Underwater Soundscape and Modeling Metadata Standard
Version 1.0

Atlantic Deepwater Ecosystem Observatory Network (ADEON): An Integrated System for Long-Term Monitoring of Ecological and Human Factors on the Outer Continental Shelf

Contract: M16PC00003

Jennifer Miksis-Olds
Lead PI

John Macri
Program Manager

21 May 2018

Approvals: Jennifer Miksis-Olds

Jennifer Miksis-Olds (Lead PI) 21 May 2018
Date

John Macri (PM) 21 May 2018
Date

Underwater Soundscape and Modeling Metadata Standard

Date: 21 May 2018

Ainslie, M.A., Miksis-Olds, J.L., Martin, B., Heaney, K., de Jong, C.A.F., von Benda-Beckmann, A.M., and Lyons, A.P. 2018. *ADEON Underwater Soundscape and Modeling Metadata Standard*. Version 1.0. Technical report by JASCO Applied Sciences for ADEON Prime Contract No. M16PC00003.

Contents

Abbreviations

Non-acoustical abbreviations are listed in Table 1. For acoustical abbreviations see Ainslie et al. (2017).

Table 1 – Non-acoustical abbreviations

Abbreviation	Meaning
ADEON	Atlantic Deepwater Ecosystem Observatory Network
AIS	Automatic Identification System (for shipping)
ANSI	American National Standards Institute
BIPM	International Bureau of Weights and Measures
BOEM	Bureau of Ocean Energy Management
EC	European Commission
EEZ	Exclusive Economic Zone
ESA	Endangered Species Act
EU	European Union
GES	(MSFD) Good Environmental Status
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
ISQ	International System of Quantities
IWC	International Whaling Commission
JASCO	JASCO Applied Sciences
MMPA	Marine Mammal Protection Act
MS	(EU) Member State
MSFD	(EU) Marine Strategy Framework Directive
NA	not applicable
NMFS	NOAA National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OASIS	Ocean Acoustical Services and Instrumentation Systems, Inc.
OCS	outer continental shelf
ONR	Office of Naval Research
PI	principal investigator
SFA	Sustainable Fisheries Act
SI	International System of Units
TG Noise	Technical Group Noise (EU expert group, previously TSG Noise)
TNO	Netherlands Organisation for Applied Scientific Research
UNH	University of New Hampshire
US	United States of America
USNO	US Naval Observatory
UTC	Coordinated Universal Time

1. Introduction

ADEON project

The Atlantic Deepwater Ecosystem Observatory Network (ADEON) for the US Mid- and South Atlantic Outer Continental Shelf (OCS) has been developed and was deployed in the fall of 2017. The lead principal investigator (PI) for this project is Dr. Jennifer Miksis-Olds, University of New Hampshire (UNH). Dr. Miksis-Olds leads a collaborative research team consisting of individuals from UNH, OASIS, TNO, JASCO, Stony Brook University, and NOAA's Southwest Fisheries Science Center.

This observatory network will generate multi-year measurements of both the natural and human factors active in this region, thus informing the ecology and soundscape of the OCS. Long-term observations of living marine resources and marine sound will assist federal agencies, including the Bureau of Ocean Energy Management (BOEM), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA), in complying with mandates in the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Sustainable Fisheries Act (SFA).

Objectives

ADEON project objectives

The ADEON project objectives are to:

- Establish an ecosystem observation network that provides baseline monitoring and supports predictive modeling of the soundscape and its relationship to marine life and the environment of the Mid- and South Atlantic Planning Areas.
- Develop standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks.
- Assess baseline soundscape and ecosystem conditions in support of predictive environmental modeling and trend analyses in the planning areas.
  - How do soundscape and ecosystem components vary with water depth across the OCS?
  - How do the soundscape and ecosystem components vary with latitude along the OCS?
  - Where are the hot spots of human activity for consideration in ecosystem/habitat health impacts?
- Assess the spatial and temporal distribution of the soundscape and biological scatterers, including their expected variation and correlation with distance from the lander locations.
  - What are the environmental factors that define and constrain the horizontal range of appropriate extrapolation of observations measured at the stationary lander sites?
- Develop and apply new methods for the effective visualization of five-dimensional (5D – time, latitude, longitude, frequency, and depth) soundscape data with interactive visual analysis tools that enable users to explore, analyze, and integrate ancillary ecosystem data streams with the 5D soundscape.
- Develop a robust data management system that archives and provides public access to multiple data streams to encourage future development of ecological models targeted at questions beyond the scope of this study.

ADEON standardization objectives

The objectives of ADEON’s Standardization task are to:

- Ensure compatibility within ADEON between soundscapes based on measurements and those based on models;
- Ensure compatibility between measurements made by different researchers or institutes within ADEON;
- Facilitate compatibility between ADEON soundscapes, whether based on measurement or model prediction, and soundscapes produced by a hypothetical future or parallel project within the US Exclusive Economic Zone (EEZ);
- Facilitate compatibility between metrics used to quantify ADEON soundscapes and those used to monitor ambient sound in the context of the EU’s Marine Strategy Framework Directive (MSFD).

Soundscape standard document objectives and scope

This document, the ADEON *Underwater Soundscape and Modeling Metadata Standard*, is the first of five standardization products. Its purpose is to specify a minimum metadata standard for measured and predicted OCS soundscapes in the US EEZ. It is intended to be used as a tool to facilitate direct comparisons between soundscapes reported by different projects. Compliance with this standard in no way precludes calculation of metrics not specified by the standard or of the same metrics in different frequency bands or averaging intervals.

While no minimum monitoring duration is specified (management decisions, including the number of soundscape monitoring stations, their location and duration of monitoring, are outside the scope of this document), for situations in which monitoring takes place over a period of time at the same location, adherence to this standard permits an assessment of changes of the soundscape over that time.

Soundscape monitoring comprises both measurement and modeling components, and these components differ in their temporal and spatial resolution. By their nature, measurements typically have a high temporal resolution and low spatial resolution, whereas model predictions by comparison can have a high spatial resolution but typically low temporal resolution.

The accuracy and precision of measurements are limited by the characteristics of the equipment used, on the way the equipment is deployed and used, and on how the measured data are processed – our (initial) ignorance of the soundscape does not affect our ability to measure it. Prediction of soundscapes is possible by combining available information about underwater sound sources with advanced acoustic propagation models, but the accuracy and precision of model predictions are fundamentally limited by our knowledge of the properties of all sources that contribute to the soundscape. The question then arises of how much information is needed about the presence or absence of any given sound source, and if present the temporal, spatial and spectral distribution of that source.

In many situations it is not known which sources contribute significantly to a given soundscape, and even when the nature of a dominant source can be identified, its location or characteristics are for most sources of interest not known in sufficient detail to match the characteristics of each measured signal, especially for natural and transient sources. Any project aspiring to quantitative validation of soundscape modeling for such sources would need to carry out research to address these shortcomings. The scope of ADEON includes measurement and modeling using state of the art knowledge. It does not include research to extend the state of the art knowledge of sound sources.

In addition to this metadata standard, companion ADEON products specify hardware properties (Martin et al., 2017), guidelines for equipment calibration and deployment (Warren et al., 2017), data processing (Heaney et al., 2017) and terminology (Ainslie et al., 2017). The ADEON Standardization objectives are met by these five products together.

Document structure and terminology

The remainder of this document is structured as follows. In Sec. 2, the meaning of "soundscape" is discussed, and a specific meaning selected for the ADEON project. Quantitative and qualitative soundscape metrics are listed in Secs. 3 and 4, respectively, followed by requirements for reporting soundscape products in Sec. 5. Appendix 1 contains the 2013 Galway Statement on Atlantic Ocean Cooperation.

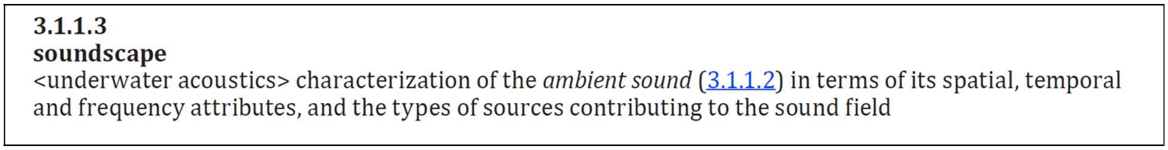
The terminology standard ISO 18405:2017 Underwater Acoustics – Terminology (ISO, 2017) has been adopted by the ADEON project. The main reasons for preferring ISO (2017) over other available terminology standards (e.g., ANSI S1.1-2013 Acoustical Terminology (ANSI, 2013)) are that it has international consensus and was developed specifically for underwater acoustics. For example, sound exposure level (SEL) is by default an unweighted quantity according to ISO (2017), consistent with the way this term is normally used by practitioners of underwater acoustics, whereas ANSI (2013) defines SEL as a weighted quantity, and by default A-weighted, making this ANSI standard less suitable for underwater acoustics applications. Additional terminology specific to soundscapes has been developed and is reflected in the ADEON Terminology Standard (Ainslie et al., 2017). This standard adheres to both ISO (2017) and Ainslie et al. (2017).

The word "shall" is used throughout this document to mean "shall at a minimum", indicating a requirement for compliance with this standard. Similarly the word "should" means "should if possible", indicating a recommendation, not required for compliance with this standard.

2. What is a soundscape?

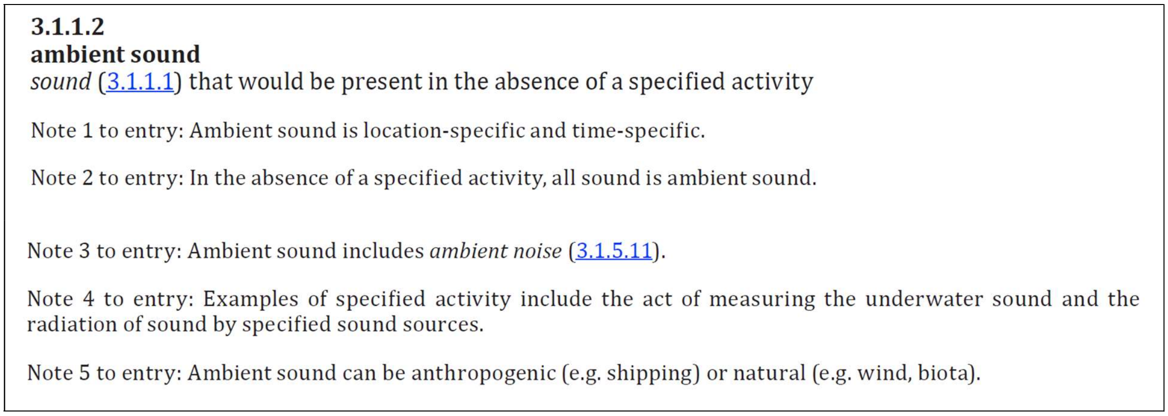
Formal definition

For airborne acoustics, in the context of human hearing, the term "soundscape" usually implies an element of perception of the sound. For example, entry 2.3 of ISO (2014) defines this term as "acoustic environment as perceived or experienced and/or understood by a person or people, in context". However, the same term is used without this implication in contexts other than human hearing, both in air (Pijanowski et al., 2011; Farina et al., 2011; Gage and Axel, 2014) and in water (Fay, 2009; Dugan et al., 2013; Hastings and Širović, 2015; Van Opzeeland and Boebel, 2018). For this reason, the definition of "soundscape" according to the international underwater acoustical terminology standard (ISO, 2017) also excludes a perception element. Following ISO (2017), ADEON therefore defines the terms 'soundscape' and 'ambient sound' as shown in Figure 1 and Figure 2, respectively. The related terms "auditory scene" and "auditory stream" are in use to describe the perception of a soundscape by a listener (Hulse, 2002; Shamma et al., 2011).



3.1.1.3
soundscape
<underwater acoustics> characterization of the *ambient sound* (3.1.1.2) in terms of its spatial, temporal and frequency attributes, and the types of sources contributing to the sound field

Figure 1 – Definition of "soundscape" from ISO (2017).



3.1.1.2
ambient sound
sound (3.1.1.1) that would be present in the absence of a specified activity

Note 1 to entry: Ambient sound is location-specific and time-specific.

Note 2 to entry: In the absence of a specified activity, all sound is ambient sound.

Note 3 to entry: Ambient sound includes *ambient noise* (3.1.5.11).

Note 4 to entry: Examples of specified activity include the act of measuring the underwater sound and the radiation of sound by specified sound sources.

Note 5 to entry: Ambient sound can be anthropogenic (e.g. shipping) or natural (e.g. wind, biota).

Figure 2 – Definition of "ambient sound" from ISO (2017).

Remarks on formal definition

The definition of soundscape excludes non-acoustic pressure fluctuations, such as caused by turbulence or surface gravity waves. It also excludes acoustic self-noise such as the sounds from our ship or equipment, and sounds made by animals within the immediate proximity of the transducer attracted by our presence.

Requirements

In principle there are an infinite number of ways to quantify a sound field or soundscape. In practice we must select between these, and the purpose of this document is to make this choice, guided by inputs from our sponsors (BOEM, ONR, and NOAA), the EU's MSFD, and an international soundscapes workshop held in 2014.

Sponsor guidance

The project sponsors have indicated their interest in the following characteristics of a soundscape:

- Sound pressure time series;
- Root-mean-square (rms) sound pressure and peak sound pressure, including statistics of the rms sound pressure;
- A measure of the anthropogenic addition to the natural background noise (ISO, 2017);
- Ambient noise statistics suitable for estimating ambient noise level and detection threshold with a time-resolution compatible with the capability of modern global physical oceanography models;
- Metrics of relevance to masking or disturbance.

MSFD guidance

The project objective "Develop standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks" requires international cooperation because underwater sound does not respect national boundaries. In addition, the Galway Statement (Appendix 1) announces a cooperation of EU, Canada, and USA intended to advance a shared vision of a "healthy, resilient, safe, productive, understood and treasured" Atlantic Ocean.

To ensure international cooperation with Canada and the EU, it is important to seek international agreement on appropriate acoustical metrics. Compared with sound in air, for which 202 ISO standards have been published since the inception of the ISO Technical Committee TC43 Acoustics in 1947, there exist at the time of writing only three ISO standards relevant to underwater acoustics. Of these three, only one (ISO, 2017) is of direct relevance to soundscapes. In the absence of suitable international standards it makes sense to seek agreement on common metrics with international projects generally and with Canada and the EU, to the extent that suitable acoustical metrics have been specified, or are being specified, by these parties.

The EU's MSFD (EC, 2008) requires its Member States (MS) to achieve or maintain Good Environmental Status (GES) by the year 2020, which implies a requirement for the MS to monitor underwater sound. The MSFD specifies eleven descriptors of GES, one of which (Descriptor 11) specifically addresses underwater noise. GES Descriptor 11[1] is

> *Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment*

In 2010 the European Commission (EC) defined two indicators for Descriptor 11, one (11.1.1) requiring MS to register use of impulsive sound sources, the other (11.2.1) requiring them to monitor underwater sound. Indicator 11.2.1, for "Continuous low frequency sound" reads (EC, 2010)

> *Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate*

The EU expert group set up to advise MS on interpretation (TG Noise) offered the following interpretation of Indicator 11.2.1 (Dekeling et al., 2014a):

> *Trends in the annual average of the squared sound pressure associated with ambient noise in each of two third octave bands, one centred at 63 Hz and the other at 125 Hz, expressed as a level in decibels, in units of dB re 1 µPa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations*

For the annual average, TG Noise proposed processing by which the mean square sound pressure is determined in successive time intervals (temporal observation windows) of duration T. A distribution of temporal observation windows with fixed T is then obtained by collecting them over one or more consecutive years. TG Noise considered the mode, median, arithmetic mean (AM) and geometric mean (GM) of this distribution. Of these, all except the AM were found to depend on the choice of temporal observation window duration T. Because of the need for a robust measure and because there was no consensus on appropriate temporal observation window duration, the AM was therefore recommended for calculating trends based on the annual average. However, recognizing that the temporal observation window duration relevant to impact was likely to be less than a year, TG Noise further recommended to retain a histogram in 1 dB level bins, and the full time history of the root-mean-square sound pressure level (SPL[2]) with a temporal observation window duration not greater than one minute. The full TG Noise (previously known as TSG Noise) recommendation (Dekeling et al., 2014b) reads

---

[1] see http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-11/

[2] SPL is also referred to as Lrms to distinguish this quantity from peak sound pressure level (Lpk).

The advantages and disadvantages of different averaging methods (arithmetic mean, geometric mean, median and mode) are reviewed, and TSG Noise ***recommends that Member States adopt the arithmetic mean****.*

In order to establish the statistical significance of the trend, additional statistical information about the distribution is necessary. TSG Noise recommends that ***complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time****. TSG Noise advises the retention of the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration. TSG Noise advises MS that the snapshot duration should not exceed one minute.*

An example of an SPL time series in the MSFD band centered at 125 Hz, and its corresponding histogram, is shown in Figure 3.

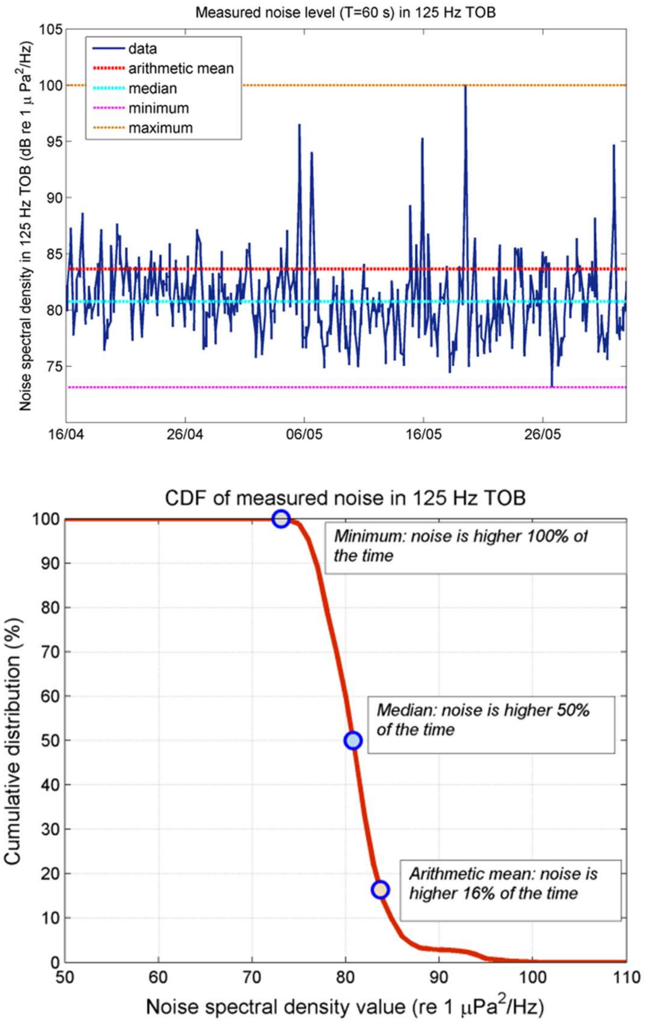


Figure 3 – Upper: Spectral density level time series (blue curve) for a temporal observation window duration of 60 s, also showing the arithmetic mean (red line) and median (cyan line); lower: histogram showing complete distribution, also showing the arithmetic mean, close to the 84th percentile (16 % exceedance level) and the median (50th percentile). UK Crown copyright. Reproduced with permission from Robinson et al. (2014).

The 2010 Commission Decision (EC, 2010) was updated in 2017 (EC, 2017). The 2017 Commission Decision includes the text

> *Annual average, or other suitable metric agreed at regional or subregional level, of the squared sound pressure in each of two '1/3-octave bands', one centred at 63 Hz and the other at 125 Hz, expressed as a level in decibels in units of dB re 1 µPa, at a suitable spatial resolution in relation to the pressure. This may be measured directly, or inferred from a model used to interpolate between, or extrapolated from, measurements. Member States may also decide at regional or subregional level to monitor for additional frequency bands.*

IWC guidance

The international workshop 'Predicting sound fields – Global soundscape modelling to inform management of cetaceans and anthropogenic noise', sponsored by the International Whaling Commission (IWC), the International Quiet Ocean Experiment (IQOE), NOAA, ONR Global, TNO, and the Netherlands Ministry of Infrastructure and the Environment, was held in Leiden (the Netherlands) on 15-16 April 2014. The purpose of the workshop was to discuss sound modeling and mapping methodologies, to assess data needs, and to make recommendations for further development of existing techniques. The workshop report (IWC, 2014) makes the following recommendations

- *Record for 1 minute at least once per hour*
- *Compute daily sound level statistics*
- *Compute the arithmetic mean … in each 1/3 octave band from 10-1000 Hz for every 24h period*
- *Compute percentile power spectrum density levels (10th , 25th , 50th , 75th , 90th) in each 1/3 octave band from 10-1000 Hz, in 1-minute windows, for every 24-hour period.*

3. Quantitative soundscape metrics

In this section we specify the quantitative characteristics (metrics) that make up a soundscape. Practical considerations mean that what is measured is not identical to what is modeled. For example, measurements typically have high temporal resolution and low spatial resolution. Conversely, model predictions are capable of high spatial resolution, while their temporal resolution is limited.

Metrics derived from the sound pressure are used to describe a soundscape. Sound pressure is widely quantified in terms of its root-mean-square or peak values (Figure 4), often as a level in decibels. A higher order metric, less widely used, is kurtosis.

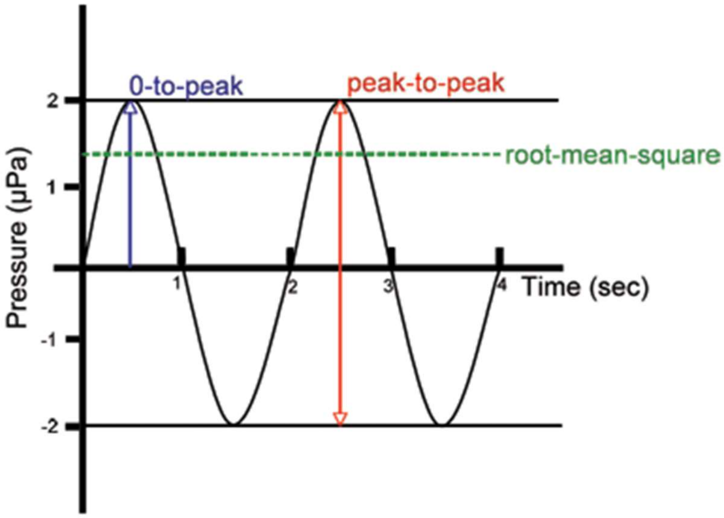


Figure 4 – Sound pressure time series with a zero-to-peak sound pressure (i.e., amplitude) of 2 μPa, peak-to-peak sound pressure of 4 μPa and rms sound pressure of $\sqrt{2}$ μPa). Reproduced with permission from the Discovery of Sound in the Sea website[3].

Specific metrics selected include the mean-square sound pressure level (Lrms), $L_{p,\mathrm{rms}}$, zero-to- peak sound pressure level (abbreviated peak sound pressure level, or Lpk), $L_{p,\mathrm{pk}}$,

$$L_{p,\mathrm{rms}} = 10\,\mathrm{lg}\frac{p_{\mathrm{rms}}^2}{p_0^2}\ \mathrm{dB}$$

$$L_{p,\mathrm{pk}} = 10\,\mathrm{lg}\frac{p_{\mathrm{pk}}^2}{p_0^2}\ \mathrm{dB},$$

where $p_0 \ = \ 1\ \mu\mathrm{Pa}$ is the reference sound pressure. Also selected is the kurtosis, β

$$\beta = \frac{\mu_4}{\mu_2^2},$$

where μ_2 and μ_4 are the second and fourth moments of a quantity $x(t)$

$$\mu_2 = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} [x(t) - \bar{x}]^2\,\mathrm{d}t$$

$$\mu_4 = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} [x(t) - \bar{x}]^4\,\mathrm{d}t.$$

The time-dependent quantity $x(t)$ is either the sound pressure, $x(t) = p(t)$, or the magnitude of the analytic signal, $x(t) = |q(t)|$, and $\bar{x}$ is the mean value of $x(t)$ between t_1 and t_2. The analytic signal $q(t)$ is a complex function whose real part is the sound pressure $p(t)$ and whose imaginary part is the Hilbert transform of the sound pressure $h(t)$ (ISO, 2017)

$$q(t) = p(t) + \mathrm{i}h(t).$$

---

[3] https://dosits.org/science/advanced-topics/introduction-to-signal-levels/

Particle motion is also relevant, especially for sensing of sound by fish and invertebrates, and for this reason the ADEON project plans to deploy receivers sensitive to particle motion. However, the study of particle motion is considered not yet sufficiently advanced for formal standardization, and is therefore excluded from the scope of this document.

Unlike for air acoustics, which has undergone widespread standardization since the late 1940s, the process of international standardization in underwater acoustics started only recently, in the early 2010s. As a result, standards for measurement, modeling, or data processing for underwater acoustics are virtually non-existent. In particular, no widely accepted value for temporal observation window duration exists for underwater sound (nor for airborne sound applied to non-human animals). Therefore, the time window (temporal observation window duration) over which the various statistics are calculated needs to be specified.

Sound metrics shall be provided as a function of time. The use of such time series for underwater noise management is outside the scope of the ADEON project.

Statistics

Arithmetic mean (AM)

Consider a temporal observation window i, during which the mean-square sound pressure, averaged over the temporal observation window duration T_i is Q_i $(Q_i = \overline{p^2})$

$$Q_i = \frac{1}{T_i} \sum_j p_{i,j}^2,$$

where p_{ij} is the jth sample of the ith temporal observation window.

The sound pressure level (Figure 3) is the level of the arithmetic mean of squared sound pressure samples

$$L_{p,\mathrm{a}} = 10 \lg \frac{Q_\mathrm{a}}{Q_0} \mathrm{dB},$$

where Q_0 = 1 μPa^2 and

$$Q_\mathrm{a} = \frac{\sum_{i=1}^{N} w_i Q_i}{\sum_{i=1}^{N} w_i}.$$

The individual mean-square sound pressures Q_i are weighted by w_i. This weighting factor is normally equal to 1. One exception is for combining contributions from unequal duration months to form an annual average. Assuming stationary statistics, a non-unity weighting would also be appropriate to compensate for planned or unplanned downtime (for example, when constructing a one-hour average from six 5-minute samples at a 50 % duty cycle). Stationarity could be tested by deliberately omitting selected temporal observation windows, adjusting the weights accordingly, and comparing the resulting AM with that computed with all recorded temporal observation windows.

For the case $w_i = 1$ the weighted mean simplifies to the unweighted arithmetic mean, i.e.,

$$Q_\mathrm{a} = \frac{1}{N} \sum_1^N Q_i.$$

An important benefit of the AM is that its value is independent of the choice of temporal observation window duration.

Geometric mean (GM)

In the same way that Q_a is the AM of the individual Q_i values, we introduce Q_g as the GM of the Q_i. The weighted geometric mean (GM) of the temporal observation window Q_i values, Q_g , is related to the individual Q_i by

$$\log\frac{Q_\mathrm{g}}{Q_0} = \frac{\sum_{i=1}^{N} w_i \log\frac{Q_i}{Q_0}}{\sum_{i=1}^{N} w_i}.$$

For the case $w = 1$ the expression for $\log\left(Q_\mathrm{g} / Q_0\right)$ simplifies to the unweighted geometric mean

$$\log\frac{Q_\mathrm{g}}{Q_0} = \frac{1}{N}\sum_{1}^{N} \log\frac{Q_i}{Q_0}$$

The logarithm can be any base, but it simplifies conversion to decibels if base 10 is chosen. Specifically:

$$L_{p,\mathrm{g}} = 10\,\mathrm{lg}\frac{Q_\mathrm{g}}{Q_0}\,\mathrm{dB}$$

$$\therefore L_{p,\mathrm{g}} = \frac{10\ \mathrm{dB}}{N}\sum_{1}^{N} \mathrm{lg}\frac{Q_i}{Q_0} = \frac{1}{N}\sum_{1}^{N} 10\,\mathrm{lg}\frac{Q_i}{Q_0}\,\mathrm{dB}.$$

The GM is defined for completeness, primarily to clarify the difference between AM and GM. It is not used further in this standard.

Cumulative distribution function

The empirical cumulative probability distribution function (abbreviated cdf) provides temporal level percentiles (Figure 3). It is a cumulative histogram of the individual L_i values:

$$L_{p,i} = 10\,\mathrm{lg}\frac{Q_i}{Q_0}\,\mathrm{dB}.$$

The cdf resolution shall be sufficient to extract at least the 10th, 25th, 50th, 75th and 90th temporal level percentiles. Where the number of samples is sufficiently high, the 1st, 5th, 95th and 99th temporal level percentiles should be considered. TG Noise (Dekeling et al., 2014b) advises a bin size no larger than 1 dB.

In the following, soundscape products are considered first for measurements, then for predictions.

Measurements

Metrics

Measured soundscape metrics are listed in Table 2 . Where 'AM' is stated, the arithmetic mean (AM) of the mean-square sound pressure values is calculated within a specified temporal observation window, and expressed as a level in a decidecade band, $L_{p,\mathrm{ddec}}$, in decibels. A decidecade (symbol ddec), defined as one tenth of a decade, is sometimes referred to as a "one-third octave" because it is approximately equal to one third of an octave. The AM is expected to vary horizontally along each row, whereas its value in any one column should be a constant. The purpose in including the AM in every row is to provide a consistency check. Where 'cdf' is stated in a cell, it is calculated for all variables listed in the leading diagonal of that cell's row. In addition to its robustness (percentiles are sensitive to the choice of averaging time and therefore less robust), a further advantage of the AM is the simple way the resulting sound pressure level $L_{p,T}$ is related to sound exposure level $L_{E,T}$ via the averaging (or integration) time T:

$$L_{E,T} = L_{p,T} + 10\lg\frac{T}{t_0}\ \mathrm{dB}.$$

For temporal observation window durations of 60 s or longer, the full time series of each variable shall be stored.

For temporal observation window durations of 1 s or longer, the full time series of each variable should be stored.

Soundscape products shall incorporate temporal observation window durations of one second (1 s), one minute (1 min = 60 s), one hour (1 h = 3600 s), one day (1 d = 24 h), one month (1 mo), and one year (1 a) and are chosen because of their correspondence with the way humans experience and report time. Where there is interest in the perception of sound, whether with regard to audibility, masking or loudness, a temporal observation window duration, δt_{H}, should be chosen to be of relevance to the form of perception of interest. Possible values of δt_{H} range from a few hundred microseconds in connection with the detection of echolocation clicks (Vel'min and Dubrovskii, 1976; Moore et al., 1984; see also Branstetter et al., 2007) to a few hundred milliseconds for detection of other signals in noise (see Madsen, 2005; Kastelein et al., 2010a; 2010b and references therein). For this purpose it is desirable to select simple sub-multiples of one second such as (say) 500 μs, 20 ms or 100 ms, such that an integer number of samples could be combined to recreate the statistics of a 1-s temporal observation window. While we consider it premature to recommend a value, based on audibility measurements on two harbor seals (Kastelein et al., 2010b) and a beluga whale (Johnson, 1991), possible choices include values in the range 10 to 50 ms.

Table 2 – Temporal analysis and observation window truth table: soundscape measurement products. Pale blue shading indicates optional metrics.

	Temporal analysis window duration						
Temporal observation window duration	δt_{H}	**1 s**	**60 s**	**1 h**	**24 h**	**1 mo**	**1 a**
$\delta t_{\mathrm{H}} < 1$ s (optional)	$L_{p,\mathrm{ddec},\delta t_{\mathrm{H}}}$ $L_{p,\mathrm{pk},\delta t_{\mathrm{H}}}$ $\beta_{\delta t_{\mathrm{H}}}$	AM	AM, cdf	AM, cdf	AM, cdf	AM, cdf	AM, cdf
1 s		$L_{p,\mathrm{ddec,1s}}$ $L_{p,\mathrm{pk,1s}}$ β_{1s}	AM	AM, cdf	AM, cdf	AM, cdf	AM, cdf
60 s			$L_{p,\mathrm{ddec,60s}}$ $L_{p,\mathrm{pk,60s}}$ β_{60s}	AM	AM, cdf	AM, cdf	AM, cdf
1 h				$L_{p,\mathrm{ddec,1h}}$	AM	AM, cdf	AM, cdf
24 h					$L_{p,\mathrm{ddec,24h}}$ $L_{E,\mathrm{ddec,24h}}$ $L_{E,\mathrm{w,24h}}$	AM	AM, cdf
1 mo						$L_{p,\mathrm{ddec,1mo}}$	AM
1 a							$L_{p,\mathrm{ddec,1a}}$

For decidecade bands whose index is less than -20 (see Table 5, on page 19), the acoustic period is comparable with (and in some cases greater than) 1 s, making the choice of a 1-second temporal observation window duration questionable. For this reason, the 1-second temporal observation window duration is optional for frequency bands comprising decidecade bands with $n < -20$.

If weekly or seasonal averages are desired, these can be calculated from daily or monthly averages, respectively.

Finally, a duration of 200 s is of historical importance to facilitate comparisons with the records resulting from pioneering measurements by G. Wenz in the 1960s, for example at Point Sur (see Andrew et al., 2002), at San Nicolas Island (see McDonald et al., 2006), and at San Clemente Island (see McDonald et al., 2008). This duration can be approximated by combining three consecutive sixty-second samples to make a single 180 s sample using the equation

$$L_{p,\Delta f,180\mathrm{s}} = 10\lg\frac{\frac{1}{3}\sum_{i=N}^{N+2} Q_{\mathrm{a},i,60\mathrm{s}}}{Q_0}\,\mathrm{dB},$$

where

$$Q_{\mathrm{a},i,60\mathrm{s}} = Q_0 10^{L_{p,\Delta f,60\mathrm{s}}/(10\ \mathrm{dB})}.$$

The statistics for a 180 s averaging time are expected to be similar to those for a 200 s averaging time. If an averaging time of precisely 200 s is desired (for example to quantify the expected small differences between them), this can be achieved (assuming the recommendation to store all 1-s windows is followed) by averaging instead over 200 consecutive one-second samples:

$$L_{p,\Delta f,200\mathrm{s}} = 10\lg\frac{\frac{1}{200}\sum_{i=N}^{N+199} Q_{\mathrm{a},i,1\mathrm{s}}}{Q_0}\,\mathrm{dB},$$

where

$$Q_{\mathrm{a},i,1\mathrm{s}} = Q_0 10^{L_{p,\Delta f,1\mathrm{s}}/(10\ \mathrm{dB})}.$$

Monthly and annual statistics of 1 d temporal observation windows

The daily temporal observation windows place special emphasis on the weighted sound exposure level (SELw) because of the 24-hour integration time recommended by Southall et al. (2007) and NMFS (2016).

The choice of weighting should permit selection between (for example) M weighting (Southall et al., 2007), current National Marine Fisheries Service (NMFS) weighting (NMFS, 2016) and flat weighting in specified standard frequency bands. Further, the weighting should be flexible enough to incorporate improved knowledge as it becomes available – see Houser et al. (2017) for a thorough review of frequency weighting functions.

Individual (unweighted) decidecade band levels shall be stored in such a way as to permit appropriate frequency weighting in the future as understanding of animal hearing improves.

The selected weighting function(s) shall be specified for this study whenever derived products are provided.

Daily, monthly and annual statistics of 60 s temporal observation windows

The one minute temporal observation windows are used to construct a cdf of temporal level percentiles.

Broadband quantities

Peak sound pressure level (Lpk) and sound pressure kurtosis are broadband quantities and shall be reported in one or more of the decade or multi-decade frequency bands specified below (see Table 6). Broadband Lrms, SEL and SELw shall be reported in the same frequency band (or bands). The band (or bands) shall be specified.

Spectral and temporal correlation functions

Characterization of spectral and temporal correlations will be specified in the data processing standard (Heaney et al., 2017).

Summary of measurement products

The main soundscape measurement products are:

- Monthly and annual statistics of 24 h temporal observation windows (e.g., SELw);
- Hourly, daily, monthly and annual statistics of 60 s temporal observation windows (e.g., Lrms);
- Hourly, daily statistics of 1 s temporal observation windows (e.g., Lrms).

Predictions

Metrics

Predictions combining available source information with acoustic propagation model calculations are used to improve spatial resolution, permitting the creation of soundscapes, albeit at a lower temporal resolution than is potentially available from measurements. There is therefore more emphasis on spatial statistics.

For predictions the short time scales (variability at scales less than a minute) are excluded because these are unpredictable in the sense that even with state of the art tools, prediction of such quantities is considered unreliable. Similarly, kurtosis and Lpk are excluded as they too are unpredictable, in the same sense. The predictions therefore focus on Lrms and its statistics for temporal observation window durations of 60 s and longer, and SEL and its statistics for a temporal observation window duration of 24 h. Modeled soundscape products are listed in Table 3. The weighted sound exposure level integrated over 24 hours, $L_{E,\mathrm{w},24\mathrm{h}}$, is optional.

Table 3 – Temporal analysis and observation window truth table: prediction products. Pale blue shading indicates optional metrics (see text for clarification).

	Temporal analysis window duration				
Temporal observation window duration	**60 s**	**1 h**	**24 h**	**1 mo**	**1 a**
60 s	$L_{p,\mathrm{ddec},60\mathrm{s}}$	AM	AM, cdf	AM, cdf	AM, cdf
1 h		$L_{p,\mathrm{ddec},1\mathrm{h}}$	AM	AM, cdf	AM, cdf
24 h			$L_{p,\mathrm{ddec},24\mathrm{h}}$ $L_{E,\mathrm{ddec},24\mathrm{h}}$	AM	AM, cdf
1 mo				$L_{p,\mathrm{ddec},1\mathrm{mo}}$	AM
1 a					$L_{p,\mathrm{ddec},1\mathrm{a}}$

High resolution temporal modeling should be performed at spatial positions of special interest (for example, selected measurement positions). For temporal observation window durations of 60 s or longer, the full time series of each variable should be stored. For at least one spatial position of special interest the full time series of each variable shall be stored for temporal observation window durations of 1 h and longer. Temporal observation windows of different durations are needed because it is not known in advance which ones will be needed by users of the soundscape products.

Spatial percentiles

Measurements at a fixed location provide high temporal resolution but no information about spatial variation evaluation of spatial percentiles.

Spatial statistics shall be predicted according to Table 4 for a spatial observation window of either 100 km^2 or 1000 km^2, and one or more spatial analysis windows selected from 1000 km^2, 10 000 km^2 and 100 000 km^2. The analysis will be carried out in a volume given by the specified area and a range of depths to be determined. Local geography may result in small departures from these precise values. Any such departure from the precise value shall be explained.

These spatial statistics shall be calculated for a specified temporal observation window duration. This temporal observation window duration shall be one of the durations from Table 3, i.e., one of 60 s, 1 h, 24 h, 1 mo and 1 a.

Table 4 – Spatial analysis and observation window truth table: prediction products (for a fixed temporal observation window duration to be specified). All metrics are optional, but at least one of the green-shaded cells is required (see text for clarification). The integer index refers to the power of 10 corresponding to the spatial observation window area in square kilometers. The stated values are applicable to basin or OCS-scale predictions; finer scale (up to 1 km^2 resolution) should be provided around the mooring positions.

	Spatial analysis window area					
Spatial observation window area/ km^2	**10 km^2**	**100 km^2**	**1000 km^2**	**10 000 km^2**	**100 000 km^2**	**1000 000 km^2**
10	$L_{p,\mathrm{ddec},1}$	AM	AM, cdf	AM, cdf	AM, cdf	AM, cdf
100		$L_{p,\mathrm{ddec},2}$	AM	AM, cdf	AM, cdf	AM, cdf
1000			$L_{p,\mathrm{ddec},3}$	AM	AM, cdf	AM, cdf
10 000				$L_{p,\mathrm{ddec},4}$	AM	AM, cdf
100 000					$L_{p,\mathrm{ddec},5}$	AM
1000 000						$L_{p,\mathrm{ddec},6}$

Temporal correlation functions

Characterization of temporal correlations will be specified in the data processing standard (Heaney et al., 2017).

Spatial correlation functions

Characterization of spatial correlations will be specified in the data processing standard (Heaney et al., 2017).

Summary of prediction products

The main soundscape prediction products are:

- Monthly and annual statistics of 24 h temporal observation windows;
- Daily, monthly and annual statistics of 1 h temporal observation windows.

The spatial window is to be determined.

Practical choices

Decidecade bands

Decidecade bands shall be used.[4] More specifically frequency bands of IEC (2014) are used, consistent also with ANSI (2016a). According to IEC (2014) the decidecade center frequencies f_c are

$$f_{\mathrm{c},n} = (1\ \mathrm{kHz})\ 10^{\frac{n}{10}}.$$

Upper and lower frequencies are respectively 0.5 ddec above and below the center frequency, namely

$$f_{\mathrm{max},n} = f_{\mathrm{c},n}\ 10^{\frac{1}{20}}$$

$$f_{\mathrm{min},n} = f_{\mathrm{c},n}\ 10^{-\frac{1}{20}}.$$

Table 5 shows decidecade (ddec) bands according to IEC (2014),[5] for decidecade frequency bands with center frequencies 1 Hz ($n = -30$) Hz to 1 MHz ($n = +30$). Center frequencies of nominal octave bands (the precise bandwidth of which is 3 ddec) are **bold.**

Table 5 – Decidecade frequency bands, as defined by IEC (2014), with center frequencies between 1 Hz ($n = -30$) and 1 MHz ($n = +30$). Band edge and center frequencies are stated to 5 significant figures. Alternate light and dark shading shows decade bands A to F specified in Table 6.

Band index	**Lower bound**	**Center frequency**	**Upper bound**	**(Nominal center frequency)**
n	f_min /Hz	f_c /Hz	f_max /Hz	$f_\mathrm{c,nom}$
-30	0.89125	**1.0000**	1.1220	(1 Hz)
-29	1.1220	1.2589	1.4125	(1.25 Hz)
-28	1.4125	1.5849	1.7783	(1.6 Hz)
-27	1.7783	**1.9953**	2.2387	(2 Hz)
-26	2.2387	2.5119	2.8184	(2.5 Hz)
-25	2.8184	3.1623	3.5481	(3.2 Hz)
-24	3.5481	**3.9811**	4.4668	(4 Hz)
-23	4.4668	5.0119	5.6234	(5 Hz)
-22	5.6234	6.3096	7.0795	(6.3 Hz)
-21	7.0795	**7.9433**	8.9125	(8 Hz)
-20	8.9125	10.000	11.220	(10 Hz)
-19	11.220	12.589	14.125	(12.5 Hz)
-18	14.125	**15.849**	17.783	(16 Hz)
-17	17.783	19.953	22.387	(20 Hz)
-16	22.387	25.119	28.184	(25 Hz)
-15	28.184	**31.623**	35.481	(32 Hz)
-14	35.481	39.811	44.668	(40 Hz)
-13	44.668	50.119	56.234	(50 Hz)
-12	56.234	**63.096**	70.795	(63 Hz)
-11	70.795	79.433	89.125	(80 Hz)
-10	89.125	100.00	112.20	(100 Hz)

---

[4] A decidecade is defined as one tenth of a decade (ISO, 2017).

[5] A decidecade is approximately equal to one third of an octave, and for this reason is referred to by IEC (2014) as a "one-third octave".

Band index	**Lower bound**	**Center frequency**	**Upper bound**	**(Nominal center frequency)**
-9	112.20	**125.89**	141.25	(125 Hz)
-8	141.25	158.49	177.83	(160 Hz)
-7	177.83	199.53	223.87	(200 Hz)
-6	223.87	**251.19**	281.84	(250 Hz)
-5	281.84	316.23	354.81	(320 Hz)
-4	354.81	398.11	446.68	(400 Hz)
-3	446.68	**501.19**	562.34	(500 Hz)
-2	562.34	630.96	707.95	(630 Hz)
-1	707.95	794.33	891.25	(800 Hz)
0	891.25	**1000.0**	1122.0	(1 kHz)
1	1122.0	1258.9	1412.5	(1.25 kHz)
2	1412.5	1584.9	1778.3	(1.6 kHz)
3	1778.3	**1995.3**	2238.7	(2 kHz)
4	2238.7	2511.9	2818.4	(2.5 kHz)
5	2818.4	3162.3	3548.1	(3.2 kHz)
6	3548.1	**3981.1**	4466.8	(4 kHz)
7	4466.8	5011.9	5623.4	(5 kHz)
8	5623.4	6309.6	7079.5	(6.3 kHz)
9	7079.5	**7943.3**	8912.5	(8 kHz)
10	8912.5	10000	11220	(10 kHz)
11	11220	12589	14125	(12.5 kHz)
12	14125	**15845**	17783	(16 kHz)
13	17783	19953	22387	(20 kHz)
14	22387	25119	28184	(25 kHz)
15	28184	**31623**	35481	(32 kHz)
16	35481	39811	44668	(40 kHz)
17	44668	50119	56234	(50 kHz)
18	56234	**63096**	70795	(63 kHz)
19	70795	79433	89125	(80 kHz)
20	89125	100000	112200	(100 kHz)
21	112200	**125890**	141250	(125 kHz)
22	141250	158490	177830	(160 kHz)
23	177830	199530	223870	(200 kHz)
24	223870	**251190**	281840	(250 kHz)
25	281840	316230	354810	(320 kHz)
26	354810	398110	446680	(400 kHz)
27	446680	**501190**	562340	(500 kHz)
28	562340	630960	707950	(630 kHz)
29	707950	794330	891250	(800 kHz)
30	891250	**1000000**	1122000	(1 MHz)

Remark on ISO, IEC and ANSI terminology for fractional octave and fractional decade bands

Both IEC (2014) and ANSI (2016a) use the term “one-third octave” to mean one tenth of a decade, while ISO (2017) uses the term “decidecade” for the same quantity. We follow ISO (2017), which defines “one-third octave” as one third of an octave and “decidecade” as one tenth of a decade. An alternative term for decidecade is “one-third octave (base 10)”.

Decade and multi-decade bands

One of the ADEON project objectives is to develop "standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks." To meet this objective we need to be able to compare like with like not just within ADEON but also with other projects outside our control. This implies a need to specify precise frequency bands that are both useful and achievable. The decidecade is used as a basic building block for broadband quantities because decidecade bands are well defined (IEC, 2014) and are being adopted by EU MS in connection with the MSFD.

For a decidecade band it suffices to specify the index of that band (**Table 5**) and temporal observation window duration. For other quantities we need to specify upper and lower frequency limits, but on its own that does not meet our objective, because if another project chooses a different band (or averaging time), a like comparison is no longer possible. At some stage we therefore need to prescribe the frequency band. Requirements for this frequency band are that it should be:

- Broad enough such that properties like peak sound pressure and kurtosis provide meaningful correlates with potential effects on aquatic life;
- Narrow enough to be achievable by another present or future project (e.g., US or EU) with comparable but not identical resources, such that it would be reasonable for a regulator to require it of others.

We suggest that a one decade band or wider (with each decade comprising 10 contiguous decidecade bands) meets both requirements, while accepting that there needs to be some flexibility in the precise choice of decade. In Table 6 we specify a selection of named decade and multi-decade bands from which to choose, according to local requirements and equipment availability.

Table 6 – Decade and multi-decade frequency bands.

Name of frequency band	**Index n_{min} of lowest decidecade**	**Lower frequency limit (5 sig. figs.)**	**Index n_{max} of highest decidecade**	**Upper frequency limit (5 sig. figs.)**	**Number of decades**
band A	-30	0.89125 Hz	-21	8.9125 Hz	1
band B	-20	8.9125 Hz	-11	89.125 Hz	1
band C	-10	89.125 Hz	-1	891.25 Hz	1
band D	0	891.25 Hz	+9	8.9125 kHz	1
band E	+10	8.9125 kHz	+19	89.125 kHz	1
band F	+20	89.125 kHz	+29	891.25 kHz	1
band AB	-30	0.89125 Hz	-11	89.125 Hz	2
band BC	-20	8.9125 Hz	-1	891.25 Hz	2
band CD	-10	89.125 Hz	+9	8.9125 kHz	2
band DE	0	891.25 Hz	+19	89.125 kHz	2
band EF	+10	8.9125 kHz	+29	891.25 kHz	2
band AC	-30	0.89125 Hz	-1	891.25 Hz	3
band BD	-20	8.9125 Hz	+9	8.9125 kHz	3
band CE	-10	89.125 Hz	+19	89.125 kHz	3
band DF	0	891.25 Hz	+29	891.25 kHz	3
band AD	-30	0.89125 Hz	+9	8.9125 kHz	4
band BE	-20	8.9125 Hz	+19	89.125 kHz	4
band CF	-10	89.125 Hz	+29	891.25 kHz	4

band AE	-30	0.89125 Hz	+19	89.125 kHz	5
band BF	-20	8.9125 Hz	+29	891.25 kHz	5
band AF	-30	0.89125 Hz	+29	891.25 kHz	6

On its own the existence of this table is not enough to ensure compatibility. If one project chooses to report broadband quantities in decade band CD (89.1 Hz to 8.91 kHz) while another selects band DE (891 Hz to 89.1 kHz), a quantitative inter-project comparison of such broadband quantities would still not be possible. Therefore there remains a need to encourage cross-project co-ordination to ensure compatibility.

Broadband quantities such as peak sound pressure level and kurtosis shall be reported in one or more of the standard frequency bands specified in Table 6. Each band spans an integer number (between 1 and 6) of contiguous decades. The selected band shall be specified. Frequencies outside the specified reporting band shall be removed, using appropriate filters. The choice of band should take into consideration both local conditions and the need for compatibility with other projects.

Choice of frequencies for model predictions

Decidecade band predictions shall include:

- At least three bands with center frequencies selected from Table 5;
- At least one band with nominal center frequency above 200 Hz (index $n > -7$);
- At least one band with nominal center frequency below 100 Hz (index $n < -10$);
- At least one out of the two bands with nominal center frequencies 63 Hz and 125 Hz.

Decidecade band predictions should include the bands with nominal center frequencies 16 Hz, 32 Hz, 63 Hz, 125 Hz, 250 Hz and 500 Hz.

The bands should consider the local fauna and select additional bands accordingly. For example if the presence of fin whale calls is known or suspected, the decidecade band centered at 20 Hz band should be modeled.

Duration of temporal observation windows and analysis windows

Second, minute and hour

Short durations of up to one day (1 d) shall be expressed in units of seconds, minutes or hours. The second is the SI unit of time (BIPM, 2014), while the minute, hour and day are defined in terms of the second (Table 7). Longer durations may be expressed either in these SI-compatible units or in units of days, months or years. Ambiguities in these longer units are discussed in turn below.

Table 7 – Units of time used to report ADEON statistics (ISO, 2006)

Unit	Symbol	Definition	Duration	Notes
second	s	duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom	1 s	SI base unit (BIPM, 2014)
minute	min	60 s	60 s	exact (BIPM, 2014)

Unit	Symbol	Definition	Duration	Notes
hour	h	60 min	60 min	exact (BIPM, 2014) 60 min = 3600 s
day	d	24 h	24 h	exact (BIPM, 2014) 24 h = 86 400 s
UTC month	mo	one calendar month	28 d to 31 d	the use of unequal month durations introduces a risk that selected statistics might be distorted (for example, the number of extreme events will be larger on average in long months than in short ones)
UTC year	a	one calendar year	365 d or 366 d	

Day

The day is defined by BIPM as 24 hours (86 400 s), almost identical to the UTC calendar day, which can differ from 86 400 s because of occasional leap second adjustments to UTC. This variation is considered negligible by the present authors, and no further distinction is made in this document between the UTC day and the BIPM day.

Month

The UTC calendar month varies between 28 and 31 days, a variation of up to about 10 % (Table 8). Specifically, departures from a mean Julian month of 730.5 h are between -8 % (28 d = 672 h) and +2 % (31 d = 744 h). Such a variation in temporal observation window duration or analysis window can lead to statistical artefacts caused only by the difference in this duration.[6] To avoid this risk one could instead construct statistics of equal sized (Julian) months by combining 43 830 consecutive one-minute temporal observation windows. Compliance with this ADEON standard requires reporting statistics in UTC calendar months.

Table 8 – Variations in the duration of a "month", including UTC calendar months and mean Julian month.

Duration / days	Duration / hours	Notes
28	672	February (non-leap years)
29	696	February (leap years)
30	720	even months, except February
365.25/12 = 30.4375	730.5	mean Julian month
31	744	odd months

Year

The UTC calendar year is either 365 or 366 days. This one day variation amounts to less than 0.3 %, which the present authors consider unlikely to lead to statistically significant artefacts.

---

[6] For identical weather conditions, the probability of a storm occurring in January is greater than that of a storm in February. Therefore, on average one can expect a higher value for the 99th percentile wave height in January than in February. For the same reason, on average one would expect to encounter a higher value for the 99th percentile sound pressure level in January than in February, even for statistically identical acoustical conditions.

Conversion to local time

Conversion from UTC to local time is optional, and sometimes desirable, with the time relative to dawn or dusk being of particular relevance. Nautical definitions of dawn and dusk shall be used.

Nautical dawn occurs when the sun is 12° below the horizon to sunrise. Nautical dusk occurs when the sun is 12° below the horizon to sunset (Leroy et al., 2016). Precise times of sunrise and sunset can be found at US Naval Observatory Astronomical Applications Department website (USNO, 2011).[7]

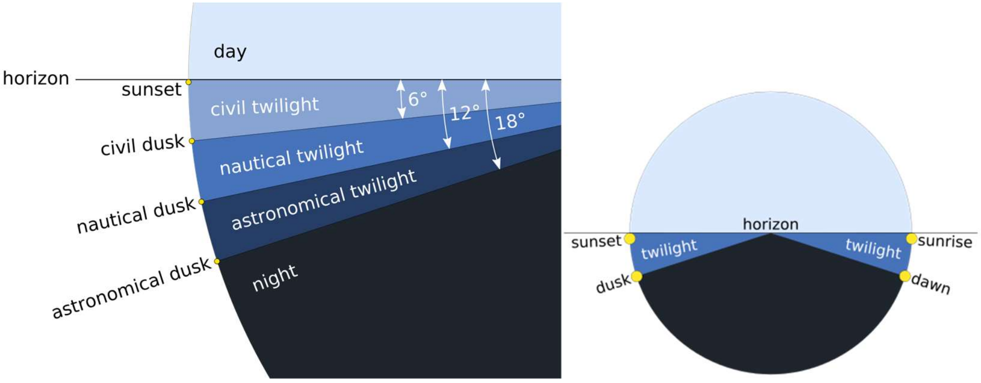


Figure 5 – Definition of dusk and dawn (source: https://en.wikipedia.org/wiki/Dawn[8]). The nautical definitions of dusk and dawn shall be used.

Duty cycle

For sampling rates up to 100 kHz (Nyquist frequency up to 50 kHz), the recording duty cycle shall be not less than three minutes in every hour.

Duty cycle (proportion of planned recording time, e.g., twenty minutes every hour) shall be specified.

Downtime (e.g., lost time due to maintenance or equipment failure) shall be specified.

Receiver depths

Receiver depths for measurements shall be chosen according to Warren et al. (2017).

Receiver depths for predictions shall comply with IWC guidelines (IWC, 2014):

> *In order to characterize the heterogeneity of the sound field in any one modelled geographic location, and allow assessment of the predicted sound fields to which marine life living at or diving to different depths might be exposed, modelling should be conducted with outputs spanning the near surface to full ocean depth. The receiver depths modelled should offer higher resolution in surface waters but include depths at well-defined intervals to the ocean bottom. To accomplish this, it is recommended that sound levels be computed at the following depth intervals where applicable: every 5 m depth interval to 30 m (5, 10, 15...), every 10 m in depth to 100 m (i.e. 30, 40, 50….), every 100 m to 1,000 m depth (200, 300, 400, 500…), at 2,000 m, 3,000 m, 4,000 m,*

---

[7] see also http://www.gaisma.com/en/

[8] left: By TWCarlson - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21159109; right: By TWCarlson - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21157096

5,000 m, and at a contour following the bottom depth directly (i.e. 1 m) above the seabed

Combination of measurement and prediction products

The combination of measurements and predictions is to be addressed during Phase IV of the ADEON project.

4. Qualitative soundscape metrics

By definition a soundscape includes qualitative information concerning "the types of sources contributing to the sound field". Relevant information concerning acoustic sources known or expected to be present, based on sources of information about activities in the area such as AIS, shipping radar, and permits for offshore activities, should be reported.

We strive to quantify the contribution from different sources. With a prediction one can attribute a proportion of the sound energy (in a specified volume) to a given source (Sertlek, 2016), but we cannot measure this proportion. What can be measured instead is the proportion of time for which the contribution from a specified source dominates, for a specified temporal observation window duration (e.g., 60 s). ADEON's approach to quantifying source contributions will be specified in the Data Processing Standard (Heaney et al., 2017).

Measurements

Geophysical sources

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows attributed to wind shall be identified.

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows in which rain is detected should be identified.

The detection of turbidity currents (Hatcher, 2017) and other geophysical events such as earthquakes, volcano eruptions (Matsumoto et al, 2011) and lightning strikes (Hill, 1985) should be considered.

The detector algorithms, manual validation methods, and detector performance results shall be clearly reported.

Biological sources

Mysticete detectors for fin, blue, sei, humpback, right and minke whales should be considered.

Whistle detectors for pilot whales and the rest of the delphinid group should be considered.

Click detectors for sperm whales, delphinids and pilot whales, beaked whales (e.g., Sowerby's, Cuvier's, Blainville's), porpoise, Kogia sp. should be considered.

Fish choruses can sometimes be identified as part of the diel cycle. Species specific detectors for fish choruses should be considered.

The detector algorithms, manual validation methods, and detector performance results shall be clearly reported.

Man-made sources

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows in which vessel sounds are detected shall be identified.

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows in which airgun pulses are detected should be identified.

The detector algorithms, manual validation methods, and detector performance results shall be clearly reported.

Predictions

For model predictions, contributions from each source type should be reported, and the dominant source type shall be identified. At a specified location, the dominant source is the one that produces the highest energy contribution (Sertlek, 2016) in a specified temporal observation window and frequency band, as specified below. The corresponding requirement for soundscape metric derived from measurements does not include identification of a dominant source, so this prediction will not be directly comparable with the corresponding measurement product. Rather than compare qualitative soundscape metrics for source identification, it will instead be possible to compare measured SPL spectra with predicted spectra at the measurement location.

Geophysical sources

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows dominated by wind shall be identified.

Biological sources

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows dominated by whale sounds shall be identified.

Man-made sources

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows dominated by vessel sounds shall be identified.

For a temporal observation window duration of 60 s and for a specified frequency band, temporal observation windows dominated by airgun pulses shall be identified.

5. Reporting soundscape products

International Systems of Quantities (ISQ)

Quantities and their units are reported following ISQ as specified by ISO/IEC 80000 Quantities and Units (ISO/IEC, 2009). The only exceptions are where overruled by the precedence rule of the ADEON Terminology Standard (Ainslie et al., 2017).

Coordinated Universal Time

Times shall be reported in UTC, following ISO (2004). Where local time is of particular relevance, for example in connection with a dawn or dusk chorus, conversion to local time should be considered.

Reporting levels in decibels

ANSI and IEC alternative forms of “dB re” notation

Levels shall be reported in one of the following forms permitted either by ANSI (2016b)

$$L_P = \langle x \rangle \text{ dB re } \langle P_0 \rangle,$$

or by IEC (2002)

$$L_P(\text{re } \langle P_0 \rangle) = \langle x \rangle \text{ dB}$$

$$L_{P/P_0} = \langle x \rangle \, \mathrm{dB} \, ,$$

where L_P is the level of a power quantity P, the numerical value of which, when expressed in decibels, is x. Once adopted, the same form shall be followed throughout any single report.

Choice of reference value

In the literature one sometimes encounters a power quantity used as the reference value (e.g., $1\ \mu\mathrm{Pa}^2$, $1\ \mu\mathrm{Pa}^2\mathrm{s}$, $1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$, or $1\ \mu\mathrm{Pa}^2\mathrm{s}/\mathrm{Hz}$) and sometimes the corresponding root-power quantity ($1\ \mu\mathrm{Pa}$, $1\ \mu\mathrm{Pa}\ \mathrm{s}^{1/2}$, $1\ \mu\mathrm{Pa}/\mathrm{Hz}^{1/2}$, or $1\ \mu\mathrm{Pa}\ \mathrm{s}^{1/2}/\mathrm{Hz}^{1/2}$). In the case of the exposure (i.e., energy) spectral density, $1\ \mu\mathrm{Pa}\ \mathrm{s}^{1/2}/\mathrm{Hz}^{1/2}$ is sometimes simplified to the (equivalent) $1\ \mu\mathrm{Pa}/\mathrm{Hz}$, easily confused with $1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$, which is the power reference value of the *power* spectral density, a different physical quantity. The intended meaning is identical whether a power or root-power reference quantity is stated, but the proliferation of mixed power and root-power reference values can cause confusion.

An additional source of confusion is the widespread use of “$1\ \mu\mathrm{Pa}$ @ 1 m”, “$1\ \mu\mathrm{Pa}^2\ \mathrm{s}$ @ 1 m” and similar as a reference value for source level. Use of this convention gives the reader the impression that one is referring to a value of SPL or SEL at a distance of 1 m from the source, whereas the source level is actually a far field quantity, whose numerical value only rarely, if ever, coincides with that of SPL at 1 m. The appropriate power quantity reference values compatible with ISO (2017) are $1\ \mu\mathrm{Pa}^2\ \mathrm{m}^2$ and $1\ \mu\mathrm{Pa}^2\mathrm{m}^2\ \ \mathrm{s}$, or $1\ \mu\mathrm{Pa}\ \mathrm{m}$ and $1\ \mu\mathrm{Pa}\ \mathrm{m}\ \mathrm{s}^{1/2}$ for the corresponding root-power quantities.

To reduce the risk of confusion, ADEON has made the following choices for reporting reference values: The reference value shall be a power quantity (not a root-power quantity or field quantity). The nature of the power quantity shall be specified. When reporting levels the reference value P_0 of the specified power quantity shall also be specified (a history of reference values used in underwater acoustics is provided by Ainslie, 2015). Specifically, for quantities listed in Table 9 the reference values shall be those of the right-hand column of that table.

Table 9 – The reference values in this table shall be used. All are compliant with ISO (2017).

Term (Ainslie et al., 2017)	**Abbr.**	**Symbol**	**Unit**	**Power quantity**	**Reference value**
mean-square sound pressure level	Lrms or SPL	$L_{p,\mathrm{rms}}$	dB	mean-square sound pressure	$1\ \mu\mathrm{Pa}^2$
peak sound pressure level	Lpk	$L_{p,\mathrm{pk}}$	dB	squared peak sound pressure	$1\ \mu\mathrm{Pa}^2$
sound exposure level	SEL	L_E	dB	sound exposure	$1\ \mu\mathrm{Pa}^2\ \mathrm{s}$
source level	SL	L_S	dB	source factor	$1\ \mu\mathrm{Pa}^2\ \mathrm{m}^2$
propagation loss	PL	N_PL	dB	reciprocal propagation factor	$1\ \mathrm{m}^2$
transmission loss	TL	ΔL_TL	dB	NA	NA
mean-square sound pressure spectral density level	PSDL	$L_{p,f}$	dB	mean-square sound pressure spectral density	$1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$
sound exposure spectral density level	ESDL	$L_{E,f}$	dB	sound exposure spectral density	$1\ \mu\mathrm{Pa}^2\ \mathrm{s}/\mathrm{Hz}$

Compliant examples include:
sound pressure level: $L_p = 80\ \mathrm{dB\ re\ 1\ \mu Pa^2}$

sound exposure level: $L_E = 170\ \mathrm{dB\ re\ 1\ \mu Pa^2 s}$

source level: $L_\mathrm{S}(\mathrm{re\ 1\ \mu Pa^2\ m^2}) = 210\ \mathrm{dB}$

sound power level: $L_{W/(1\ \mathrm{pW})} = 100\ \mathrm{dB}$

Non-compliant examples include:
sound pressure level: $L_p = 80\ \mathrm{dB_{rms}\ re\ 1\ \mu Pa^2}$

sound pressure level: $L_p = 100\ \mathrm{dB\ SPL}$

mean-square sound pressure spectral density level: $L_{p,f} = 170\ \mathrm{dB\ re\ 1\ \mu Pa/Hz^{\frac{1}{2}}}$

source level: $L_\mathrm{S} = 210\ \mathrm{dB\ re\ 1\ \mu Pa\ @\ 1\ m}$

Reporting level percentiles

For measurements, the 10th, 25th, 50th, 75th, 90th temporal level percentiles shall be reported. In addition, the 1st, 5th, 95th and 99th temporal level percentiles should be reported where justified by the number of samples available.

For predictions, the 10th, 50th, 90th spatial level percentiles shall be reported.

For applications related to human hearing, exceedance levels are used to characterize noise levels in air (ISO, 2016). Level percentiles may be converted to exceedance levels.

6. Appendix 1 – Galway Statement on Atlantic Ocean Cooperation (informative)

The Galway Statement is an announcement of cooperation between the EU, Canada and the USA to advance a shared vision of a “healthy, resilient, safe, productive, understood and treasured” Atlantic Ocean and to promote the “well-being, prosperity, and security of present and future generations”. The full text of the announcement, signed on 24 May 2013, follows:

Galway Statement on Atlantic Ocean Cooperation

Launching a European Union - Canada - United States of America
Research Alliance

The Signatories of this Statement meeting on the occasion of the high level event
The Atlantic – a Shared Resource, held on
23 and 24 May 2013
***at the* Marine Institute, Galway, Ireland**

Recognizing the importance of the Atlantic Ocean to our citizens, prosperity, human health and well-being, adaptation to climate and other environmental change, and security,

Cognizant of our reliance upon the best available science and knowledge to inform decisions affecting the Atlantic Ocean,

Realizing that our countries face similar challenges in promoting a healthy and well-understood Atlantic Ocean,

Acknowledging the critical interlink between the Atlantic Ocean and the portion of the Arctic region that borders the Atlantic,

Appreciating the value of our ongoing cooperation on ocean science and observation in the Atlantic Ocean, and

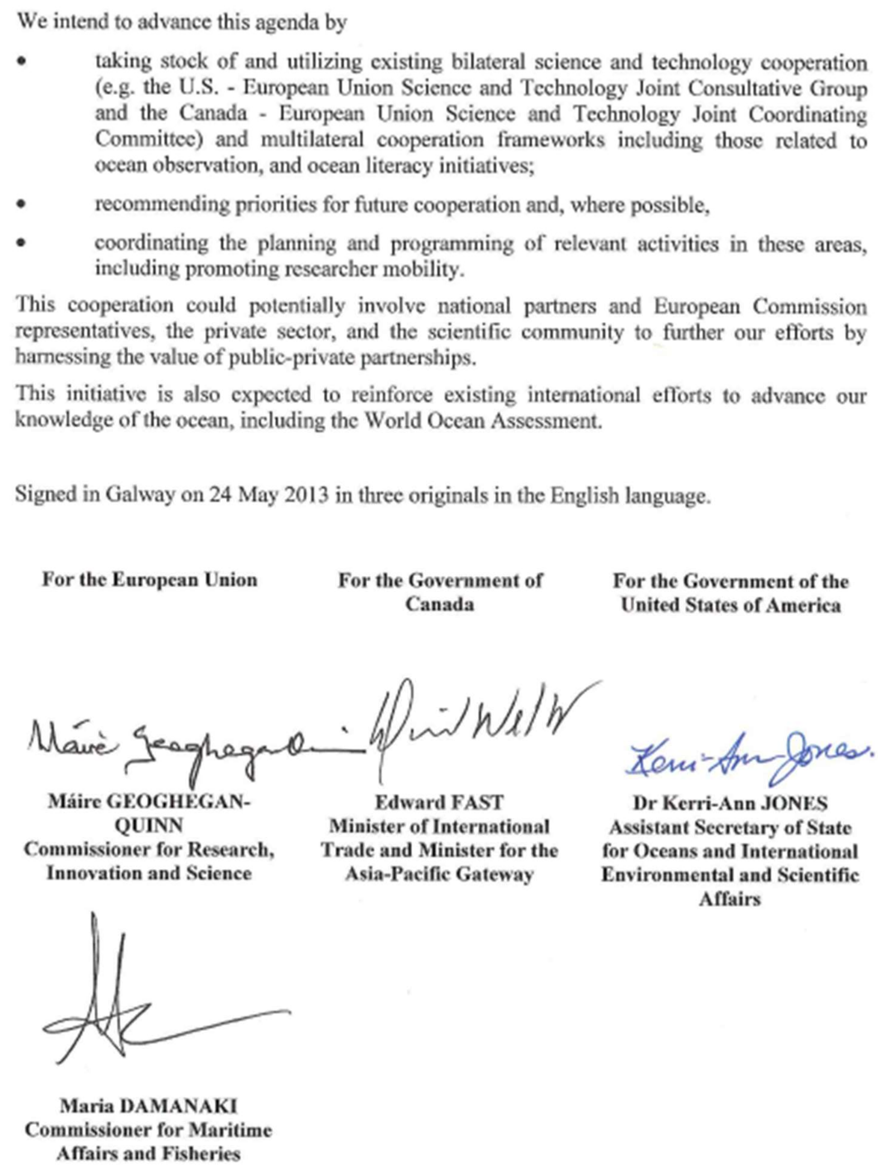
Valuing the essential role of international partnership to achieve our shared objectives and the potential of greater cooperation to advance our knowledge of the Atlantic Ocean,

Intend to advance our shared vision of an Atlantic Ocean that is healthy, resilient, safe, productive, understood and treasured so as to promote the well-being, prosperity, and security of present and future generations.

This cooperation is intended to increase our knowledge of the Atlantic Ocean and its dynamic systems - including interlinks with the portion of the Arctic region that borders the Atlantic - by aligning our ocean observation efforts to improve ocean health and stewardship and promote the sustainable management of its resources. Observation is fundamental to understanding the ocean and forecasting its future. Activities may include efforts to better coordinate data sharing, interoperability and coordination of observing infrastructures and seabed and benthic habitat mapping.

This cooperation may result in mutual benefits including better ecosystem assessments and forecasts and deeper understanding of vulnerabilities and risk, including those relating to the global climate system and climate change impacts. It can also help to generate new tools to increase resilience, conserve rich biodiversity, manage risk and determine social, environmental and economic priorities.

We further intend to promote our citizens’ understanding of the value of the Atlantic by promoting oceans literacy. We intend to show how results of ocean science and observation address pressing issues facing our citizens, the environment and the world and to foster public understanding of the value of the Atlantic Ocean.



We intend to advance this agenda by

- taking stock of and utilizing existing bilateral science and technology cooperation (e.g. the U.S. - European Union Science and Technology Joint Consultative Group and the Canada - European Union Science and Technology Joint Coordinating Committee) and multilateral cooperation frameworks including those related to ocean observation, and ocean literacy initiatives;
- recommending priorities for future cooperation and, where possible,
- coordinating the planning and programming of relevant activities in these areas, including promoting researcher mobility.

This cooperation could potentially involve national partners and European Commission representatives, the private sector, and the scientific community to further our efforts by harnessing the value of public-private partnerships.

This initiative is also expected to reinforce existing international efforts to advance our knowledge of the ocean, including the World Ocean Assessment.

Signed in Galway on 24 May 2013 in three originals in the English language.

For the European Union	**For the Government of Canada**	**For the Government of the United States of America**
Máire Geoghegan-Quinn		Kerri-Ann Jones.
Máire GEOGHEGAN-QUINN **Commissioner for Research, Innovation and Science**	**Edward FAST** **Minister of International Trade and Minister for the Asia-Pacific Gateway**	**Dr Kerri-Ann JONES** **Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs**
Maria DAMANAKI **Commissioner for Maritime Affairs and Fisheries**		

7. References

Ainslie, M. A. (2015). A Century of Sonar: Planetary Oceanography, Underwater Noise Monitoring, and the Terminology of Underwater Sound, Acoustics Today, Vol 11 Issue 1, pp12-19.

Ainslie, M. A., de Jong, C. A. F., Martin, B., Miksis-Olds, J. L., Warren, J. D., Heaney, K. D. (2017). Project Dictionary (Terminology Standard). DRAFT. Technical report by TNO for ADEON Prime Contract No. M16PC00003. Available from https://adeon.unh.edu/standards (last accessed 2018-03-29).

Andrew, R. K., Howe, B. M., Mercer, J. A., & Dzieciuch, M. A. (2002). Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoustics Research Letters Online, 3(2), 65-70.

American National Standards Institute (ANSI) (2013). ANSI S1.1-2013. American National Standard Acoustical Terminology (Standards Secretariat, Acoustical Society of America, NY).

American National Standards Institute (ANSI) (2016a). ANSI S1.6-2016 American National Standard – Preferred Frequencies and Filter Band Center Frequencies for Acoustical Measurements (Standards Secretariat, Acoustical Society of America, NY).

American National Standards Institute (ANSI) (2016b). ANSI S1.8-2016 American National Standard – Reference Values for Levels Used in Acoustics and Vibrations (Standards Secretariat, Acoustical Society of America, NY).

Astronomical Applications Department of the U.S. Naval Observatory (USNO) (2011). Available from http://aa.usno.navy.mil (last accessed 2017-05-20).

BIPM (2014). See International Bureau of Weights and Measures (2014).

Branstetter, B. K., Mercado III, E., & Au, W. L. (2007). Representing multiple discrimination cues in a computational model of the bottlenose dolphin auditory system. The Journal of the Acoustical Society of America, 122(4), 2459-2468.

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D., Young, J.V. (2014a). Monitoring Guidance for Underwater Noise in European Seas, Part I: Executive Summary, JRC Scientific and Policy Report EUR 26557 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/29293. Available from http://mcc.jrc.ec.europa.eu/dev.py?N=29&O=224&titre_chap=D11 Energy and Noise&titre_page=Methodological standards (last accessed 2017-05-21)

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D., Young, J.V. (2014b). Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications, JRC Scientific and Policy Report EUR 26555 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/27158. Available from http://mcc.jrc.ec.europa.eu/dev.py?N=29&O=224&titre_chap=D11 Energy and Noise&titre_page=Methodological standards (last accessed 2017-05-21)

Dugan, P., Pourhomayoun, M., Shiu, Y., Paradis, R., Rice, A., & Clark, C. (2013). Using high performance computing to explore large complex bioacoustic soundscapes: Case study for right whale acoustics. Procedia Computer Science, 20, 156-162.

European Commission (EC) (2008). DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance). Available from http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32008L0056 (last accessed 2017-05-21).

European Commission (EC) (2010). COMMISSION DECISION of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956) (Text with EEA relevance) (2010/477/EU). Available from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:232:0014:0024:EN:PDF (last accessed 2017-05-21).

European Commission (EC) (2017). COMMISSION DECISION (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardized methods for monitoring and assessment, and repealing Decision 2010/477/EU (Text with EEA relevance) (2010/477/EU). Available from http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1495097018132&uri=CELEX:32017D0848 (last accessed 2018-01-29).

Fay, R. (2009). Soundscapes and the sense of hearing of fishes. Integrative Zoology, 4(1), 26-32.

Farina, A., Pieretti, N., & Piccioli, L. (2011). The soundscape methodology for long-term bird monitoring: a Mediterranean Europe case-study. Ecological Informatics, 6(6), 354-363.

Gage, S. H., & Axel, A. C. (2014). Visualization of temporal change in soundscape power of a Michigan lake habitat over a 4-year period. Ecological Informatics, 21, 100-109.Hastings, P. A., & Širović, A. (2015). Soundscapes offer unique opportunities for studies of fish communities. Proceedings of the National Academy of Sciences, 112(19), 5866-5867.

Hill, R. D. (1985). Investigation of lightning strikes to water surfaces. The Journal of the Acoustical Society of America, 78(6), 2096-2099.

Heaney K., Martin B, Miksis-Olds, J., Ainslie, M., Moore, T., and Warren, J. (2017). ADEON Data Processing Specification., Version 2.0 DRAFT. Technical report by OASIS for ADEON Prime Contract No. M16PC00003. Available from https://adeon.unh.edu/standards (last accessed 2018-03-29).

Houser, D. S., Yost, W., Burkard, R., Finneran, J. J., 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.

Hulse, S. H. (2002). Auditory scene analysis in animal communication. Advances in the Study of Behavior, 31, 163-200.

International Electrotechnical Commission (IEC) (2002). IEC 60027-3:2002 International Standard IEC 60027-3 Letter symbols to be used in electrical technology – Part 3: Logarithmic and related quantities (IEC, Geneva, Switzerland).

International Electrotechnical Commission (IEC) (2014). IEC 61260-1:2014 Electroacoustics - Octave-band and fractional-octave-band filters - Part 1: Specifications (IEC, Geneva, Switzerland).

International Bureau of Weights and Measures (French: Bureau international des poids et mesures, or BIPM) (2014). The International System of Units (SI), 8th edition, 2006, *Organisation Intergouvernementale de la Convention du Mètre*. 2014 amendment.

International Whaling Commission (IWC) (2014). Joint Workshop Report: Predicting sound fields – global soundscape modelling to inform management of cetaceans and anthropogenic noise, 15-16 April 2014, Leiden, Netherlands. Available from http://scor-int.org/IQOE/Leiden_Report.pdf (last accessed 2017-05-21).

International Organization for Standardization (ISO) (2004). ISO 8601:2004 Data elements and interchange formats -- Information interchange -- Representation of dates and times, (ISO, Geneva, Switzerland).

International Organization for Standardization (ISO) (2006). ISO 80000-3:2006 Quantities and Units – Part 3: Space and Time, (ISO, Geneva, Switzerland).

International Organization for Standardization (ISO) (2009) and International Electrotechnical Commission (IEC). ISO/IEC 80000 Quantities and Units, (ISO, Geneva, Switzerland; IEC, Geneva, Switzerland).

International Organization for Standardization (ISO) (2014). ISO 12913-1:2014 Acoustics -- Soundscape -- Part 1: Definition and conceptual framework, International Organization for Standardization (ISO, Geneva, Switzerland).

International Organization for Standardization (ISO) (2016). ISO 1996-1:2016 Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures, International Organization for Standardization, (ISO, Geneva, Switzerland).

International Organization for Standardization (ISO) (2017). ISO 18405:2017 Underwater acoustics — Terminology, International Organization for Standardization (ISO, Geneva, Switzerland). Available from http://www.iso.org/iso/catalogue_detail.htm?csnumber=62406 (last accessed 2017-05-21).

Johnson, C. S. (1991). Hearing thresholds for periodic 60-kHz tone pulses in the beluga whale. The Journal of the Acoustical Society of America, 89(6), 2996-3001.

Kastelein, R. A., Hoek, L., de Jong, C. A., & Wensveen, P. J. (2010a). The effect of signal duration on the underwater detection thresholds of a harbor porpoise (Phocoena phocoena) for single frequency-modulated tonal signals between 0.25 and 160 kHz. The Journal of the Acoustical Society of America, 128(5), 3211-3222.

Kastelein, R. A., Hoek, L., Wensveen, P. J., Terhune, J. M., & de Jong, C. A. (2010b). The effect of signal duration on the underwater hearing thresholds of two harbor seals (Phoca vitulina) for single tonal signals between 0.2 and 40 kHz. The Journal of the Acoustical Society of America, 127(2), 1135-1145.

Leroy, E. C., Samaran, F., Bonnel, J., & Royer, J. Y. (2016). Seasonal and Diel Vocalization Patterns of Antarctic Blue Whale (Balaenoptera musculus intermedia) in the Southern Indian Ocean: A Multi-Year and Multi-Site Study. PloS one, 11(11), e0163587.

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.

Martin B, C.A. Hillis, J. Miksis-Olds, M. Ainslie, and J. Warren. (2017). ADEON Hardware Specification. Document 01412, Version 1.1 DRAFT. Technical report by JASCO Applied Sciences for ADEON. Available from https://adeon.unh.edu/standards (last accessed 2018-03-29).

Matsumoto, H., Haxel, J. H., Dziak, R. P., Bohnenstiehl, D. R., & Embley, R. W. (2011). Mapping the sound field of an erupting submarine volcano using an acoustic glider. The Journal of the Acoustical Society of America, 129(3), EL94-EL99.

Matthew G. Hatcher (2017). Ambient noise from turbidity currents in Howe Sound. MSc thesis. (Dalhousie University, Halifax, Nova Scotia, Canada).

McDonald, M. A., Hildebrand, J. A., & Wiggins, S. M. (2006). Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. The Journal of the Acoustical Society of America, 120(2), 711-718.

McDonald, M. A., Hildebrand, J. A., Wiggins, S. M., & Ross, D. (2008). A 50 year comparison of ambient ocean noise near San Clemente Island: A bathymetrically complex coastal region off Southern California. The journal of the Acoustical Society of America, 124(4), 1985-1992.

Moore, P. W. B., Hall, R. W., Friedl, W. A., and Nachtigall, P. E. (1984). The critical interval in dolphin echolocation: What is it?, The journal of the Acoustical Society of America 76, 314–317.

National Marine Fisheries Service (2016). Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-55, 178 p.Pijanowski, B.C., Villanueva-Rivera, L.J., Dumyahn, S.L., Farina, A., Krause, B.L., Napoletano, B.M., Gage, S.H., Pieretti, N., 2011. Soundscape ecology: the science of sound in the landscape. BioScience 61, 203–216.

Robinson, S.P., Lepper, P. A. and Hazelwood, R.A. (2014). Good Practice Guide for Underwater Noise Measurement, National Measurement Office, Marine Scotland, The Crown Estate, NPL Good Practice Guide No. 133, ISSN: 1368-6550, 2014.

Sertlek, H. O. (2016). Aria of the Dutch North Sea (Doctoral dissertation, University of Leiden, the Netherlands). Available from https://openaccess.leidenuniv.nl/handle/1887/40158 (last accessed 2018-05-19).

Shamma, S. A., Elhilali, M., & Micheyl, C. (2011). Temporal coherence and attention in auditory scene analysis. Trends in neurosciences, 34(3), 114-123.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr, C. R., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. E. and Tyack, P. L. (2007). Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic mammals, 33(4), 411.

USNO (2011). See Astronomical Applications Department of the U.S. Naval Observatory.

Van Opzeeland I. and Boebel O. (2018). Marine soundscape planning: Seeking acoustic niches for anthropogenic sound. Journal of Ecoacoustics. 2: #5GSNT8. https://doi.org/10.22261/JEA.5GSNT8

Vel’min, V. A., and Dubrovskii, N. A. (1976). The critical interval of active hearing in dolphins, Sov. Phys. Acoust. 2, 351–352.

Warren et al. (2017) DRAFT ADEON Calibration and Deployment Good Practice Guide, Version 2. Atlantic Deepwater Ecosystem Observatory Network (ADEON): An Integrated System. Contract: M16PC00003. Available from https://adeon.unh.edu/standards (last accessed 2018-03-29).