Document title	Updated HELCOM Guidelines for monitoring continuous noise
Code	3MA-5
Category	DEC
Agenda Item	3MA– Development and implementation of Recommendations
Submission date	7.4.2021
Submitted by	EN-Noise

Background

EN-Noise agreed on the need to update the continuous noise monitoring guidelines to be aligned with the continuous noise database establishment and requirements (online meeting held on 24 January 2020).

Swedish experts provided an update of the monitoring guidelines (Annex 3 of the online meeting held on 11 December 2020) which was opened for commenting by 15 February 2021. Input was provided by Denmark, Germany, and Poland. Sweden provided a further developed updated guidelines addressing the input received. EN-Noise welcomed the work conducted, discussed remaining open questions including additional ones raised by Poland before the Meeting, and agreed to invite Sweden to finalise the document based on the input by the meeting so that it is submitted by EN-Noise to STATE & CONSERVATION 14-2020 for consideration (online meeting held on 25 February 2021). A last commenting round to a more developed draft was opened, where additional input was provided by Finland and the Chair of EN-Noise.

This document contains the finalised updated HELCOM monitoring guidelines on continuous noise which have been updated to be aligned with the continuous noise database establishment and requirements.

Action requested

The Meeting is invited to approve the updated HELCOM monitoring guidelines on continuous noise.

Updated HELCOM Guidelines for monitoring continuous noise

1. Background

1.1 Introduction

Continuous anthropogenic noise may exert a significant pressure on the marine environment due to its constancy and extent over vast areas. Distant ships, wind and rain, are examples of continuous sound sources. Sound from distant ships contributes to the ambient noise in lower frequencies (frequency bands 10 Hz to 1000 Hz), whereas smaller ships and ships at closer distance also add sound pressure at higher frequencies. The sound from ships is caused by the propulsion (propellers), machinery, and by the movement of the ship itself. The relative importance of these three different sources depends amongst other things; on the ship type, speed and load [1–3]. 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[4,5].

For monitoring the ambient noise, including noise from anthropogenic sources, two 1/3-octave bands centred on 63 Hz and 125 Hz are currently used as proxies for ship noise[6]. 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 [6–8]. During the BIAS project the 2 kHz centre frequency band was included in order to cover the higher frequencies used by marine mammals for communication and orientation [9,10]. In the EU Interreg North sea project Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS), all third-octave frequency bands from 10 Hz to 20 kHz were included to provide coverage of the frequencies used by most marine species, and to allow flexible approaches to subsequent analysis, including auditory weighting to reflect the risk of impact on marine species [11].

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 are compatible with the HELCOM pre-core indicator 'Continuous low frequency anthropogenic sound' (STATE & CONSERVATION 5-2016, document 4J-2).

The procedure for data to the pre-core indicator 'Continuous low frequency anthropogenic sound' 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. Subsequently, as part of the regional monitoring sub-programme the procedure includes storing the processed data together with modelled maps in a common data-sharing platform and 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 locally and regionally.

2. Monitoring methods

A regional monitoring programme of ambient noise is adopted by STATE & CONSERVATION 8-2018 (document 3MA-5). The monitoring programme consists of measurements and soundscape modelling, whereas these guidelines consider the measurements.

2.1 Monitoring procedure

2.1.1 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 (ADC) and a data storage medium. Since member states might have instruments from several manufacturers, and the characteristics differ between them, it is important to set a minimum standard on equipment performance. For the monitoring of continuous sound in the Baltic Sea, the minimum requirements presented in Table 1 are based on the BIAS standards for noise measurements [12], and the JOMOPANS Standard procedure for equipment performance, calibration and deployment [13].

The chosen **frequency bandwidth** should be between 20 Hz and 20 kHz in order to study the potential impact on marine animals. Monitoring instruments should be chosen appropriately, so that measurements can be done accurately within this bandwidth.

The **dynamic range,** described as the amplitude range over which the system can faithfully measure the sound pressure, extends from the lowest possible level (the system self-noise) to the highest amplitude of signal (clip-level). Since the aim here is to monitor continuous sound, it is preferable that the system performs well for low amplitude signals, even if at the expense of occasional overload (clipping) of the recordings. To avoid poor resolution on the ADC for very low amplitude signals, the resolution should be at least 16-bit.

The **frequency response** of the measuring system, i.e. the sensitivity as a function of frequency, should be flat in the chosen frequency range, or it should be known and used to adjust the measurements reported to the common database appropriately. Thus, the **sensitivity** of the hydrophone can either be expressed as one value, given that the frequency response is flat within the recording bandwidth, or in the form of a calibration curve, if the sensitivity changes with frequency. The sensitivity of the recorder should be adjusted so that the clip level matches the amplitude distribution of the noise at the monitoring site, to be able to measure the lowest and highest sound levels in the current location, noting the comment above about preference for low-amplitude signals.

The sampling rate determines the recording bandwidth and should be at least two and a half times higher than the bandwidth of interest to allow room for an adequate anti-aliasing filter between the upper frequency of interest and the Nykvist frequency (half the sample rate). In order to analyse the 20 kHz third octave frequency band with an upper band limit of 22.39 kHz (Table 1), the minimum sample rate should be 56 kHz.

The **system self-noise** is the electrical noise that is generated from the hydrophone and the recording systems, and can be expressed as noise-equivalent sound pressure level (SPL) in dB re $\mu Pa^2/Hz$. The self-noise typically diminishes with increasing frequency and is therefore frequency specific.

Table 1. Minimum requirement in equipment performance for monitoring continuous sound, bearing in mind the difficulties of the calibration process (see Section 2.3.2).

Metric	Specifications
Frequency range	20 Hz – 20 kHz Note that to fully record the 34 third-octave bands in this frequency range requires measurement over the range 17.8 Hz to 22.39 kHz
Dynamic range	Minimum 16 bit (nominal dynamic range 96 dB), Note: Actual dynamic range is from noise floor defined by system self-noise to the maximum sound pressure that can be recorded without clipping the recording.
Clip level	Between 165 and 185 dB re. 1 µPa Note: Depending on location, the clip level should be selected to match the amplitude distribution of the noise.
Directionality	Omnidirectional in the horizontal plane to within +/- 3 dB up to 20 kHz
Sampling rate	Minimum 56 kHz to measure all bands up to 20 kHz. Note: 2.5 times the upper band limit of 22.39 kHz
Filtering	Characteristics of any pre-recording filters (low-pass and/or high-pass) should be known and corrections applied to the processed data, if appropriate. Note: Low pass and high pass filtering caused by instrumentation and any low frequency roll-off in recorder performance due to these filters must be known so that suitable corrections can be applied if relevant
System self-noise	Better than 64 dB re 1 μPa^2/Hz at 63 Hz; Better than 59 dB re 1 μPa^2/Hz at 125 Hz.

2.1.2 Calibration

The different parts of the acoustic measurement chain have to be calibrated. Calibration data, i.e. system sensitivity as a function of frequency (expressed in suitable units) 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 (ideally a calibration should be performed before and after each deployment). 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 (ideally all this information should be stored together with the datasets as metadata).

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 use a hydrophone-calibrator (pistonphone), which provides the hydrophone with a single-frequency tonal signal of well-defined amplitude.

It is advised to regularly perform a calibration on the full frequency spectrum. It should be noted that calibration of recording systems at low frequencies is technically very demanding and that no uniformly accepted standard method is available for frequencies below a few kHz. Further development in this field must be anticipated.

2.1.3 Metadata

During deployment and retrieval of the hydrophone rigs, the time and date should be noted, as well as the geographical position of the hydrophone. Measurements of the water depth and the hydrophones height above the bottom should be taken and noted. It is also important to describe the setup of the rig and hydrophone. In addition, the vertical sound speed profile of the water column should be measured if possible. Details on the metadata needed is available in the Continuous Underwater Noise Reporting Format by ICES.

2.1.4 Settings of the monitoring system

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.

2.2 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 1 shows an example sketch of a rig with autonomous hydrophone loggers. Fundamental requirements to the rigs are:

- The hydrophone should be deployed as a compromise between rig safety and minimising the bottom reflections. Based on experience, 3 m above the seafloor is a useful compromise in most locations.
- The hydrophone should, if possible, be detached from the housing and connected with a hydrophone extension cable at least 0.5 m from the logger unit in order to avoid reflections and vibrations from the unit itself. If the hydrophone is attached to a line extending to a subsurface float, the hydrophone must be adequately isolated from vibrations of the rope caused by the current.
- The ballast weight 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 and with some fouling on.

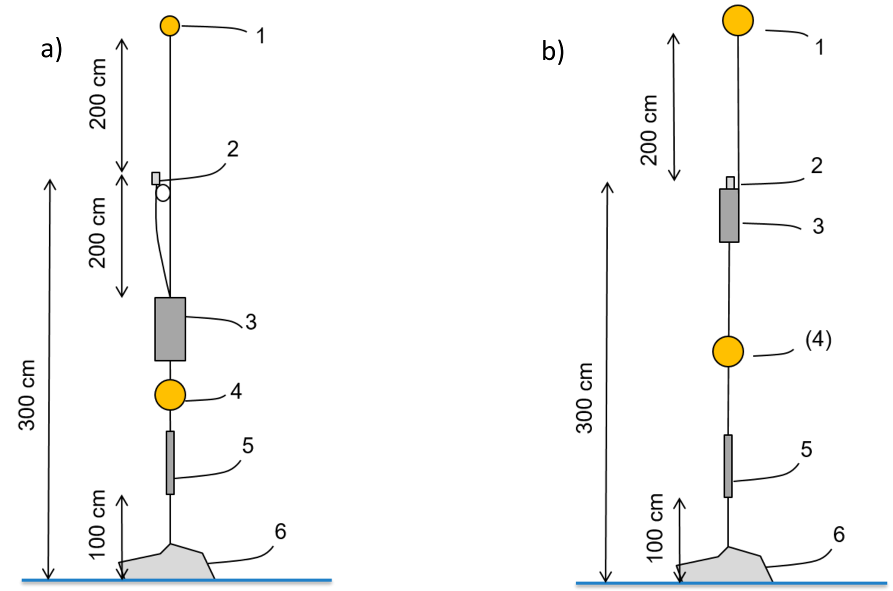

Figure 1. Sketch of two alternative rig design where a) illustrates a rig with a detachable hydrophone and b) a rig with a non-detachable hydrophone that is non-buoyant. 1 hydrophone floatation, 2 hydrophone, 3 hydrophone loggers, 4 floatation element, 5 releaser and 6 ballast weight.

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 2). 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 can slip over the whole rig.

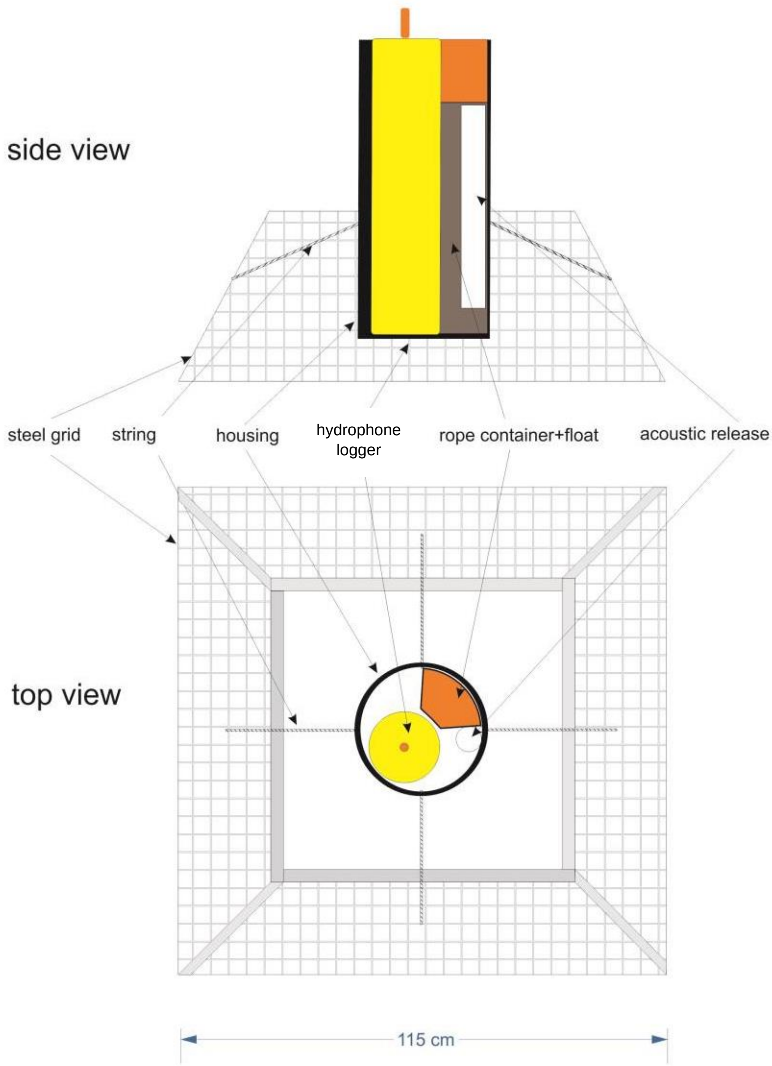

Figure 2. Trawl-protected rig used by Poland during the BIAS project.

2.2.1 Sources and mitigation of rig self-noise

The recorded signals may be influenced by rig self-noise that can arise from multiple sources.

Flow noise arises in areas with currents, and give rise to low frequency signals (the frequency depends among other on the hydrophone diameter and the speed of the current).

Cable strum can be induced when currents pull at ropes or cables of the rig, causing them to vibrate.

Mechanical noise can be caused by debris or sediments impacting the hydrophone, or ropes rubbing against the hydrophone or the rig. It can be mitigated by making sure all ropes are tightly fixed to rig, that no metal parts can come in contact with metal and keeping a distance vibration isolator between the hydrophone and the mooring rope. It may also be caused by animals physically hitting the hydrophone or rig.

The impact from **biofouling** can be mitigated by making sure the instruments are recovered or cleaned at servicing intervals or by placing them in deeper areas (below the photic zone).

3. Data analysis

3.1 Control of processing software

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.

- 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.

3.2 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:

3.2.1 Downloading and preparation of data

- Data recorded while the deployment is on-going and when the deployment ship is still near to the deployed sensor are to be saved but not to be used in analysis.
- Verify that all data files have been downloaded by verifying that the number of files and the size of the files matches between the logger data and the downloaded data.

3.2.2 Analysis of file size and clipping

- The integrity of each datafile must be checked. Duration of recording should match metadata in file.
- Non-numerical values (such as NaN (not-a-number) and Inf (too high value for a numerical representation) must be omitted prior to processing.
- Amount of clipped samples i.e. data values saturated by the recording system should be assessed. Analysis blocks (between 1 and 20 seconds) with more than 0.1% of the samples clipped should be omitted from further analysis.
- Testing of consistent recording times in filename dates.

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

3.2.3 Quality control of data and reporting

- It is important to follow the pre-processing routine described in section 3.2 to eliminate these sources of errors in the dataset. Data containing spurious signals should be included in the uploaded dataset.
- Check the quality of the processed data by plotting a time series of the data, either in the form of a spectrogram, or time series of specific third-octave frequency bands. Low frequency noise can be due to rig noise, or periodic flow noise (section 2.2.1).
- Check that the recordings are not limited by rig noise, flow noise etc. to a degree where it will affect the processed data.

3.3 Signal processing

3.3.1 Conversion to sound pressure

The data processing to convert the raw data signal to sound pressure follows the same standard as described in Wang et al 2019 [14].

1. Read 1-second segment of data, i.e. $N = T\,fs$, where fs is the sample rate and T the analysis window.
2. Apply the sensitivity of the hydrophone using either a sensitivity response curve or a single value provided the sensitivity response of the instrument is uniform in the frequency range.

The full-bandwidth sound pressure level (SPL) in dB re 1 µPa may be calculated in the time domain using

$$Lp = 10log_{10}\left(\frac{1}{Np_0^2}\sum_{i=1}^{N} p_i^2\right),$$

where p_0 is the reference pressure of 1 µPa and p_i the time series of the sound pressure (Crawford et al. 2019).

3.3.2 Third- octave bands

The sound pressure is converted to third-octave frequency SPL according to:

$$Lp = 10log_{10}\left(\frac{1}{N\ \ p_0^2}\sum_{i=1}^{N} |P_k\ |^2\right),$$

where P_k are the coefficients in the discrete Fourier transform (DFT). The DFT is derived from 1-second segments of the signal, yielding a nominal analysis bandwidth of 1 Hz. Several adjacent bins are summed together to approximate a 1/3rd-octave band filter. The bands to be used are IEC bands number 13 to 43 (IEC, 61260-1:2014), which are shown in Table 2.

To improve the accuracy at lower frequency bands below 100 Hz, two methods can be used. First, bandwidth correction, which reflects the difference in the actual frequency band and the upper and lower edges of the band. Secondly, by zero-padding the data, i.e. artificially increasing the frequency resolution in the analysis window. Details on the calculations are found in Crawford et al. 2019 [13].

Table 2. Information on the 1/3rd-octave band filters to be used.

IEC/ANSI band no.[15]	Band index n	Lower bound (Hz)	Center frequency (Hz)	Upper bound (Hz)	Nominal centre frequency (Hz)
13	-17	17,8	20,0	22,4	20
14	-16	22,4	25,1	28,2	25
15	-15	28,2	31,6	35,5	31,5
16	-14	35,5	39,8	44,7	40
17	-13	44,7	50,1	56,2	50
18	-12	56,2	63,1	70,8	63
19	-11	70,8	79,4	89,1	80
20	-10	89,1	100,0	112,2	100
21	-9	112,2	125,9	141,3	125
22	-8	141,3	158,5	177,8	160
23	-7	177,8	199,5	223,9	200
24	-6	223,9	251,2	281,8	250
25	-5	281,8	316,2	354,8	315

26	-4	354,8	398,1	446,7	400
27	-3	446,7	501,2	562,3	500
28	-2	562,3	631,0	707,9	630
29	-1	707,9	794,3	891,3	800
30	0	891,3	1000,0	1122,0	1000
31	1	1122,0	1258,9	1412,5	1250
32	2	1412,5	1584,9	1778,3	1600
33	3	1778,3	1995,3	2238,7	2000
34	4	2238,7	2511,9	2818,4	2500
35	5	2818,4	3162,3	3548,1	3150
36	6	3548,1	3981,1	4466,8	4000
37	7	4466,8	5011,9	5623,4	5000
38	8	5623,4	6309,6	7079,5	6300
39	9	7079,5	7943,3	8912,5	8000
40	10	8912,5	10000,0	11220,2	10000
41	11	11220,2	12589,3	14125,4	12500
42	12	14125,4	15848,9	17782,8	16000
43	13	17782,8	19952,6	22387,2	20000

3.4 Data reporting and storage

3.4.1 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), but also detailed information on the instrumentation, the calibration value and gain settings, and the rig design.

ICES hosts the continuous noise data, and information on the format and details on the data that are to be reported can be found on the Continuous noise data portal on the ICES webpage.

3.4.2 Data storage

Raw data shall be stored by the Contracting Parties.

4. Contacts and references

4.1 Contact persons

HELCOM Expert Network on Underwater Noise (EN-Noise).

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