Report on the definition and implementation of the processing protocols

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Summary

Abstract

The processing protocols for all expected results are agreed upon, defined and described in detail. All processing protocols will be implemented on the commonly agreed platform and delivered to all involved partners.

1. Introduction

There has been an increased need to make *in-situ* measurements of underwater noise for the assessment of risk to marine life. Evaluating the underwater noise (UN) as described in the D11 of the Marine strategy Framework directive (MSFD) requires the implementation of a monitoring programme that guarantees that underwater noise of anthropogenic origin, is at levels that do not adversely affect the marine environment. The Soundscape project establishes interdisciplinary and transnational collaboration between partners having complementary skills and know-how in biology, physics, underwater acoustics, monitoring and maritime spatial planning to measure and evaluate UN levels and impact for marine environment. The partners have common interest to assess the underwater noise pollution in the North Adriatic Sea and to preserve its biodiversity. The monitoring of underwater noise foreseen by the MSFD D11 has not really started yet in the Adriatic Sea and Soundscape is a first wide scale approach to do so.

By integrating the acoustical and ecological dimensions of the marine environment, SOUNDSCAPE will help industry, public authorities and regulators to be aware of the impact of underwater noise on marine ecosystems and evaluate the consequences of proposed marine developments towards a knowledge-based management of the marine resources, developing sustainable blue growth solutions.

2. Scope

This document specifies the signal processing procedures that were accepted by all partners of the Soundscape project. The main topic is restricted to digital signal processing, identification of the common acoustic metrics for describing underwater noise, including definitions and units, and how these metrics should be reported including quality check.

For each step relevant in the processing of the data, a general description will be given to what has been done in the Soundscape project with some justification to why it has been done based on the previous knowledge and MSFD recommendations.

3. Brief review and guidelines on signal processing to extract noise indicators

The main interest of Soundscape project is to evaluate anthropogenic noise from ships and recreational boats, creating a methodology for evaluating the underwater noise. As described in the D11 of the Marine strategy Framework criterion D11C2 for continuous low-frequency sound sources, there are specific measure of the spatial distribution, temporal extent and levels of anthropogenic
noises that should not exceed levels that adversely affect populations of marine animals. Noise measurements consist in performing some data acquisition and extracting the corresponding noise indicators. Many different approaches can be used for that purpose, but it is important that the steps taken guarantee that noise indicators can be compared among different countries.
In this document we followed guidelines from previous projects for UN evaluation from different areas: Batlic Sea (BIAS, 2015), Mediterranean Sea (quietMed, 2018) and also good practice guide (NPL Good Practice Guide No. 133, 2014). Another important source of recommendations is the EU Technical Sub-Group on Noise (EU TSG Noise), an expert committee which was set up to provide guidance on the implementation of the EU Marine Strategy Framework Directive (MSFD), it has produced recent reports which partly cover the topic of guidance on noise measurement [EU TSG 2014a, 2014b, 2014c].

4. Metrics

Considering units standardisation for underwater noise measurements there are some works under the auspices of the International Organization for Standardisation (ISO) that has special panel called 'underwater acoustics' (ISO/TR 25417:2007, ISO/PAS 17208-1:2012) but the work is still in progress, although crucial units for this topic are established. However, more important for this study are measures related to sound pressure and their averaged quantities that can in time and frequency domain show sound variability and are described below.

4.1. Acoustic quantities

Underwater sound is a disturbance in pressure and consists of alternating compressions and rarefactions of the water. Sound pressure is often defined as the difference between instantaneous total pressure and the pressure which would exist in water with the absence of sound waves. It is also the quantity to which a hydrophone responds and that is a basis of sound description. The most common measures used in underwater acoustics are (NPL, 2014; BIAS, 2015):

- **sound pressure (or "instantaneous sound pressure")**

$$p(t) \text{ in [Pa]}$$

The difference between instantaneous total pressure and pressure that would exist in the absence of sound (‘static pressure’). Sound pressure is expressed in units of pascals (Pa, equivalent of N/m²).

- **peak sound pressure (or zero-to-peak sound pressure)**

p_{peak} in [Pa]
$p_{peak} = \max(\mathrm{abs}(p(t)))$

The maximum sound pressure during a stated time interval. A peak sound pressure may arise from a positive or negative sound pressure, and the unit is the pascal (Pa). This quantity is typically useful as a metric for a pulsed waveform, though it may also be used to describe a periodic waveform.

- **root mean square (RMS) sound pressure**

p_{rms} in [Pa]

$$p_{rms} = \sqrt{1/T \int_T p(t)^2 dt}$$

With T = integration (averaging) time.

The square root of the mean square pressure. The RMS sound pressure is calculated by first squaring the values of sound pressure, averaging over the specified time interval, and then taking the square root. The RMS sound pressure is expressed in pascals (Pa). The averaging time must always be stated.

- **bandwidth**

B in [Hz]

The frequency range within which a recording system is sensitive or the range of frequencies between lower and upper limits within which most of the energy is contained.

- **spectral density**

The spectral density is a frequency domain representation of a time series. Any quantity expressed as a contribution per unit of bandwidth.

- **third-octave frequency band**

A frequency band whose bandwidth is one third of an octave, where an octave represents a doubling in frequency. The IEC (IEC 61260:1995) recommended standard defines a **third octave band** as one tenth of a decade (called base 10 method).

Third-octave bands originate from studies on human hearing and the extent to which noise at one frequency can interfere with hearing,other species may have different critical bands. This measure is very important while MSFD indicators are based on the third octave bands (Commission Decision 2010/477/EU, 2010), their centre frequencies are 63 Hz and 125 Hz but TSG recommendations are that data collection and analysis should be taken until 20kHz. It is especially valid for the Soundscape project, because contribution to UN of recreational boats and their noise frequency are not well known so far. Here is a table with the third-octave low, centre and upper frequencies that we are planning to use. Beside the frequencies foreseen by the MSFD, we also select the third octave bands centered on the frequencies 250 Hz and 4 kHz, according to the indications of the deliverable *D-4.2.1. Gap-analysis report based on existing knowledge of the sensitivity of target species.*

Table 1. The third octave frequencies referred to base 10 calculations. Red colour shows bands recommended for SPL calculations for noise monitoring

Band Number	Lower Frequency [Hz]	Nominal Frequency [Hz]	Upper Frequency [Hz]
1	14.13	16	17.78
2	17.78	20	22.39
3	22.39	25	28.18
4	28.18	31.5	35.48
5	35.48	40	44.67
6	44.67	50	56.23
7	56.23	63	70.79
8	70.79	80	89.13
9	89.13	100	112.20
10	112.20	125	141.25
11	141.25	160	177.83
12	177.83	200	223.87
13	223.87	250	281.84
14	281.84	315	354.81
15	354.81	400	446.68
16	446.68	500	562.34
17	562.34	630	707.95
18	707.95	800	891.25
19	891.25	1000	1122.02
20	1122.02	1250	1412.54
21	1412.54	1600	1778.28
22	1778.28	2000	2238.72
23	2238.72	2500	2818.38
24	2818.38	3150	3548.13
25	3548.13	4000	4466.84
26	4466.84	5000	5623.41
27	5623.41	6300	7079.46
28	7079.46	8000	8912.51
29	8912.51	10000	11220.18
30	11220.18	12500	14125.38
31	14125.38	16000	17782.79
32	17782.79	20000	22387.21

4.2. Sound level measures

The most generally used logarithmic scale for describing sound is the decibel scale (dB) using one microPascal (1 µPa) as reference pressure for water environment.

a) sound pressure level (SPL)

SPL in [dB re 1 µPa]

$$SPL = 10 \cdot log_{10} \frac{1/_T \int_0^T p(t)^2 dt}{p_0^2} = 10 \cdot log_{10} \left(\frac{p_{rms}}{p_0}\right)^2 = 20 \cdot log_{10} \left(\frac{p_{rms}}{p_0}\right)$$

with T = integration time.

p_0 in [Pa] – reference pressure

1 µPa in underwater acoustics,20 µPa in air acoustics.

SPL is a measure of the effective pressure of a sound, averaged in time, and relative to a standard reference pressure. It can be calculated as ten times the logarithm to base 10 of the ratio of the mean square sound pressure over a stated time interval to the reference value of sound pressure squared ($1µPa^2$) and it is called “mean-square-sound-pressure level”. Another way to calculate itis twenty times the logarithm to base 10 of the ratio of the root mean square (RMS) sound pressure over a stated time interval to the reference value for sound pressure (1µPa) which is called “root-mean-square-sound-pressure level”. As in recommendations (NPL, 2014) the time interval used in the calculation of SPL must be stated as well as any frequency weighting.

b) sound exposure level (SEL)

SEL in [dB re 1 $µPa^2s$]

$$SEL = 10 \cdot log_{10} \left(\frac{E}{p_0^2 T_0}\right) = SPL + 10 log_{10} \left(\frac{T}{T_0}\right)$$

With reference time T_0 = 1 s
With T being the time period of the event of interest in seconds.

Takes the different duration of sounds into account and it is ameasure of the accumulated energy over a defined period (often 1 second). The reference value for sound exposure level in water is 1 $µPa^2$*s.
When applied to an acoustic pulse, the integration time is the pulse duration. If a specific frequency weighting is applied, this should be stated or indicated by appropriate subscripts. When applied to a

single event, the quantity is commonly called the "single event sound exposure level" (or "single pulse sound exposure level").

c) power spectral density level (PSD)

All organisms can only perceive a limited subset of sound frequencies, depending on their perception mechanisms. It is therefore necessary to describe how the power of sound relates to the frequency. Power spectral density level is expressed in dB re 1 $\mu Pa^2/Hz$ and represents the average sound pressure for each band of frequency width (1 Hz).

d) 1/3-octave band level

Coarse sound level spectrum with logarithmic frequency scaling, dB ref. 1 µPa. These levels show the power in frequency bands that widen exponentially with increasing frequency and are evenly spaced on a logarithmic frequency axis.

e) percentile level

It is defined as the level LN that is exceeded for N percent of the time interval considered. For example, L1 is the level that is exceeded 1% of the time. The L1 can be used as a measure for the maximum level. Accordingly, L99 and L95 are used to describe the minimum level. L50 is the median level.

5. Data processing workflow

5.1 Pre-processing of data

Data must be checked to ensure the quality of the recording priorto calculating any corresponding ambient noise indicators. Prior to deployment test measurements should prove that self-noise of a noise recording set is below ambient noise levels at the place of monitoring.

Size and time stamp of each file should be checked if referring to time schedule of recordings is with sufficient duration. Each station should be checked for data coverage, gaps in data extend according to measurement period. All corrupted files should be moved to separate folder, so they do not interrupt further data processing.

First check of the data content should involve non-numerical values control and clipping. Clipping occurs when sound pressure exceeds the dynamic range of the acquisition system, that happens when the device sensitivity is inadequate for the sound level to be measured.

Acoustic data are recorded in WAV format that represents signal in relative measure. To calculate the physical units of pressure $[\mu Pa]$ transfer function (also called 'inverse sensitivity') needs to be used to calibrate recorded signal due to sensor sensitivity $[dB\ re\ 1V/1\mu Pa]$, preamplifier and filter board gain [dB] and ADC ([dB re digital counts/1V]) scale factors [EU TSG 2014b].

5.2 Signal processing

In Soundscape data processing workflow assumes that all basic filtering and processing is made using algorithms implemented on the server to fasten calculations and make them available for all users and

project participants. Basic noise measures are also stored there and can be downloaded and processed further on.
The processed signal range is limited to 20Hz threshold due to cut-off frequency calculations described in the deliverable 3.2.1. It was decided to use this value for every hydrophone to unify processing process, although those data are not rejected from the recordings and can be included to further and more detailed analysis.
In the first step, an FFT-analysis is done over consecutive 1second periods, giving amplitude spectra with a 1 Hz resolution to calculate the sound pressure levels (SPL) as defined above in the required 1/3-octave bands over 1 second. These SPL's are corrected due to gain and sensitivity factors. Sensitivity curve is delivered by the manufacturer of hydrophones and interpolated for every Hertz and averaged to cover all necessary 1/3-octave bands. The 1s SPL averages are then further processed to averages over 20 seconds. A standard method for time-averaging spectra is used (Welch, 1967).
Estimates such as hourly, daily and monthly averages are calculated based on the 20s averages, depending what information's are required for further modelling. Finally, the annual mean is also derived using the 20s averages.
The extraction of the energy through 1/3-octave bands is made with an FFT-filter. Frequencies of the 1/3 octave filters as well as bandwidth corrections were computed following the standard (IEC 61260, 1995). The spectrum is derived by calculating the Discrete Fourier Transform (DFT) of the signal. The filters used in Soundscape are all 1/3-octave bands until 32 included (Table 1), even though only bands 18 and 21 that are the 1/3- octave bands centred at 63 Hz and 125 Hz, respectively, are required by the MSFD.
Following BIAS (BIAS, 2015) recommendations with regards to the filtering it is suggested to derive the DFT with a nominal bandwidth of 1 Hz. This is a compromise between time resolution and the possibility of implementing FFT-based band-pass filters with reasonable shape even at low frequencies. Using a segment size of 1 s for the DFT, the nominal bandwidth of the DFT-bins becomes 1 Hz.
In general it is recommended by EU TSG Noise group with regard to averaging of noise data to use arithmetic mean and median. Arithmetic mean is in that case the average of the snapshot (analysis time window) values expressed as mean square sound pressures (or RMS values). This method is very much influenced by high amplitude events. Median of the snapshot values is an equivalent to the 50th percentile. It is much less sensitive for high amplitude events occurrence.

6. Presentation of Results

There are three basic representations for ambient noise indicators: SPL versus time, SPL histograms and Spectral representations (1/3 octave and narrowband).

SPL versus time might be visualize as inexample of the 1/3 octave indicators (63 Hz, 125 Hz) computed during6 hours. SPL can be averaged for 1 second, 20 seconds, 1 minute, 10 minutes and 1 day.

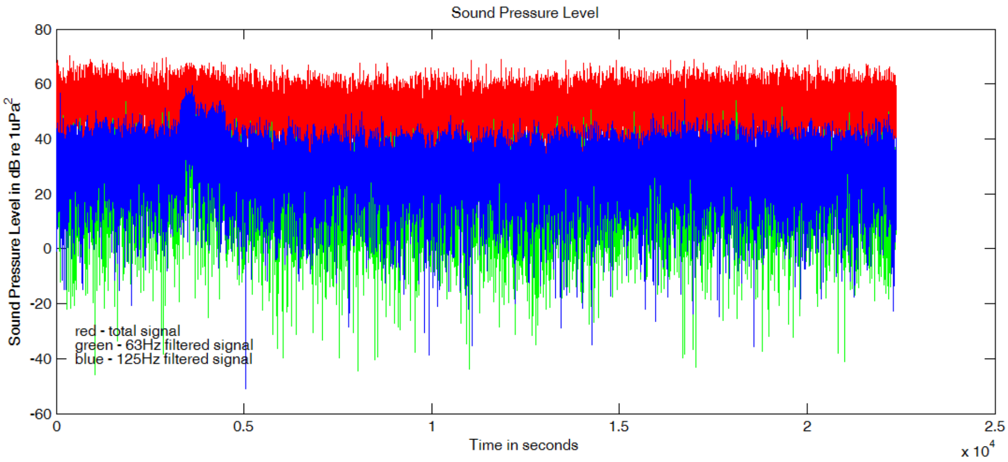


Fig.6.1. Example of sound pressure level at intervals of 1 second - arithmetic averaging, red line – total signal, green line – 63 Hz, blue line – 125 Hz. Ship noise visible at 1 hour.

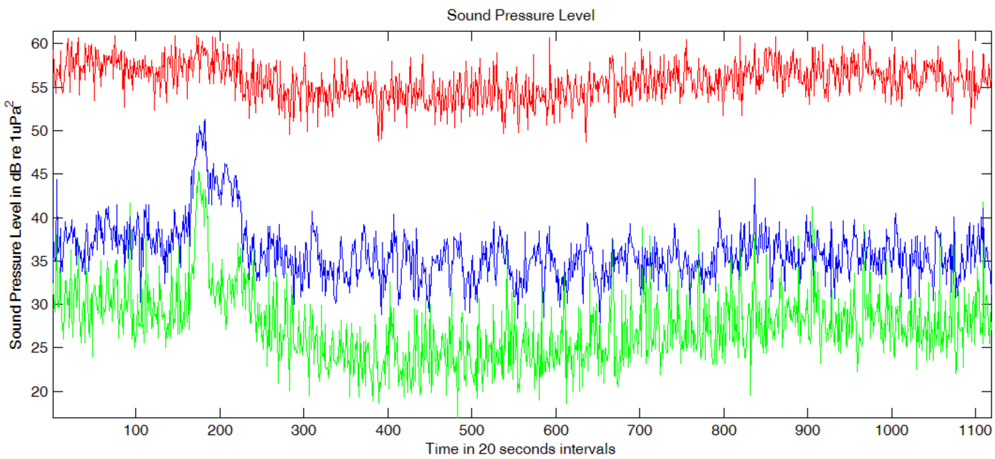


Fig.6.2. Example of sound pressure level at intervals of 20 seconds - arithmetic averaging, red line – total signal, green line – 63 Hz, blue line – 125 Hz.

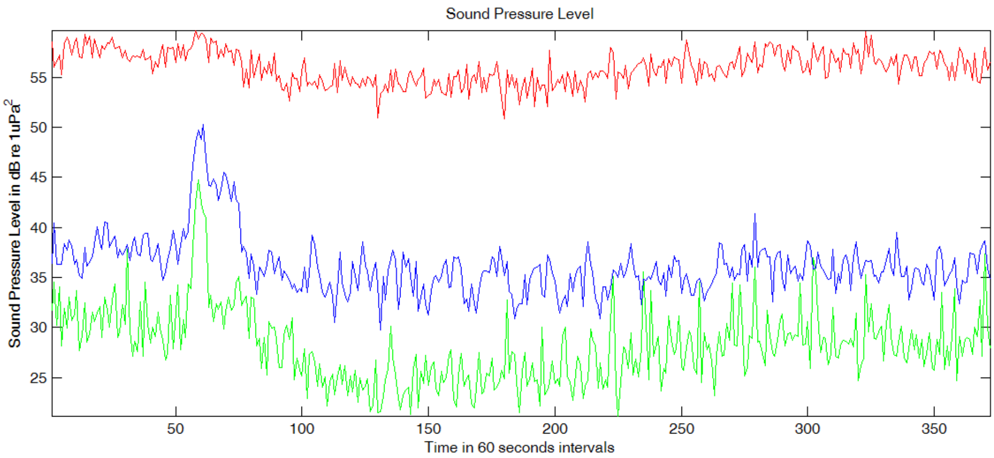


Fig.6.3. Example of sound pressure level at intervals of 60 seconds - arithmetic averaging, red line – total signal, green line – 63 Hz, blue line – 125 Hz.

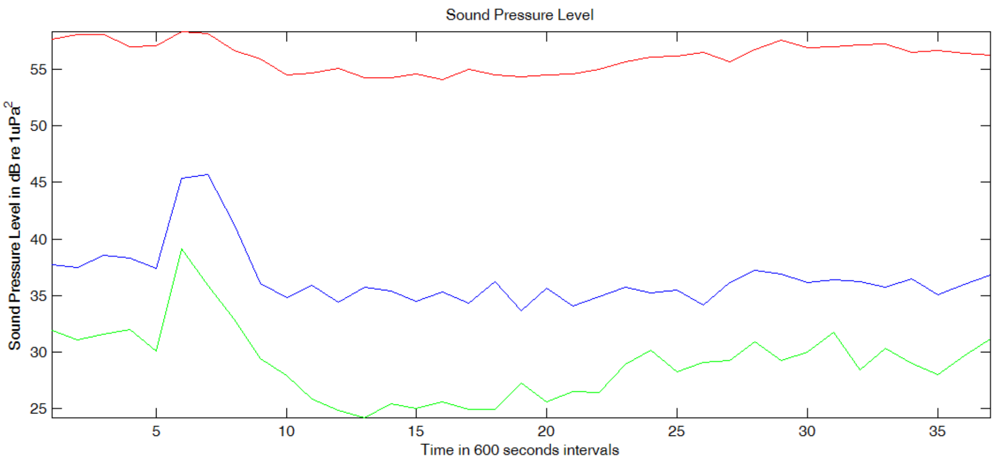


Fig.6.4. Example of sound pressure level at intervals of 600 seconds - arithmetic averaging, red line – total signal, green line – 63 Hz, blue line – 125 Hz.

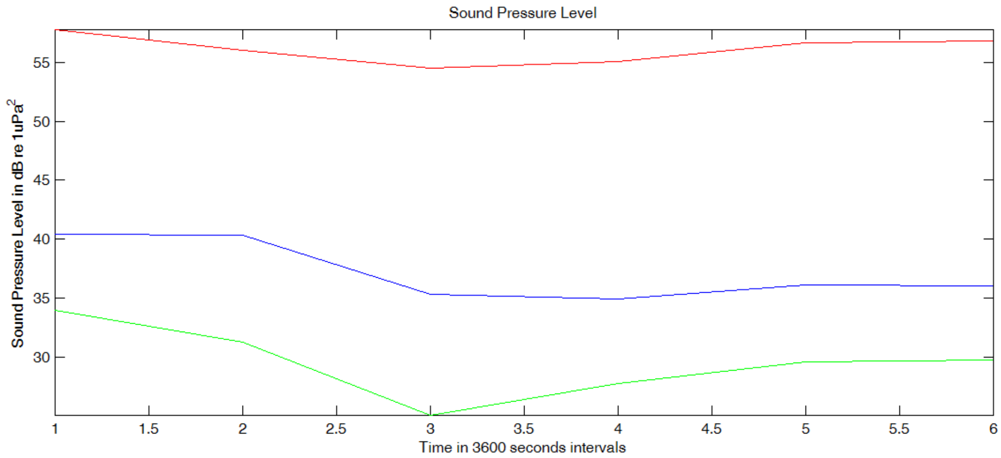


Fig.6.5. Example of sound pressure level at intervals of 3600 seconds - arithmetic averaging, red line – total signal, green line – 63 Hz, blue line – 125 Hz.

Acoustic noise spectrum level presented as well for certain time period. This kind of graph can show dominant frequencies for noise sources.

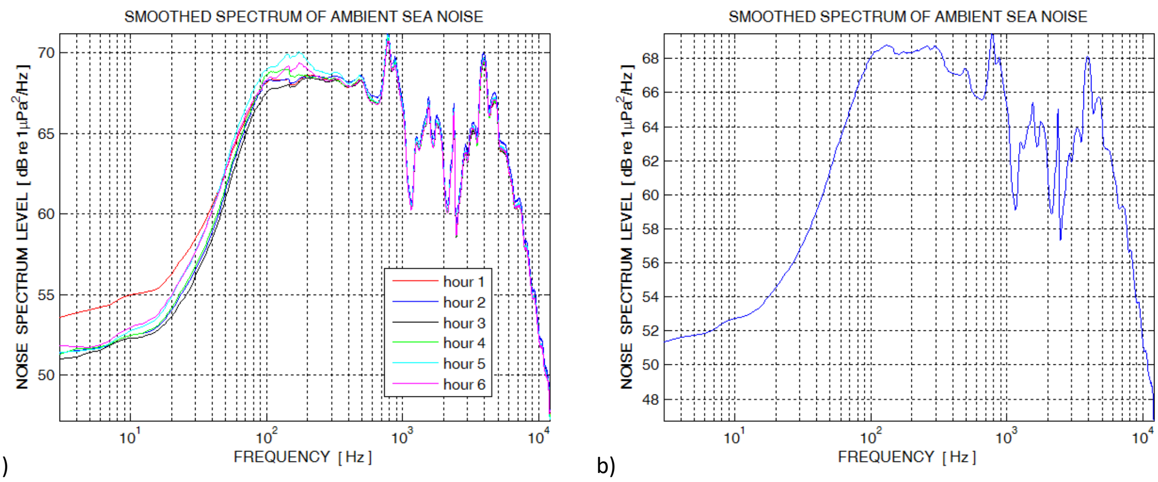
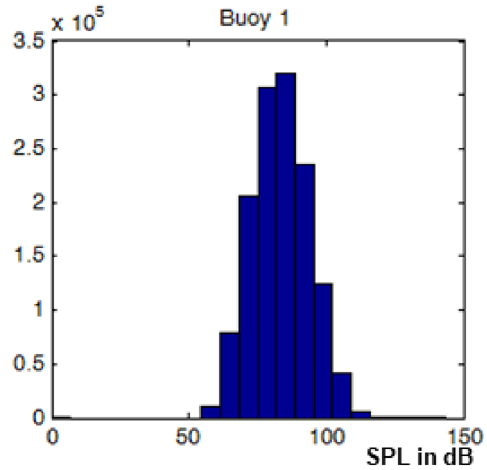
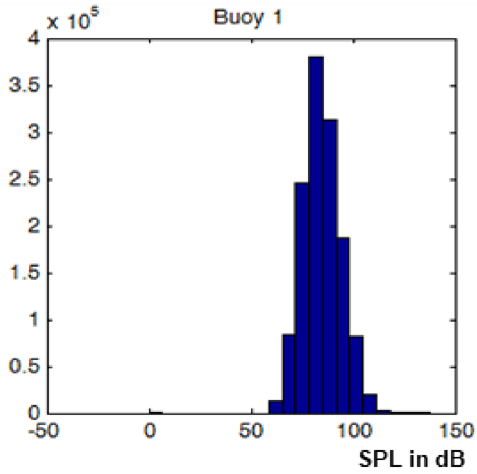


Fig.6.6. Example of noise spectrum level for 6 hours registration (figures 6.1 ÷ 6.5) a) averaged for 1 hour consecutive registrations, b) averaged for total 6 hours registration.

SPL histogram representations show contribution of SPL levels for certain 1/3 octave band within time period (weekdays and weekends, winter and summer), giving an estimate of dominant SPL levels to be compared between different time frame.



a)



b)

Fig.6.7. Example of histogram of Sound Pressure Levels (SPL) in a) 63 Hz band, b) 125 Hz band averaged for the one year of registration.

7. References

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