1. Background

1.1 Introduction

Continuous anthropogenic noise may exert a significant pressure on the marine environment due to its constant presence and as it covers most of the water body. Distant ships, wind, rain and thermal motion, are examples of continuous sound sources. Sound from distant ships contributes to the ambient noise in the frequency band 10 Hz to 1000 Hz, closer ships also at higher frequencies. The sound from ships is caused by the propulsion (propellers), machinery, and by the movement of the hull through the water. The relative importance of these three different sources depends, amongst other things, on the ship type, speed and load (Breeding et al., 1996; Wales & Heitmayer, 2002; Wittekind, 2014). Wind-induced sound (breaking waves and bubbles) are generated primarily in the band 100 Hz to 30 kHz. Rain produces noise mainly in the band 1 kHz to 10 kHz but also contributes to higher frequencies. Thermal noise resulting from molecular agitation dominates as a source at frequencies higher than 100 kHz. With respect to animal sources, sounds are produced in the frequency range from a few Hz to several 100 kHz. The duration of animal sounds range from very short (a few tens of microseconds) to tens of seconds.

For monitoring the ambient noise, including the anthropogenic part, two 1/3-octave bands centred on 63 Hz and 125 Hz are used as proxies for ship activities (Dekeling et al. 2014, Part I). EU Technical Group on Underwater Noise (TG Noise) furthermore recommends including one or more third octave bands in the frequency range up to 20 kHz. (Dekeling et al. 2014, Part II, p. 20). For the Baltic it has been recommended to use at least the 2 kHz centre frequency band in order to cover the higher frequencies used by marine mammals for communication and orientation (Nikolopoulus et al. 2016, p.13). If it is appropriate, more frequency bands could be added in the future (cf. for example European Commission, 2017).

1.2 Purpose and aims

The aim of these guidelines is to provide a standardized procedure to ensure that the output data from the monitoring is compatible with the HELCOM pre-core indicator 'Continuous low frequency anthropogenic sound' (STATE & CONSERVATION 5-2016, document 4J-2).

The procedure for the pre-core indicator is to record ambient noise in the Baltic Sea, process the data to achieve temporal averages for selected frequency bands and store the data nationally. This is what is covered in these guidelines. Subsequently, the aim of the regional monitoring sub-programme is to store the processed data together with modelled maps in a data sharing platform and in a soundscape planning tool that will be open access. This way, data on measured and modelled sound pressure levels from the monitoring sub-program will provide spatiotemporal information that can be used for assessment of short-term status and long-term trends in sound pressure levels in the region.

1.3 Monitoring Strategy

Preliminary results from projects and monitoring activities indicate that monthly averages of measured sound pressure levels is a suitable time scale for assessing good status of continuous noise levels in the Baltic Sea. Further, it has been demonstrated that annual and monthly soundscape maps can be created that cover the full area of the Baltic Sea (Nikolopoulus et al., 2016). The benefit of the soundscape maps is that they extend the local measurement to the full Baltic Sea and thus they can be used to address impact in areas of interest and/or during specific periods, even if no actual measurements are available for these areas.

2. Monitoring methods

2.1 Monitoring features

Underwater sound is measured with a hydrophone (underwater microphone). Its design is adapted to the acoustic impedance of water. Further details included in Section 2.4.2 and 2.4.3.

2.2 Time and area

A proposed regional monitoring programme of ambient noise based on the output from the BIAS project (Life+ project Baltic Sea Information on the Acoustic Soundscape) was considered at STATE & CONSERVATION 8-2018 (document 3MA-5). The proposal is based on two alternating monitoring programmes; a yearly minor assessment in a few prioritized locations and one major assessment at regular intervals. Further discussion on the monitoring proposal will continue under the State and Conservation Working Group.

2.3 Monitoring procedure

2.3.1 Sampling method(s) and equipment

Underwater acoustic sensors are used to convert acoustic energy in water to electric energy. A typical system consists of a hydrophone, an amplifier, a filter unit, an analogue to digital converter and a data storage media. For guidance on technical specifications of equipment for monitoring, see Dekeling et al. 2014b and Verfuß et al. 2015. Care must be taken to ensure sensors are handled properly during storing, deployment and recovery. Details regarding this can be found in Verfuß et al 2015.

2.3.2 Calibration

The instruments of the acoustic measurement chain have to be calibrated. Calibration charts of measurement equipment must be available, and dated back at maximum 24 months before the measurements. Details on the test equipment used (description, manufacturer, type, serial number) and the applied software (description, manufacturer, type, revision/modification status) shall be noted for each measurement. In order to be able to retrace the impact of such test devices, which are subsequently found to be faulty, the serial numbers of all measuring devices must be given as well as the revision state of respective instrument firmware and analysis software.

The complete measurement chain (hydrophone-amplifiers-filters-A/D conversion) should be tested before deployment to check whether it functions within its specifications. It is advised to make use of a hydrophone-calibrator (pistonphone), which provides the hydrophone with a single-frequency tonal signal of well-defined amplitude.

2.3.3 Metadata

During deployment and retrieval of the hydrophone rigs, the time and date should be recorded. Measurements of the water depth and the hydrophones height above the bottom water should be taken and noted. In addition, the sound speed profile of the water column should be measured if possible.

2.3.4 Settings of the monitoring system

The sampling rate determines the recording bandwidth and should be at least two and a half times higher than the bandwidth of interest. In order to analyse the 2 kHz frequency band, the minimum sampling rate needs to be at least 5.6 kHz. However, to ensure maximal use of the recordings for other purposes it is recommended to use the highest possible recording bandwidth within the limitations given by the recorder memory capacity and battery endurance and in any case not lower than 10 kHz (corresponding to a sample rate of 25 kHz).

Duty cycle of recordings must be sufficiently high to secure that each recording constitutes a representative statistical sample. It is recommended to record as minimum 15 minutes per hour, with recordings always starting at the full hour.

It is useful to make a preliminary assessment of the natural noise levels in the deployment location based on experience or BIAS sound maps. If the natural noise levels are relatively low, it is advised to use low-noise hydrophones or apply a gain in order to be able to record sounds corresponding to the low sea-states.

2.3.5 Rig design

Hydrophones can be deployed in various ways. Rigs that are used for the deployment of autonomous noise loggers can be relatively small and easy to handle or larger cabled station connecting a bottom mounted hydrophone to a surface buoy or land. In order to minimize noise from waves and wind, a rig design omitting surface buoys is preferred. Figure 3 shows an example sketch of a rig. Fundamental requirements to the rigs are:

- The hydrophone should be 3 m above the seafloor in order to minimize bottom reflections.
- If an acoustic releaser is used, it should be at least 1 m above the seafloor to assure that it does not sink into the mud if the rig is deployed on a very soft bottom.
- The ballast should have a sufficient negative buoyancy (wet weight) to keep the rig at the deployment location. If the ballast is sacrificed on recovery, the ballast and ropes should be environmentally neutral (such as sand or gravel in biodegradable bags and manila or sisal ropes).
- The rig should have sufficient positive buoyancy in water without the ballast to surface quickly, even in strong currents. Two independent flotation elements are preferred for safety reasons, i.e. even if the sensor itself has positive buoyancy, additional (backup) flotation, such as one or more trawl floats should be added. The additional flotation should preferably be added below the hydrophone.

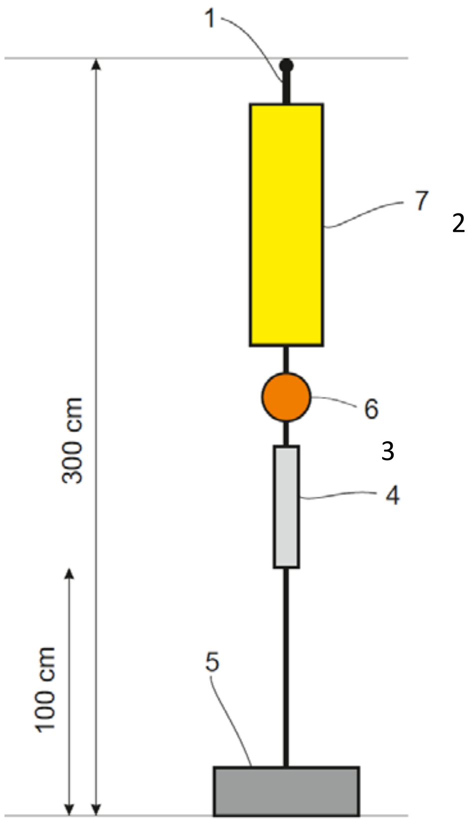

Figure 3. Sketch of an example of a sub-surface rig: 1 hydrophone, 2 hydrophone logger, 3 trawl float 4 acoustic releaser and 5 ballast weight.

A trawl resistant version of the rig is an alternative for areas with high probability of fishing trawls picking up and removing the rig from its deployment location (see Figure 4). This rig is made from reinforcing steel nets in a pyramid-shaped frame and a plastic tube connected to the pyramid with four strings. In this rig-design, the hydrophone is located only 1 m above the seafloor instead of 3 m. This configuration allows the central tube, containing both datalogger and acoustic releaser, to tilt on impact such that an otter trawl net slips over the whole rig.

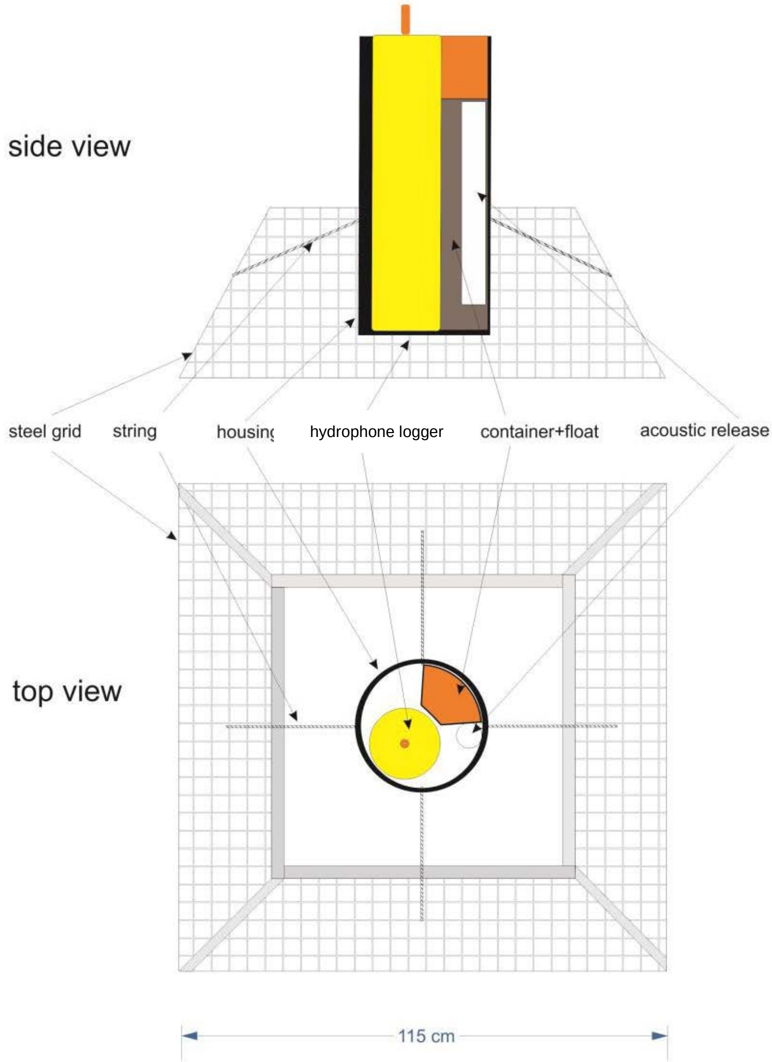

Figure 4. Trawl-protected rig.

2. 4 Data analysis

2. 4.1 Pre-processing

Pre-processing is a step in signal processing to prepare data for estimation and analysis, being the order of the procedure recommended as follows:

- Organisation of recorded data in monthly folders for each station: all data files for one station and a specific month are placed in the corresponding data folder,
- Testing of file size and file length of the recorded files: a minimum of 15 minutes per hour is to be recorded,
- Testing of non-numerical values NaN (not-a-number) and Inf (too high value for a numerical representation) in the recorded data files: these values are to be omitted prior to processing,
- Testing of clipping, i.e. if the data values are saturated by the recording system: the percentage of clipped samples (i.e. samples whose value equals the minimum or the maximum level) should be calculated for each 20 s interval of the data file. The recommendation is to flag the 20 s interval as clipped when at least 0.1% of the samples are clipped. Information on the flagged data should be noted in the processing protocol for further consideration and tracking.

Data recorded before deployment and after retrieval of the system is to be removed. Data recorded while the deployment is on-going and when the deployment ship is still near to the deployed sensor is to be saved but not to be used.

Control of data coverage is done by quantifying the time that data is recorded relative to the planned time. The coverage is given in percentage.

2.4.2 Processing

Mean sound pressure levels in the 1/3-octave bands centred on 63 Hz, 125 Hz and 2 kHz are to be provided. Mean sound pressure levels in other frequency bands may also be considered relevant at a later stage. For that reason all 1/3 octave band shall be evaluated and stored nationally.

2.4.2.1 1/3rd octave filters

The filters to be used are IEC bands number 18, 21 and 33 (IEC, 61260-1:2014). Number 18 and 21, respectively, are the 1/3-octave bands centred on 63 Hz and 125 Hz, while number 33 is the one centred on 2 kHz (see Table 1).

Calculation of band levels should be done by filters fulfilling requirements of IEC 61260-1:2014. A computationally efficient way to realize such filters is by applying FFT (Fast Fourier Transform) filters. Such filters calculate the sum of the energy from frequency bins covered by the frequency range of the 1/3 octave band. The spectrum derived by calculating the Discrete Fourier Transform (DFT) of the signal and applying an appropriate windowing function should be used. A Hann window is recommended, as this window yields a favourable compromise between narrow filter bandwidth and high sidelobe supression.

It is recommended to derive the DFT from 1-second segments of the signal, yielding a nominal analysis bandwidth of 1 Hz. Several adjacent FFT-bins are summed together to approximate a 1/3rd-octave band filter.

IEC/ANSI band no.	Centre frequency (Hz)	f_1 (Hz)	f_m (Hz)	f_2 (Hz)	Number of 1 Hz bands
18	63	56.23	63.10	70.79	14
21	125	112.2	125.9	141.3	29
33	2000	1778	1995	2239	460

Table 1. Information on the 1/3rd-octave band filters to be used.

2.4.2.2 Averaging sound pressure levels

Consecutive steps to calculate the average:

- Calculate averages of one second, non-overlapping blocks;
- Calculate the sound pressure level (SPL) as defined in Betke et al. (2015) in the 1/3 octave bands over 1 second, as described above. The 1-s averages are to be further processed to averages over 20 seconds.

Similarly, monthly and annual arithmetic means are to be established for 63, 125 and 2000 Hz, based on the 1-s averages.

3. Data reporting and storage

3.1 Format for data reporting

The processed acoustic dataset should always be accompanied by descriptive metadata such as time of measurement (UTC) and position (expressed in decimal degrees, positive latitudes towards North and positive longitudes towards East).

Processed acoustic data should be stored in a text file format (ASCII). The filename should follow the following convention:

StationIdSSS_BBBFFFHz_StartyyyymmddHHMMSS_EndyyyymmddHHMMSS.asc

Where:

- SSS is the Station Id, format: %03d;
- BBB is a keyword describing the bandwidth. It shall be 'ThirdOctave' or 'BroadBand' according to the nature of the acoustic data that is stored in the file;
- FFF is the rounded central frequency of the bandwidth when BBB is 'ThirdOctave', or the total bandwidth of the recording if BBB is 'BroadBand'. Format: %05d;
- Start designate the time of the first acoustic data contained in the file. Must be given in UTC where yyyy is year, mm is month, dd is day, HH is hour (24 hour format) MM is minute and SS is second.
- Time for recordings beginning at midnight is given as 000000;
- End design the time of the last acoustic data contained in the file. Must be given in UTC; Format as start time. Time for recordings ending at midnight is 240000.

3.2 Content of the processed acoustic files

Each file should contain the values for only a single bandwidth. It is recommended to restrict the file length to one month of data. Each file should contain a header with metadata about the recording and a table with the actual data. The header and a table are to be formatted as indicated in Table 2 and 3, respectively. In the case of an unknown header value, the field must be replace by a dash ('-').

Organization name	% Issued by	String
StationId	% Station	Id Integer %03d
StationName	% Name of the Station	String
LoggerId	% Data Logger unit Id	String
Hydrophone ID	% Type and serial number of hydrophone	String
Hydrophone sensitivity	% Sensitivity in dB re. 1 V/µPa	Float %5.1f
DataType	% Type of acoustic data	'SPL' or 'SEL'
dBunit	% Units of the acoustic data	String
BandType	% ThirdOctave/ Broadband	String
Fc	% Central frequency of the band	Float %8.2f
Fmin	% Minimum frequency of the band	Float %8.2f
Fmax %	Maximum frequency of the band	Float %8.2f
Window	% Processing window (sec)	Integer
Latitude	% Lat Signed decimal degrees, WGS84	Float %11.8f
Longitude	%Lon Signed Decimal degrees, WGS84	Float %11.8f
L	% Height above bottom (m)	Float %5.1f
H	% Water depth (m)	Float %5.1f
Hdate	% Date of water depth measurement (UTC)	String YYYYMMDD
Issued	% Date of issue	String YYYYMMDD
ProgramName	% Processing program used	String
Sync	% Synchronisation Date of Data Logger	String YYYYMMDD
Drift	% Logger Drift (s/day)	Float %10.8f
N	% Number of lines in the table	Integer

Table 2. Overview of the content of the header file.

The data table section of the data file contains one line for each 20 second period, with processed results according to the format in table 3.

1st column	Date – String – YYYYMMDDHHMMSS giving the UTC time for the beginning of the 20 second period.
2nd column	Minimum Level (%6.2f): for 20-second values, the minimum level is defined as the minimum of the 20 values of 1-second processed data
3rd column	Median Level (%6.2f): for 20-second values, the median value of the 20 values of 1-second processed data
4th column	Maximum Level (%6.2f): for 20-second values, the maximum level is defined as the maximum of the 20 values of 1-second processed data
5th column	Standard deviation (%6.2f): for 20-second values, the standard deviation level is defined as the standard deviation of the 20 values of 1-second processed data
6th column	Ratio of positive clipping samples in the processed window to the number of samples in the processed window (%10.8f) – Number between 0 and 1
7th column	Ratio of Negative clipping samples in the processed window to the number of samples in the processed window (%10.8f) – Number between 0 and 1

Table 3. Overview of the content of the data file.

The format for numbers in these files is to follow the standard C-language convention (see Table 4).

Format	**Explanation**	**Example**
%03d	Integer coded with 3 digits. If the value is less than 100, force the number to be padded with 0s.	074
%05d	Integer coded with 5 digits. If the value is less than 10000, force the number to be padded with 0s.	01984
%8.2f	Floating point written with maximum 8 characters and with 2 decimals digits printed after the decimal point.	534.24
%11.8f	Floating point written with maximum 11 characters and with 8 decimals digits printed after the decimal point.	98.98747263
%5.1f	Floating point written with maximum 5 characters and with 1 decimal digit printed after the decimal point.	234.6
%10.8f	Floating point written with maximum 10 characters and with 8 decimals digits printed after the decimal point.	9.98747263

Table 4. Overview of the format to be used in the data file.

3.3 Data storage

Raw data shall be stored by the Contracting Parties. An arrangement of data storage at a regional level can be envisaged for processed data.

4. Quality control

4.1 Quality control of methods

Contracting Parties should follow the HELCOM monitoring guideline but minor deviations from this are acceptable if the methods produce comparable results. Validation of the adopted method needs to be performed by participating in regular inter-calibration studies or proficiency testing schemes.

4.1.1 Control of processing software

A protocol for handling processing software should be established and adhered to. This protocol should specify how to keep track of which versions of analysis software is used. Any new software or modifications to existing software, including new releases of commercial packages, should be recorded in a log with the date when they came into use. A standard set of sample data must be available to check that new versions of processing software produce identical output to previous versions. It is recommended that a ring-test of the software is performed with regular intervals, as part of inter-calibration procedure. A ring test is an inter-organization comparison of signal processing methods and is performed by having identical samples of raw data processed by different organisations with the exact same software as used in the processing of real monitoring data.

4.2 Quality control of data and reporting

Error reports should be created and archived whenever irregularities are discovered. This includes, but is not limited to:

- Irregularities encountered during deployment and recovery of sensors, including loss of data due to loss or malfunction of sensors.
- Errors in setup and programming of sensors discovered after recovery.
- Loss of data post recovery due to irrecoverable errors in data storage systems etc.
- Errors discovered in data handling and processing, either due to faults by operator or errors discovered in processing software.

Error reports should contain information about date for discovery of the irregularity/error, whether the error has been partly or fully corrected, and the amount of data known to be or potentially affected by the error.

5. Contacts and references

5.1 Contact persons

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