports and specifications, and non-peer reviewed journal articles;
- national or international standards in airborne bioacoustics with indirect relevance to marine bioacoustical standardization.

If the scope of this inventory were limited to national and international standards, the list would contain two documents. There is only one relevant international standard (terminology, ISO 18405:2017) and one national standard (audiogram for toothed whales, ANSI/ASA S3/SC1.6-2018). Generally, in underwater acoustics and particularly in marine bioacoustics there is a void of standards for measurement, reporting, and interpretation.

Most of the documents listed in this inventory are not standards but supporting documents that could be used to develop *new* standards. Such documents are included as they are considered helpful in guiding the development of a future national or international standard in marine bioacoustics. This inventory also included standards in air bioacoustics - while not directly applicable, these may serve as a model for developing underwater bioacoustics standards. After each standard or guideline is a list of key words indicating its relevance.

Some standards or guidelines are relevant to more than one section; therefore, these documents have been included more than once. For each occurrence, the key words may be different because the relevance of the standard or guideline is likely different.

[1] International Organization for Standardization, Geneva, Switzerland
[2] International Electrotechnical Commission, Geneva, Switzerland

1. Bioacoustical terminology

International standards

ISO 18405:2017. Underwater acoustics — Terminology. International Organization for Standardization, Geneva, Switzerland, 2017.

> *Key Words: terms and definitions (auditory frequency weighting; sound production; sound reception)*

ISO 80000-8:2020 Quantities and Units – Part 8: Acoustics.

> *Key Words: terms and definitions (sound exposure; sound exposure level)*

National standards

None

Peer reviewed publications

Ainslie et al. 2021, A terminology standard for underwater acoustics and the benefits of international standardization. IEEE J Oceanic Eng. In press.

> *Key Words: ISO 18405; terms and definitions (frequency weighting)*

Hawkins AD, Johnson C, and Popper AN 2020. How to set sound exposure criteria for fishes. The Journal of the Acoustical Society of America, 147(3), 1762-1777.

> *Key Words: Terms and definitions for sound exposure criteria: Biologically significant, Criterion (plural criteria), Disturbance, Effect, Exposure, Fitness, Guidelines, Harass, Impact, Injury, Onset, Salience, Susceptibility, Threshold, Vulnerability*

MacLennan D, Fernandes PG, and Dalen J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science, 59(2), 365-369.

> *Key Words: Terms and definitions (fisheries acoustics)*

Other publications relevant to marine bioacoustical standardization

Ainslie MA, de Jong CAF, Martin SB, Miksis-Olds JL, Warren JD, Heaney KD, Hillis CA, and MacGillivray AO. 2020. ADEON Project Dictionary: Terminology Standard. Document 02075, Version 1.0. Technical report by JASCO Applied Sciences for ADEON. DOI https://doi.org/10.6084/m9.figshare.12436199.v2.

> *Key Words: Terms and definitions (soundscapes)*

Ainslie MA, de Jong CAF, Halvorsen MB, Ketten DR. 2018a. E&P Sound and Marine Life JIP Standard: Underwater Acoustics – Task 1: Terminology. Report by TNO for the Joint Industry Programme on E&P Sound and Marine Life.

> *Key Words: Terms and definitions for E&P Sound and Marine Life JIP*

Ainslie MA, Tyack P, Wensveen PJ. 2009. BRS-3S collaboration: A common acoustical terminology for behavioural response studies. May 2009.

> *Key Words: Terms and definitions for BRS (general; see Appendix A and B)*

Ainslie MA, DeRuiter S. 2009. BRS-3S collaboration: A common acoustical terminology for behavioural response studies (proposed SNR definitions). May 2009. see appendix.

Key Words: Terms and definitions (SNR in behavioural response studies)

Au WWL and Hasting MC. 2008. Principles of Marine Bioacoustics. Springer Science Business Media. DOI: 10.1007/978-0-387-78365-9_1.

Key Words: bandwidth, duration

Morfey CL. 2001. Dictionary of acoustics. Academic press.

Key Words: Terms and definitions (acoustics)

Nedelec S, et al. 2021. Best Practice Guide for Underwater Particle Motion Measurement for Biological Applications. Document number 1. Technical report by Exeter University for the IOGP Marine Sound and Life Joint Industry Programme.

Key Words: Terms and definitions (particle motion)

Wang L, Robinson S. 2020. JOMOPANS standard: Terminology for ambient noise monitoring. Version 2.0. Available from https://northsearegion.eu/media/13062/jomopans_wp3-standard-terminology_version_-2.pdf (last accessed 2021-06-02).

Key Words: Terms and definitions (soundscapes)

International and national standards in airborne bioacoustics

ANSI S1.1-2013, American National Standard: Acoustical terminology (Standards Secretariat, Acoustical Society of America, New York, USA).

Key Words: Terms and definitions (acoustics)

ANSI/ASA S12.9 PART 1 2013 Edition, February 27, 2013 American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound – Part 1: Basic Quantities and Definitions (Standards Secretariat, Acoustical Society of America, New York, USA).

Key Words: Terms and definitions (environmental sound)

ANSI S3.20-2015, American National Standard: Bioacoustical terminology (Standards Secretariat, Acoustical Society of America, New York, USA).

Key Words: Terms and definitions for bioacoustics (human hearing in air)

2. Metrics

International standards

None

National standards

None

Peer reviewed publications

Houser DS, Yost W, Burkard R, Finneran JJ, Reichmuth C, Mulsow J. 2017. A review of the history, development and application of auditory weighting functions in humans and marine mammals. The Journal of the Acoustical Society of America, 141(3), 1371-1413.

Key Words: auditory weighting functions

Madsen P T. 2005. Marine mammals and noise: Problems with root mean square sound pressure levels for transients. The Journal of the Acoustical Society of America, 117(6), 3952-3957.

Key Words: peak sound pressure, signal duration, sound exposure level, sound pressure level,t_90, t_95,

Madsen PT, Johnson M, Miller PJO, Aguilar Soto N, Lynch J, Tyack P. 2006. Quantitative measures of air-gun pulses recorded on sperm whales (Physeter macrocephalus) using acoustic tags during controlled exposure experiments. J Acoust Soc Am 120:2366–2379

Key Words: airgun metrics

Martin SB, Lucke K, Barclay DR. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. *The Journal of the Acoustical Society of America*, *147*(4), 2159-2176.

Key Words: kurtosis

Müller RA, von Benda-Beckmann AM, Halvorsen MB, Ainslie MA. 2020. Application of kurtosis to underwater sound. The Journal of the Acoustical Society of America, 148(2), 780-792.

Key Words: kurtosis

Southall BL, Bowles AE, Ellison WT, Finneran JJ, Gentry RL, Greene Jr CR, Kastak D, Ketten DR, Miller JH, Nachtigall PE, Richardson WJ, Thomas JA, Tyack PL. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, 33(4), 411-521.

Key Words: impulse, non-pulse, peak sound pressure, sound exposure level, signal duration,

Southall BL, Finneran JJ, Reichmuth C, Nachtigall PE, Ketten DR, Bowles AE, ... Tyack PL. 2019. Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. Aquatic Mammals, 45(2), 125-232.

Key Words: auditory frequency weighting functions; hearing thresholds; weighted sound exposure; peak sound pressure

Tougaard J, Wright AJ, and Madsen PT. 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises, Mar. Pollut. Bull., 90, 196–208. doi:10.1016/j.marpolbul.2014.10.051

Key Words: frequency weighting, loudness, t_short

Other publications relevant to marine bioacoustical standardization

Au WW, and Hastings MC. 2008. Principles of marine bioacoustics (pp. 121-174). New York: Springer.

Key Words: click centroid frequency, click rms bandwidth

National Marine Fisheries Service. 2018. 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

Key Words: peak sound pressure, weighted sound exposure

Popper AN, Hawkins AD, Fay RR, Mann DA, Bartol S, Carlson TJ, Coombs S, Ellison WT, Gentry RL, Halvorsen MB, Løkkeborg S, Rogers PH, Southall BL, Zeddies DG, Tavolga WN. 2014. ASA S3/SC1. 4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report Prepared by ANSI-Accredited Standards Committee S3/SC1 and Registered with ANSI. Springer.

Key Words: peak sound pressure; peak velocity; sound exposure; rms sound pressure

International and national standards in airborne bioacoustics

ISO 13474: 2009. Acoustics — Framework for calculating a distribution of sound exposure levels for impulsive sound events for the purposes of environmental noise assessment.

Key Words: airborne noise assessment

ISO 1996-1:2016, Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures

Key Words: airborne noise terminology

ISO 1996-2:2007, Acoustics -- Description, measurement and assessment of environmental noise -- Part 2: Determination of environmental noise levels

Key Words: airborne noise assessment

IEC 61672-1:2013. Electroacoustics - Sound level meters - Part 1: Specifications

Key Words: airborne noise measurement

3. Reporting

International standards

None

National standards

None

Peer reviewed publications

None

Other publications relevant to marine bioacoustical standardization

Ainslie et al. 2018. UNDERWATER ACOUSTICS - TASK 3: REPORTING. A report prepared by TNO for the Joint Industry Programme on E&P Sound and Marine Life.

Key Words: reporting standard

International and national standards in airborne bioacoustics

None

4. Sound production

International standards

None

National standards

None

Peer reviewed publications

Dähne M, Verfuß UK, Brandecker A, Siebert U, Benke H. 2013. Methodology and results of calibration of tonal click detectors for small odontocetes (C-PODs). The Journal of the Acoustical Society of America, 134(3), 2514-2522.

Key Words: Proposed methodology

Madsen PT, and Wahlberg M. 2007. Recording and quantification of ultrasonic echolocation clicks from free-ranging toothed whales, Deep. Res I, 54, 1421–1444. doi:10.1016/j.dsr.2007.04.020

Key Words: acoustic localisation, array configuration, echolocation, odontocete, sound propagation, source parameters

Madsen PT. 2005. Marine mammals and noise: Problems with root mean square sound pressure levels for transients, J. Acoust. Soc. Am. 117, 3952–3957.

Key Words: peak sound pressure, signal duration, sound exposure level, sound pressure level, t_90, t_95,

Other publications relevant to marine bioacoustical standardization

None

International and national standards in airborne bioacoustics

None

5. Sound absorption and scattering

International standards

None

National standards

None

Peer reviewed publications

None

Other publications relevant to marine bioacoustical standardization

Heaney KD, Martin B, Miksis-Olds JL, Ainslie MA, Moore T, Warren J. 2020. ADEON Data Processing Specification, Version 1.0 FINAL. Technical report by Applied Ocean Sciences for Prime Contract No. M16PC00003. DOI https://doi.org/10.6084/m9.figshare.12412610.v1.

Key words: AFZP data processing

Madsen EL., Dong F, Frank GR, Garra BS, Wear KA, Wilson T, ... Feleppa EJ. 1999. Interlaboratory comparison of ultrasonic backscatter, attenuation, and speed measurements. Journal of ultrasound in medicine, 18(9), 615-631.

Key words: Harmonization of backscatter and extinction cross sections

Martin B, Hillis CA, Miksis-Olds J, Ainslie MA, Warren J, Heaney KD. 2018. ADEON Hardware Specification. Document 01412, Version 2.3. Technical report by JASCO Applied Sciences for ADEON. DOI https://doi.org/10.6084/m9.figshare.6809711.

Key words: AFZP specification

Warren JD, Ainslie MA, Miksis-Olds JL, Martin B, Heaney KD. 2018. ADEON Calibration and Deployment Good Practice Guide. Version 1.0. Technical report by Stony Brook University for ADEON Prime Contract No. M16PC00003. DOI https://doi.org/10.6084/m9.figshare.6793745.

Key words: AFZP calibration and deployment

International and national standards in airborne bioacoustics

None

6. Sound reception

International standards

None

National standards

ANSI/ASA S3/SC1.6-2018. Procedure For Determining Audiograms in Toothed Whales Through Evoked Potential Methods.

Key words: AEP, Audiogram, Hearing

Peer reviewed publications

Ladich F, and Fay RR. 2013. Auditory evoked potential audiometry in fish. Reviews in Fish Biology and Fisheries, 23(3), 317-364.

Key words: AEP, Communication, Hearing, Noise, Ontogeny, Particle acceleration levels, Sound pressure level, Thresholds

Martin B, Lucke K, and Barclay DR. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. *The Journal of the Acoustical Society of America* 147.4: 2159-2176.

Key words: kurtosis

Müller RAJ, et al. 2020. Application of kurtosis to underwater sound. *The Journal of the Acoustical Society of America* 148.2 (2020): 780-792.

Key words: kurtosis

Tougaard J, and Beedholm K. 2019. Practical implementation of auditory time and frequency weighting in marine bioacoustics, Appl. Acoust., 145, 137–143. doi:10.1016/j.apacoust.2018.09.022.

Key words: frequency weighting, integration time, loudness, temporal weighting

Other publications relevant to marine bioacoustical standardization

Au WWL., Popper AN, Fay RR. 2000. *Hearing by Whales and Dolphins*, Springer, New York, NY

Key words: acoustic communication, auditory system, bioacoustics, cetaceans, echolocation, odontocetes, marine mammal hearing, psychoacoustics, sound production, sound propagation.

Museum für Naturkunde Berlin. Animal Audiogram Database. https://animalaudiograms.museumfuernaturkunde.berlin/audiogrambase.

Key words: audiogram

National Marine Fisheries Service (2018). "Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0) —Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts," (National Oceanic and Atmospheric Administration, Silver Springs, MD).

Key words: acoustic threshold, auditory masking threshold, behavioural impact threshold, noise exposure, hearing sensitivity, marine mammal, permanent threshold shift, temporary threshold shift, underwater sound, weighting function

International and national standards in airborne bioacoustics

ISO 8253-1:2010. Acoustics -- Audiometric test methods -- Part 1: Pure-tone air and bone conduction audiometry.

Key words: threshold audiometry, air conduction, bone conduction, audiogram

ISO 8253-2:2009. Acoustics -- Audiometric test methods -- Part 2: Sound field audiometry with pure-tone and narrow-band test signals.

Key words: threshold audiometry, binaural listening, pure tone, frequency-modulated tone, narrow-band noise, air conduction, audiogram

ISO 8253-3:2012. Acoustics -- Audiometric test methods -- Part 3: Speech audiometry.

Key words: speech recognition, speech audiometry, air conduction, sound field audiometry, earphone, speech detection threshold

7. Soundscapes

This section overlaps with the scope of IQOE WG Standardization. The focus here is on bioacoustical aspects of soundscapes.

International standards

None

National standards

None

Peer reviewed publications

Lin TH, Akamatsu T, Sinniger F, Harii S. 2021. Exploring coral reef biodiversity via underwater soundscapes. *Biological Conservation*, *253*, 108901.

> *Key words: Ocean sound, Mesophotic corals, Remote sensing, Noise, Acoustic habitat, Acoustic diversity*

Lindseth A, and Lobel P. 2018. Underwater soundscape monitoring and fish bioacoustics: a review. Fishes, 3(3), 36.

> *Key words: acoustic monitoring, ambient noise, coral reef, environmental monitoring, fish, passive acoustic detection, underwater sound*

Sertlek HÖ, Slabbekoorn H, Ten Cate C, Ainslie MA. 2019. Source specific sound mapping: Spatial, temporal and spectral distribution of sound in the Dutch North Sea. *Environmental pollution*, *247*, 1143-1157.

> *Key words: Energy budget (wind, shipping, seismic surveys, explosions)*

Other publications relevant to marine bioacoustical standardization

Ainslie MA, Miksis-Olds JL, Martin B, Heaney KD, de Jong CAF, von Benda-Beckmann AM, and Lyons AP. 2018. ADEON Underwater Soundscape and Modeling Metadata Standard. Version 1.0. Technical report by JASCO Applied Sciences for ADEON Prime Contract No. M16PC00003. DOI https://doi.org/10.6084/m9.figshare.6792359.v2.

> *Key words: ADEON soundscape specification*

Ainslie, de Jong, Prior. 2018c. TNO 2017 R10022. Standard Procedures for Underwater Noise Measurements for Activities Related to Offshore Oil and Gas Exploration and Production. Phase I: Processing and Reporting Procedures: Data processing, TNO report, March 2018.

> *Key words: Data processing*

International and national standards in airborne bioacoustics

ANSI/ASA S3/SC1.100-2014/ANSI/ASA S12.100-2014. Methods to Define and Measure The Residual Sound In Protected Natural And Quiet Residential Areas (Standards Secretariat, Acoustical Society of America, New York, USA).

> *Key words: measurement procedures, protected natural areas, quiet residential areas, residual sound levels*

ANSI/ASA S12.9 PART 2 1992 Edition, August 13, 1992. American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound Part 2: Measurement of Long-Term, Wide-Area Sound (Standards Secretariat, Acoustical Society of America, New York, USA).

Key words: time-averaged noise, environmental assessment, distributed sound sources, spatial sampling, temporal sampling

ANSI/ASA S12.9 PART 3 2013 Edition, January 15, 2013. American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound – Part 3: Short-term Measurements with an Observer Present (Standards Secretariat, Acoustical Society of America, New York, USA).

Key words: source emissions, received sound, background noise correction, frequency weighting, filtering

ISO 12913-1:2014. Acoustics -- Soundscape -- Part 1: Definition and conceptual framework.

Key words: acoustic environment, soundscape, sound sources

ISO/TS 12913-2:2018. Acoustics -- Soundscape -- Part 2: Data collection and reporting requirements.

Key words: background sound, descriptor, foreground sound, indicator, local expert, noise, soundwalk, total sound

8. Effects on marine life

International standards

None

National standards

None

Peer reviewed publications

Dunlop RA, Noad MJ, McCauley RD, Kniest E, Paton D, Cato D. 2015. The Behavioural Response of Humpback Whales (Megaptera novaeangliae) to a 20 Cubic Inch Air Gun. Aquatic Mammals, 41(4), 412-433.

Key words: air gun, anthropogenic noise, baleen whales, diving behaviour, focal follow, migration, migration speed, seismic survey

Erbe C, Reichmuth C, Cunningham K, Lucke K, Dooling R. 2016. Communication masking in marine mammals: A review and research strategy. Marine pollution bulletin, 103(1-2), 15-38.

Key words: anti-masking, audiograms, auditory integration time, auditory masking, critical ratio, critical bandwidth Lombard effect, marine mammal hearing, masking release, spatial release, underwater noise,

Finneran JJ. 2015. Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores. San Diego, CA: SSC Pacific.

Key Words: methodology for deriving frequency weighting functions from TTS measurements

ISO/DIS 23730 (draft international standard) Marine Technology - Marine environmental impact assessment (MEIA) - General technical requirement.

Key words: International standard for marine EIA (draft)

Madsen PT. 2005. Marine mammals and noise: problems with root mean square sound pressure levels for transients, J Acoust Soc Am, 117, 3952–3957.

Key Words: peak sound pressure, signal duration, sound exposure level, sound pressure level, t_90, t_95

Miller PJO, Kvadsheim PH, Lam FPA, Wensveen PJ, Antunes R, Alves AC, Visser F, et al. 2012. The severity of behavioral changes observed during experimental exposures of killer (Orcinus orca), long-finned pilot (Globicephala melas), and sperm (Physeter macrocephalus) whales to naval sonar. Aquat. Mamm., 38, 362–401. doi:10.1578/AM.38.4.2012.362.

Key words: acoustic exposure, behavioral responses, controlled exposure experiments, disturbance, military sonar, odontocetes

Tyack PL, Zimmer, WMX, Moretti D, Southall BL, Claridge DE, Durban JW, Clark CW, et al. 2011. Beaked whales respond to simulated and actual navy sonar. PLoS One, 6, e17009. doi:10.1371/journal.pone.0017009.

Key words: acoustic exposure, behavioral responses, Blainville's beaked whales, disturbance, echolocation clicks, foraging, military sonar, opportunistic monitoring, playback

Other publications relevant to marine bioacoustical standardization

Lydolf M, and Møller H. 2000. Measurements of equal-loudness contours between 20 Hz and 1 kHz. In *Proceedings of the 29th International Congress and Exhibition on Noise Control Engineering (InterNoise).* August.

Key Words: History of ISO 226

International and national standards in airborne bioacoustics

ISO 226:2003. Acoustics — Normal equal-loudness-level contours.

Key Words: audiogram, equal loudness contour, loudness function

ISO 389-7:2019. Acoustics — Reference zero for the calibration of audiometric equipment — Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions.

Key Words: threshold audiometry, normal hearing, pure tone, white noise, pink noise, binaural, free field, diffuse field

Appendix A: BRS-3S terminology (main)

This appendix lists terms and definitions developed to support behavioural response studies. The definitions have the status of unpublished proposals, largely superseded by ISO 18405. They are included here because they might be useful to the process of updating ISO 18405 or developing a new terminology standard for a specific application, and because they are not otherwise publicly available.

Selected definitions are copied verbatim from Morfey's Dictionary of Acoustics (Morfey, 2001). Such definitions use upper case letters to indicate cross-references to other entries in the Dictionary of Acoustics.

BRS-3S collaboration: A common acoustical terminology for behavioural response studies
authors: MA Ainslie (TNO), P Tyack (WHOI) and PJ Wensveen (SMRU)

Introduction

It is proposed to develop a joint measurement and data analysis protocol to maximise compatibility between BRS and SSS datasets. The first step to achieve this is to establish a common language. The purpose of the present document is to propose a common nomenclature. Where practical to do so it adheres to definitions from the following publications:

- ANSI 1989 (Reference Quantities)
- ANSI 1994 (Acoustical Terminology)
- IEC (IEV online)
- Morfey 2001 (Dictionary of Acoustics)
- Madsen 2005 (JASA)
- Ainslie 2006 (TNO booklet)
- Southall et al 2007 (Aquatic Mammals)
- Ainslie 2008 (Acoustics 08)

The definitions are grouped into 6 categories:

- general acoustics
- properties of continuous sounds
- properties of transient sounds
- properties related to SNR (separate document)
- properties related to animal hearing or physiology
- weighted measures of continuous and transient sounds

general acoustics:

term	symbol	definition	notes
instantaneous acoustic pressure	$p(t)$	$P(t) - P_0$	
instantaneous total pressure	$P(t)$	force per unit area	
reference frequency	f_{ref}	1 Hz	National standard: ANSI 1989
reference pressure	p_{ref}	1 µPa	National and international standard
reference time	t_{ref}	1 s	Usual practice in water [3]
static pressure	P_0	to be defined[4]	Relevant questions are: • What is the meaning of "static" here? • What happens to the recorded pressure on a DTAG during the overhead passage of a surface gravity wave? • What happens to the recorded pressure on a DTAG during a dive to 1000 m? • Such non-acoustic fluctuations would normally be removed by filtering, but what is the lowest frequency of interest to hearing? Can whales hear sound of frequency 1 Hz, 30 mHz, 1 mHz? • What is a reasonable lower limit for choice of LF cut-off of the bandpass filter? [5]

[3] No standard is known to the authors

[4] Large non-acoustic pressure fluctuations can be expected on a time scale of seconds, minutes or hours. In deep water there must also be acoustic waves at these frequencies (generated by seismic activity).

[5] Is there also an *upper* limit for choice of HF cut-off of the bandpass filter?

measures characterising a continuous, statistically stationary signal (all unweighted):

term	symbol	definition	notes
averaging time	*T*	For a **continuous signal**, the time *T* in the integral for **RMS sound pressure**	
band-limited signal			
continuous signal			
mean square pressure (MSP)		For a **continuous signal**, the quantity p_{RMS}^{2}	in a specified frequency band
MSP spectral density	*Q*	For a **continuous signal**, the contribution to MSP per unit of bandwidth	
MSP spectral density level	MSP-SDL	For a **continuous signal**, the $10\log_{10}\frac{Q}{p_{\mathrm{ref}}^{2}/f_{\mathrm{ref}}}$	units: dB re µPa² / Hz
RMS sound pressure	p_{RMS}	For a **continuous signal** and specified averaging time *T*, the quantity $\sqrt{\frac{1}{T}\int_{T} p(t)^{2}\,\mathrm{d}t}$	
signal bandwidth	$\beta_{x\%}$	For a **band-limited signal**, the frequency band within which a percentage *x* of sound power arrives (e.g., β_{90} is the bandwidth in which 90 % of the power is contained)	made unambiguous by starting at 50-*x*/2 % and ending at 50+*x*/2 % of total power. (e.g., for β_{90} this range is from 5 to 95 % of the sound power)
sound pressure level	SPL	For a **continuous signal**, the quantity $10\log_{10}\frac{p_{\mathrm{RMS}}^{2}}{p_{\mathrm{ref}}^{2}}$	in a specified frequency band always unweighted units: dB re µPa² (following Morfey 2001)

measures characterising a **transient signal** (all unweighted):

term	symbol	definition	notes
peak sound pressure[6]		For a transient signal, the quantity max(abs(p(t)))	in a specified frequency band also known as 'zero to peak pressure' The term 'peak to peak pressure' is also used but is more difficult to define.[7]
recording bandwidth			needed for interpretation of peak pressure (f_{min}, f_{max})
signal duration (1)	$\tau_{x\%}$	For a transient signal, the time during which a specified percentage *x* of unweighted sound exposure occurs (eg, τ_{90} is the time window during which 90 % of the energy arrives)	based on Madsen 2005 made unambiguous by starting at 50-*x*/2 % and ending at 50+*x*/2 % of total energy. (eg, for τ_{90} this is 5 to 95 %)[8]
signal duration (2)	$\tau_{y\mathrm{dB}}$	For a transient signal and a specified averaging time, the time during which the SPL exceeds a specified threshold *y* decibels below the maximum SPL	based on Madsen 2005 if there is more than one threshold crossing in each direction, made unambiguous by choosing the time interval between the first crossing with increasing SPL and the last one with decreasing SPL difficult to measure precisely if amplitude varies slowly with time
transient signal			
unweighted sound exposure[9]	E	For a transient signal, the quantity $\int_{-\infty}^{\infty} p(t)^2 \, \mathrm{d}t$	always unweighted Another term (used by Medwin & Clay) is "time integrated pressure squared" (tips) but this is a bit of a mouthful.
unweighted sound exposure level	SEL	For a transient signal, the quantity $10\log_{10} \frac{E}{p_{\mathrm{ref}}{}^2 t_{\mathrm{ref}}}$	always unweighted units: dB re µPa² s
unweighted sound exposure spectral density	E_f	For a transient signal, the contribution to sound exposure *E* per unit of bandwidth	always unweighted
unweighted sound exposure spectral density level		For a transient signal, the quantity $10\log_{10} \frac{E_f}{p_{\mathrm{ref}}{}^2 t_{\mathrm{ref}} / f_{\mathrm{ref}}}$	always unweighted units: dB re µPa² s / Hz

[6] the term 'peak sound pressure level' is avoided as it can be interpreted as either one of:
peak (sound pressure level), ie, the maximum RMS sound pressure (running average), expressed in dB;
(peak sound pressure) level, ie the peak sound pressure, expressed in dB.

[7] this can be added later if found to be necessary

[8] suggestion for practical implementation:
first make an estimate of noise spectral density Q_{N};
subtract this noise estimate from the measurement of $Q_{\mathrm{S+N}}$;
integrate in frequency. What is left is the mean square pressure of the signal alone.
If the windows are well chosen, the average signal MSP will be zero except when there really is a signal. See also Southall et al 2007 (p499).

[9] An early version of this document proposed "sound energy" for this term. This has been replaced by "unweighted sound exposure" to avoid use of "energy" for a quantity that is not measured in joules.

animal hearing:

term	symbol	definition	notes
barely audible signal		A signal that is detected with a 50% success rate.	For specified false alarm probability.[10]
critical bandwidth	B_c	A bandwidth parameter associated with mammal hearing, defined as follows: The signal to noise ratio associated with a barely audible signal (SNR_{ba}) is measured and plotted as a function of noise bandwidth.[11] The SNR_{ba} increases linearly with increasing bandwidth when the bandwidth is low, and levels off when the bandwidth is high. The critical bandwidth is the value of the bandwidth at which the transition between these two types of behaviour takes place.	Based on Au 1993 (see also Ainslie & Verboom 2006) see also critical ratio sometimes reported in decibels as $10\log_{10}B_c$ (units: dB re Hz) Sometimes interpreted as the width of the bandpass filters of a mammal auditory system.
critical ratio	CR	A bandwidth parameter associated with mammal hearing, defined as the difference between the sound pressure level of a barely audible tone and the MSP spectral density level of the background noise at the frequency of that tone.	Based on Au 1993 (see also Ainslie & Verboom 2006) see also critical bandwidth units: dB re Hz Sometimes interpreted as the width of the bandpass filters of a mammal auditory system.
detection threshold			
hearing integration time		A time parameter associated with the response of mammal hearing, defined as the time over which the mammalian auditory system appears to sum acoustic energy.	measurements of hearing integration time can be found in the following: • Zwislocki 1960 • Johnson 1968 • Terhune, 1988 • Gerken, 1990 • Johnson, 1991
hearing level		*in pure-tone audiometry, for a specified method of auditory stimulus presentation at a given frequency* the signal level produced by the stimulus in a specified ear simulator or similar device, minus the appropriate (standardized) REFERENCE EQUIVALENT THRESHOLD LEVEL. In pure-tone air-conduction audiometry, for example, the stimulus is provided by an earphone; the hearing level is then given by subtracting the reference equivalent threshold sound pressure level from the sound pressure level produced by the earphone in an ear simulator. For a correctly calibrated auidiometer, the hearing level equals the dial setting. Compare HEARING THRESHOLD LEVEL. *Units* dB.	verbatim from Morfey 2001 see also hearing threshold level

[10] What is the convention?
[11] What is the definition of "bandwidth" for this application?

term	symbol	definition	notes
hearing threshold level		in pure-tone audiometry, for a specified method of auditory stimulus presentation at a given frequency the threshold of hearing at that frequency, expressed as a HEARING LEVEL in decibels. Units dB. Note: Hearing threshold level depends on the ear under test, whereas hearing level depends only on the audiometric test equipment.	verbatim from Morfey 2001 see also hearing level
sensation level		*in medical physiology, for a tone of a specified frequency* the level of a sound in decibels relative to the threshold level for that frequency for the individual listener.	based on Moore, 2004
weighting function	*W*(*f*)	analogous to A-weighting function in air	e.g., M-weighting (Southall et al 2007)

weighted measures

term	symbol	definition	notes
sound level		For a **continuous signal**, a synonym for weighted SPL.	in a specified frequency band always weighted [10] units: dB re µPa²
weighted MSP	$\mathrm{MSP_w}$	For a **continuous signal**, for a specified frequency band *B*, the quantity $\int_{-B/2}^{+B/2} W(f)Q(f)\,\mathrm{d}f$	in a specified frequency band
weighted RMS pressure	p_w	For a **continuous signal**, the quantity $\sqrt{\mathrm{MSP_w}}$	in a specified frequency band
weighted sound exposure level	$\mathrm{SEL_w}$	For a **transient signal**, the quantity $10\log_{10}\frac{\int_{-\infty}^{+\infty} p_\mathrm{w}(t)^2\,\mathrm{d}t}{p_\mathrm{ref}^2 t_\mathrm{ref}}$	always weighted [12] units: dB re µPa² s. See unweighted sound exposure level.
weighted SPL	$\mathrm{SPL_w}$	For a **continuous signal**, the quantity $10\log_{10}\frac{\int_T p_\mathrm{w}(t)^2\,\mathrm{d}t}{p_\mathrm{ref}^2 T}$	from Morfey 2001

[12] In air, the standard is A-weighted and re 20 µPa.
In water there are no standards. It is suggested to always specify weighting and reference values (time, frequency, pressure)

Characterisation of pulse (suggest characterisation by energy, duration, and bandwidth)

Main parameters (1st pass):

- unweighted sound exposure *E*
- time duration (τ_{50}, τ_{90})
- bandwidth (β_{50}, β_{90})
- peak pressure (& recording bandwidth)
- SNR

Detailed parameters (2nd pass):

- unweighted sound exposure spectral density (in specified frequency bins) vs frequency: dE/df (dB re µPa² s/Hz)
- mean square pressure (in specified time bins) vs time: dE/dt (dB re µPa²)

More detail (3rd pass):

- MSP spectral density (in specified time & frequency bins): $d^2E/dfdt$ (dB re µPa²/Hz)

MSP versus EPWI discussion:

The definitions are cast in terms of mean square pressure (MSP) rather than equivalent plane wave intensity (EPWI), i.e., MSP divided by impedance. This is a deliberate choice intended to remove ambiguity in the definition in situations where the impedance might be unknown or time-dependent (see Ainslie 2008).[13] This might still be an issue for calibration though. Are the DTAGs sensitive to MSP or EPWI?

[13] For example, the effect on sound speed of near surface bubbles caused by breaking waves or a ship wake. Lamarre and Melville 1994 show measurements of a sound speed deficit up to 200 m/s at a depth of 0.75 m (or 800 m/s at 0.5 m).

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Appendix B: BRS-3S terminology (Signal to Noise Ratio)

This appendix lists terms and definitions developed to support behavioural response studies. The definitions have the status of unpublished proposals, largely superseded by ISO 18405. They are included because they might be useful to the process of updating ISO 18405 or developing a new terminology standard for a specific application, and because they are not otherwise publicly available.

BRS-3S collaboration: A common acoustical terminology for behavioural response studies (proposed signal to noise ratio (SNR) definitions)

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It is proposed to develop a joint measurement and data analysis protocol to maximise compatibility between BRS and SSS datasets. The first step to achieve this is to establish a common language. See Ref. [1][15] for more background and proposed definitions for general acoustics, properties of continuous sounds, properties of transient sounds, properties related to animal hearing, and weighted measures of continuous and transient sounds.

Parameters related to SNR were excluded from Ref. [1]. The purpose of the present document is to propose common definitions of these SNR-related parameters, including four possible definitions of SNR itself, from which one is selected.

signal measures

term	symbol	definition	notes
signal averaging bandwidth	B_S	averaging bandwidth used to calculate signal "energy" (i.e., unweighted exposure) and signal MSP	suggest use β_{50} or β_{90}
signal averaging time	T_S	time duration of averaging window used to calculate signal MSP	suggest use τ_{50} or τ_{90}
unweighted signal exposure	E_S	unweighted sound exposure of the signal in a specified bandwidth B_S: $\int_{B_S} \int_{-\infty}^{\infty} Q_S(f,t) \mathrm{d}f \mathrm{d}t$	robust measure of signal
signal MSP	$\overline{p_S^2}$	mean square pressure (MSP) of the signal in a specified bandwidth B_S and specified averaging time T_S: $\frac{1}{T_S} \int_{B_S} \int_{T_S} Q_S(f,t) \mathrm{d}f \mathrm{d}t$	intuitive measure of signal

15 Ref. [1]: Ainslie, Tyack & Wensveen, BRS-3S collaboration: Proposed definitions (DRAFT) v 0.1.5.0 , 27 May 2009

noise measures

term	symbol	definition	notes
averaging bandwidth for noise	B_N	averaging bandwidth used to calculate noise MSP and mean noise spectral density	It is suggested that B_N be chosen equal to B_S, where practical to do so. The option of a different choice is left open in case that should later prove necessary or desirable.
averaging time for noise	T_N	time duration of averaging window used to calculate noise spectral density and noise MSP	It is suggested that the duration T_N be chosen greater than T_S (and earlier in time, i.e., before the signal, not after, to avoid reverberation)
mean noise spectral density	$\overline{D_N}$	the noise spectral density, averaged over a specified bandwidth B_N $\frac{1}{B_N}\int_{B_N} D_N(f)\mathrm{d}f$	robust measure of background (for white noise, independent of B_N)
noise MSP	$\overline{p_N^{\,2}}$	$\frac{1}{T_N}\int_{B_N}\int_{T_N} Q_N(f,t)\mathrm{d}f\mathrm{d}t$	intuitive measure of background
noise spectral density	$D_N(f)$	spectral density of noise[16], averaged over a specified time interval T_N $\frac{1}{T_N}\int_{T_N} Q_N(f,t)\mathrm{d}t$	For statistically stationary noise, independent of T_N

[16] for a specified analysis bandwidth

SNR measures

term	symbol	definition	notes
signal to noise ratio (1a)	R_E	The ratio $$R_\mathrm{E} \equiv \frac{E_S}{D_\mathrm{N}}$$ i.e., $$R_\mathrm{E} = \frac{\int_{B_\mathrm{S}} \int_{-\infty}^{\infty} Q_S(f,t)\,\mathrm{d}f\mathrm{d}t}{\frac{1}{B_\mathrm{N}} \int_{B_\mathrm{N}} D_\mathrm{N}(f)\,\mathrm{d}f}$$	unfiltered noise
signal to noise ratio (1b)	R_Ew	in a specified bandwidth B_S, the quantity[17] $$R_\mathrm{Ew} \equiv \int_{B_\mathrm{S}} \int_{-\infty}^{\infty} \frac{Q_S(f,t)}{D_\mathrm{N}(f)}\,\mathrm{d}f\mathrm{d}t$$	pre-whitened noise
signal to noise ratio (2a)	R_P	The ratio $$R_\mathrm{P} \equiv \frac{\overline{p_\mathrm{S}^{\,2}}}{\overline{p_\mathrm{N}^{\,2}}}$$ i.e., $$R_\mathrm{P} = \frac{\frac{1}{T_\mathrm{S}} \int_{B_\mathrm{S}} \int_{T_\mathrm{S}} Q_S(f,t)\,\mathrm{d}f\mathrm{d}t}{\int_{B_\mathrm{N}} D_\mathrm{N}(f)\,\mathrm{d}f}$$	unfiltered noise
signal to noise ratio (2b)	R_Pw	in a specified bandwidth B_S and specified averaging time T_S, the quantity[18] $$R_\mathrm{Pw} \equiv \frac{1}{B_\mathrm{S} T_\mathrm{S}} \int_{B_\mathrm{S}} \int_{T_\mathrm{S}} \frac{Q_S(f,t)}{D_\mathrm{N}(f)}\,\mathrm{d}f\mathrm{d}t$$	pre-whitened noise

The ratios R_E and R_P are related as follows:

$$\frac{R_\mathrm{E}}{R_\mathrm{P}} = \frac{E_\mathrm{S} B_\mathrm{N} T_\mathrm{S}}{\int_{B_\mathrm{S}} \int_{T_\mathrm{S}} Q_S(f,t)\,\mathrm{d}f\mathrm{d}t}$$

If $T_\mathrm{S} = \tau_x$, it then follows that

$$\frac{R_\mathrm{E}}{R_\mathrm{P}} = \frac{100}{x} B_\mathrm{N} \tau_x \, .$$

[17] for a specified analysis bandwidth

[18] for a specified analysis bandwidth

	pros	cons
R_E	robust (independent of *T*; only weakly dependent on *B*) mimics matched filter	
R_P	intuitive (translates to colour contrast on spectrogram) mimics energy detector	sensitive to choice of *B*, *T*
R_{Ew}	robust mimics matched filter with pre-whitener	sensitive to choice of analysis bandwidth δB
R_{Pw}	intuitive (translates to colour contrast on pre-whitened spectrogram) mimics energy detector with pre-whitener	sensitive to choice of *B*, *T* sensitive to choice of analysis bandwidth δB

Desirable characteristics for the choice of SNR definition are:

- robust to choice of *B*, *T*
- intuitive
- physically meaningful
- biologically meaningful (correlated with animal behaviour)

We propose to adopt R_{Pw} initially. If it turns out to be a good correlate, then we can consider alternatives later. Any practical implementation must average $D_N(f)$ over a small but finite analysis bandwidth. If the chosen bandwidth is too small, there is a risk of unduly weighting regions that happen to have a null in the noise spectrum. The risk can be mitigated by careful choice of analysis bandwidth.

For those who prefer to see definitions cast in logarithmic (decibel) form:

term	abbr.	definition	notes
noise sound pressure level	SPL_N	sound pressure level of the noise in a specified bandwidth and averaging time $\mathrm{SPL}_\mathrm{N} = 10\log_{10} \frac{\overline{p_\mathrm{N}^2}}{p_\mathrm{ref}^2}$	unit: dB re µPa²
noise spectral density level	SDL_N	$10\log_{10} \frac{D_\mathrm{N}(f)}{p_\mathrm{ref}^2 / f_\mathrm{ref}}$	unit: dB re µPa² /Hz
unweighted signal exposure level	SEL_S	unweighted sound exposure level of the signal in a specified bandwidth $10\log_{10} \frac{E_\mathrm{S}}{p_\mathrm{ref}^2 t_\mathrm{ref}}$	unit: dB re µPa² s
signal sound pressure level	SPL_S	sound pressure level of the signal in a specified bandwidth and averaging time $\mathrm{SPL}_\mathrm{S} = 10\log_{10} \frac{\overline{p_\mathrm{S}^2}}{p_\mathrm{ref}^2}$	unit: dB re µPa²
signal to noise ratio in dB (1a)	SNR_E	$\mathrm{SNR}_\mathrm{E} \equiv 10\log_{10} \frac{R_\mathrm{E}}{f_\mathrm{ref} t_\mathrm{ref}}$	unit[19]: dB re Hz s
signal to noise ratio in dB (1b)	SNR_{Ew}	in a specified bandwidth, the quantity $\mathrm{SNR}_\mathrm{Ew} \equiv 10\log_{10} \frac{R_\mathrm{Ew}}{f_\mathrm{ref} t_\mathrm{ref}}$	unit: dB re Hz s
signal to noise ratio in dB (2a)	SNR_P	$\mathrm{SNR}_\mathrm{P} \equiv 10\log_{10} R_\mathrm{P}$	unit: dB
signal to noise ratio in dB (2b)	SNR_{Pw}	in a specified bandwidth and averaging time, the quantity $\mathrm{SNR}_\mathrm{Pw} \equiv 10\log_{10} R_\mathrm{Pw}$	unit: dB

[19] This unit for SNR_E seems strange at first. The purpose of this (proposed) notation is to help reinforce the fact that the ratio R_E is proportional to a product of pulse duration and bandwidth (in the same way that use of ⌠Pa² s / Hz instead of ⌠Pa² s² for energy spectral density helps to convey an energy *divided* by bandwidth).