QUIETMED – Joint programme on noise (D11) for the implementation of the Second Cycle of the MSFD in the Mediterranean Sea.

Deliverable

D3.2 Best practices guidelines on signal processing algorithms for the pre-processing of the data and for obtaining noise indicators.

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No	Participant organization name	Participant short name	Country
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2	Instituto Español de Oceanografía	IEO	Spain
3	Universitat Politècnica de València	UPV	Spain
4	Service Hydrographique et Océanographique de la Marine	SHOM	France
5	Ispra Instituto Superiore per la Protezione e la Ricerca Ambientale	ISPRA	Italy
6	Inštitut za vode Republike Slovenije/Institute for water of the Republic of Slovenia	IZVRS	Slovenia
7	Permanent Secretariat of the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area	ACCOBAMS	Monaco
8	The Conservation Biology Research Group, the University of Malta	UoM	Malta
9	Institute of Oceanography and Fisheries	IOF	Croatia
10	Foundation for Research and Technology - Hellas	FORTH	Greece

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Abstract

This document is Deliverable "D3.2 Best practices guidelines on signal processing algorithms for the pre-processing of the data and for obtaining noise indicators" of the QUIETMED project funded by the DG Environment of the European Commission within the call "DG ENV/MSFD Second Cycle/2016". This call funds the next phase of MSFD implementation, in particular to achieve regionally coherent, coordinated and consistent updates of the determinations of GES, initial assessments and sets of environmental targets by July 2018, in accordance with Article 17(2a and 2b), Article 5(2) and Article 3(5) of the Marine Strategy Framework Directive (2008/56/EC). The QUIETMED project aims to enhance cooperation among Member States (MS) in the Mediterranean Sea to implement the Second Cycle of the Marine Directive and in particular to assist them in the preparation of their MSFD reports by 2018 through: i) promoting a common approach at Mediterranean level to update GES and Environmental targets related to Descriptor 11 in each MS marine strategies ii) development of methodological aspects for the implementation of ambient noise monitoring programs (indicator 11.2.1) iii) development of a joint monitoring programme of impulsive noise (Indicator 11.1.1) based on a common register, including gathering and processing of available data on underwater noise. This confidential document reports the different steps that need to be taken to go from the registered sounds to the ambient noise indicators as described in the MSFD with particular emphasis of how it has been done in the QUIETMED project.

quietMED European Commission

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List of Abbreviations

CTN	Centro Tecnológico Naval y del Mar
IEO	Instituto Español de Oceanografía
UPV	Universitat Politècnica de València
SHOM	Service Hydrographique et Océanographique de la Marine
ISPRA	Ispra Instituto Superiore per la Protezione e la Ricerca Ambientale
IZVRS	Inštitut za vode Republike Slovenije
ACCOBAMS	Permanent Secretariat of the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area
UoM	The Conservation Biology Research Group, the University of Malta
IOF	Institute of Oceanography and Fisheries
FORTH	Foundation for Research and Technology - Hellas
MSFD	Marine Strategy Framework Directive

1 Introduction.

The QUIETMED Project is funded by DG Environment of the European Commission within the call "DG ENV/MSFD Second Cycle/2016". This call funds the next phase of MSFD implementation, in particular to achieve regionally coherent, coordinated and consistent updates of the determinations of GES, initial assessments and sets of environmental targets by July 2018, in accordance with Article 17(2a and 2b), Article 5(2) and Article 3(5) of the Marine Strategy Framework Directive (2008/56/EC).

The QUIETMED project aims to enhance cooperation among Member States (MS) in the Mediterranean Sea to implement the Second Cycle of the Marine Directive and in particular to assist them in the preparation of their MSFD reports by 2018 through: i) promoting a common approach at Mediterranean level to update GES and Environmental targets related to Descriptor 11 in each MS marine strategy ii) development of methodological aspects for the implementation of ambient noise monitoring programmes (indicator 11.2.1) iii) development of a joint monitoring programme of impulsive noise (Indicator 11.1.1) based on a common register, including gathering and processing of available data on underwater noise. The Project has the following specific objectives:

- ✓ Achieve a common understanding and GES assessment (MSFD, Article 9) methodology (both impulsive and continuous noise) in the Mediterranean Sea.
- ✓ Develop a set of recommendations to the MSFD competent authorities for review of the national assessment made in 2012 (MSFD, Article 8) and the environmental targets (MSFD, Article 10) of Descriptor 11- Underwater Noise in a consistent manner taking into account the Mediterranean Sea Region approach.
- ✓ Develop a common approach to the definition of threshold at MED level (in link with TG Noise future work and revised decision requirements) and impact indicators.
- ✓ Coordinate with the Regional Sea Convention (the Barcelona Convention) to ensure the consistency of the project with the implementation of the EcAp process
- ✓ Promote and facilitate the coordination of underwater noise monitoring at the Mediteranean Sea level with third countries of the region (MSFD Article 6), in particular through building capacities of non-EU Countries and taking advantage of the ACCOBAMS-UNEP/MAP cooperation related to the implementation of the Ecosystem Approach Process (EcAp process) on underwater noise monitoring.
- ✓ Recommend methodology for assessments of noise indicators in the Mediterranean Sea basin taking into account the criteria and methodological standards defined for Descriptor11 (Decision 2010/477/EU, its revision and Monitoring Guidelines of TG Noise).
- ✓ Establish guidelines on how to perform sensor calibration and mooring to avoid or reduce any possible mistakes for monitoring ambient noise (D 11.2.1). These common recommendations should allow traceability in case the sensor give unexpected results and help to obtain high quality and comparable data.
- ✓ Establish guidelines on the best signal processing algorithms for the pre-processing of the data and for obtaining the ambient noise indicators (D 11.2.1).

- ✓ Implement a Joint register of impulsive noise (D11.1.1) and hotspot map at Mediterranean Sea Region level by impulsive noise national data gathering and joint processing.
- ✓ Enhance collaboration among a wide network of stakeholders through the dissemination of the project results, knowledge share and networking.

To achieve its objectives, the project is divided in 5 work packages which relationships are shown in Figure 1.

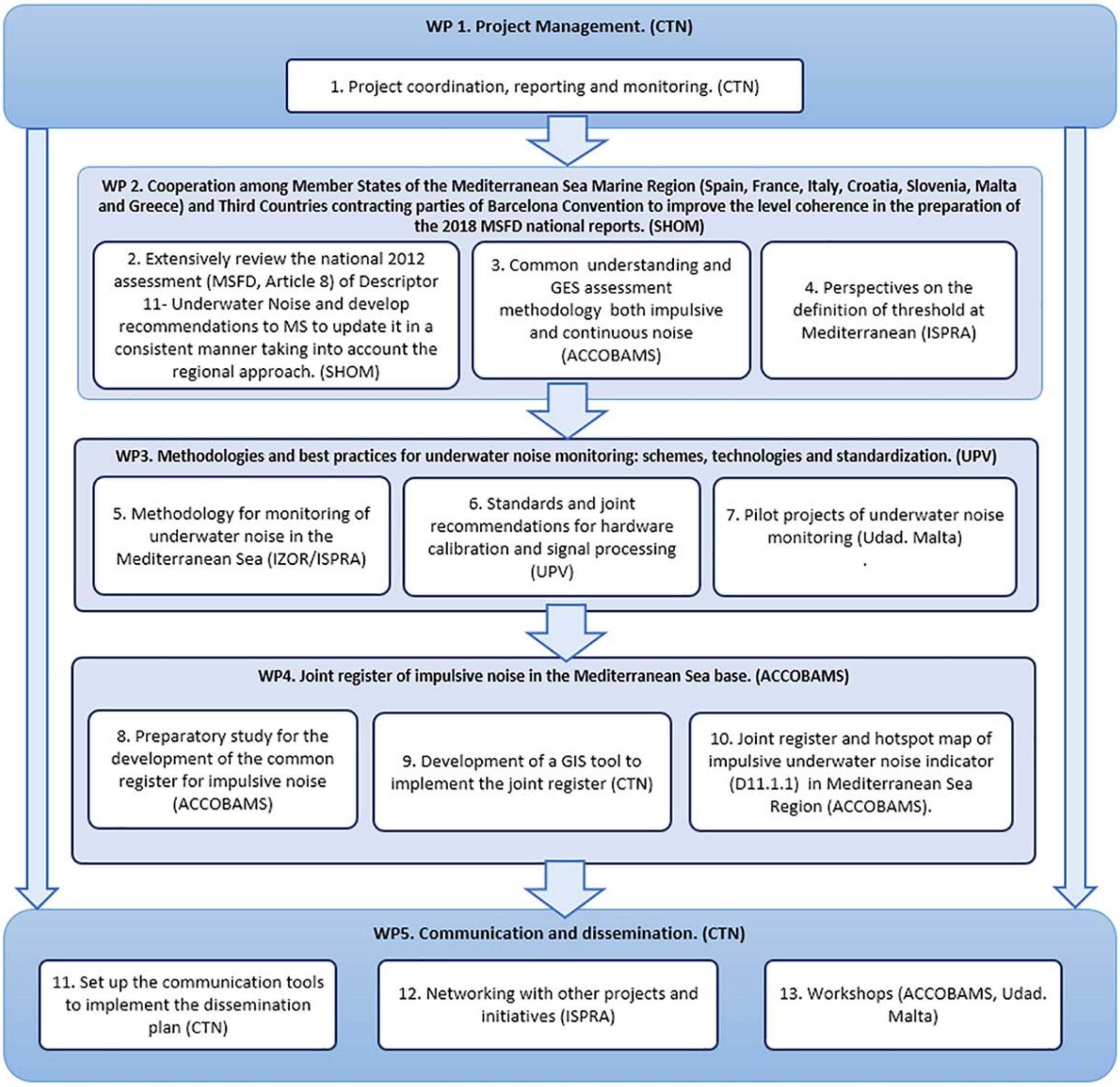

Figure 1. Work Plan Structure

The project is developed by a consortium made up of 10 entities coordinated by CTN and it has a duration of 24 months starting on January 2017.

The aim of this document is to give an overview of the different steps that need to be taken to go from the registered sounds to the ambient noise indicators as described in the MSFD with particular emphasis of how it has been done in the QUIETMED project. The remainder of this document is structured in the following parts. In the Section 2 we present the list of acronys that will be used in this deliverable. Later, in Section 3, we will enumerate and briefly summarize the main steps that need to be taken for the extraction of the different noise indicators. Details of how these approaches are implemented in the present project will be given in the Section 4. In the Section 5, the different ways of representing noise indicators are introduced. This document concludes with some recommendations for the quality control and as well as guidelines to guarantee that the data is properly preserved and its value maintained over time.

2 List of technical abreviations in the document.

ADC:	Analog to Digital Converter
PLP:	Perceptual Linear Prediction
gPLP :	Generalised Perceptual Linear Prediction
MFCC:	Mel Frequency Cepstral Coefficients
GFCCs :	Greenwood Function Cepstral Coefficients
PTR:	Pulsed to Tonal Ratio
SNR:	Signal to Noise Ratio
SPL:	Sound Pressure Level
SEL:	Sound Expossure Levels
ICI:	Inter Click Interval

3 Brief review and guidelines of the different approaches on pre-processing and signal processing to extract noise indicators.

Evaluating the underwater noise as described in the D11 of the Marinne strategy Framework Directive (MSFD) requires the implementation of a monitoring programme that guarantees that the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment. For this purpose two criteria had been stablished D11C1 and D11C2. Both criteria control that the spatial distribution, temporal extent and levels of anthropogenic noises do not exceed levels that adversely affect populations of marine animals. With this idea D11C1 focus on impulsive sound sources, whereas D11C2 does in continuous low-frequency sound sources. An important part of this process consists in performing some measurements and extracting the corresponding noise indicators. Many different approaches can be used but it is important that the steps taken guarantee that noise indicators can be compared among different countries. With this idea in mind we will review, from the signal processing point of view, the different stages involved in the process of extracting noise indicators.

3.1 Pre-processing.

Pre-processing is a crucial step in the processing of the acoustic recordings for an adequate extraction of noise indicators. Data must be checked to ensure the quality of the recording prior to calculating any corresponding ambient noise indicators. As it was done in previous projects [1], QUIETMED data is tested for: consistency and data coverage (making sure that the length of the data is in accordance with the planned recording schedule), self-noise (to ensure self-noise does not exceed ambient noise levels typically found at the measuring station) and clipping (to make sure noise levels do not exceed the dynamic range of the acquisition system). We also perform data cropping to remove audio data recorded before deployment and after the retrieval and so ensuring these parts are not used for ambient noise indicators statistics.

Checking of data coverage:

For calculating data coverage, the period of measured data is compared relative to the planned recording period. The coverage is given as percentage of period covered per planned period. File lengths are also tested to assure that all files have the same length.

Clipping:

Clipping happens when the device sensitivity is inadequate for the sound level to be measured. However, sometimes clipping can also occur when a loud source passes very close to the acoustic recorder location. We can have different kinds of clipping: hard and soft. Analog to digital converters (ADCs) are obviously mixed-signal devices with analog and a digital components. When clipping is due to the digital components of the ADC we can talk about hard clipping. However, when the analog components are the responsables of the signal distortion we can talk about soft clipping. Figure 2 illustrates the two different types of clipping and how they affect the signal shape.

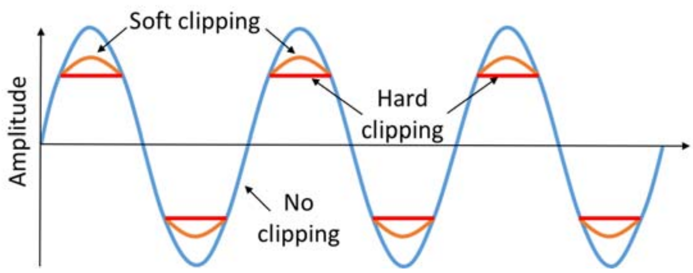

Figure 2: Hard clipping vs soft clipping.

In order to guarantee that ambient noise indicators are not affected by clipping, it is necessary to determine if clipping has occurred. This can be done by means of time-domain analysis as well as by means of histogram analysis. While the former is preferred for its simplicity, as only the number of clipped samples needs to be counted and expressed as a percentage of the signal length, it may not be the best option if soft clipping has occurred [2], [3]. In addition, clipping detection based on histogram analysis performs better when the data has short-time events of high level sound that affects only a small percentage of samples.

Thus, although histogram analysis may discard more clipped data than time-domain analysis, it guarantees that noise level estimates are not affected by clipping artefacts. The histogram of a non-clipped signal can be reasonably well approximated by a symmetric distribution with a smoothly decaying tail. Nevertheles, the histogram of a clipped signal shows an unnaturally high number of samples having an amplitude near the clipping level (Figure 3). Clipping can thus be detected by computing the deviation of the clipped histogram related to some known “base” non-clipped histogram. Alternatively, clipping can be also detected by counting the number of local maxima in the tails of the calculated histogram.

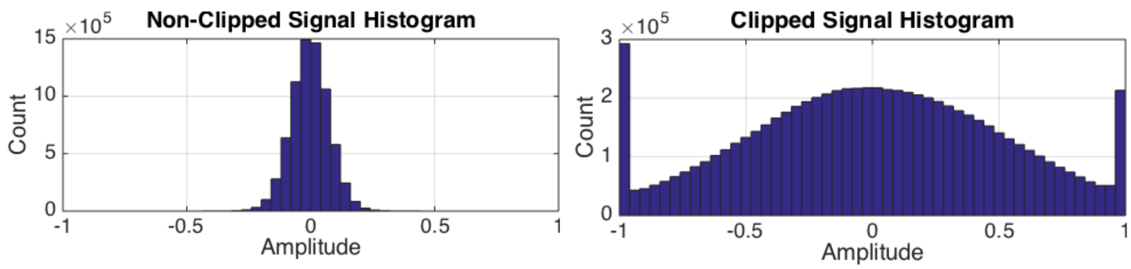

Figure 3: Left panel: histogram of a non clipped audio recording. Right panel: histogram of a heavily clipped audio recording.

The Matlab scripts created for clipping detection are based on histogram analysis. They have been used in the pre-processing of the QUIETMED data (Cabrera and Malta Pilot Project).

Transfer function calculation (gain corrections):

Since the audio files (*.WAV or any other format) units are in [counts] a transfer function to obtain the physical units of pressure [μPa] needs to be applied. The transfer function is described as the inverse sensitivity or 1/sensitivity [dB re $\mu Pa/counts$] and is frequency dependent.

Calculation:

1) Sensor sensitivity (Hydrophone) can be frequency dependent or flat $\left[dB\ re\,\frac{1V}{\mu Pa}\right]$.
2) Preamplifier+Filter Board Gain (usually frequency dependent) $[dB]$.
3) ADC (usually flat response) $[dB\ re\ counts/1\ V]$.

Example calculation for a given frequency:

Hydophone 8106 : -174 dB $\left[dB\ re\,\frac{1V}{\mu Pa}\right]$

Preamplifier: + 20 $[dB]$ gain

ADC (16-bit, +1-1 V range): $20\ \log_{10}(2^{16-1}/1\ \mathrm{V}) = 90.3\ [dB\ re\ \ counts/V]$

Transfer function or inverse sensitivity = - (-174 +20 +90.3)=63.7 $[dB\ re\ \ \mu Pa/counts]$

Self noise:

Althought device self-noise should be known prior to the deployment, whether because it has been provided by the manufacturer or because it has been estimated during calibration, noise generated by the deployment platform or mooring remains unknown. Undesired noise coming from the deployment itself contaminates the measured acoustic data even if care is taken during the preparation of the deployment. It is important thus to check acoustic signals to be sure no noise coming from the mooring contaminates the recordings. This can be done by listening to some of the signals and plotting spectrograms as well as comparing the obtained averaged levels of recorded sound (once ambient noise levels are obtained) with what it is expected in that location. If ambient noise data are not available for that region classic empirical curves for ambient noise levels can be used [4] and [5] as a baseline level.

3.2 Processing.

Following Commission Decision 2010/447/EU (and 2017/848/UE) the 1/3 octave bands around 63 Hz and 125 Hz are employed as ambient noise indicators. In addition, 2kHz and 5 kHz bands were also used due to the fact that ambient noise peaks appear frequently in these bands (although much of this may not be anthropogenic). The process of obtaining this ambient noise indicators consists in filtering the signal with the corresponding 1/3 octave filter and then obtaining the Sound Pressure Level for that band following Eq. (1)

$$SPL_{1/3} = 10 \cdot \log_{10} \frac{\frac{1}{t_2-t_1}\int_{t_1}^{t_2} p_{1/3}^2(t)dt}{p_0^2} \qquad (1)$$

, where $p_{1/3}(t)$ is the sound pressure in linear units [Pa] for the corresponding 1/3-octave band and $[t_1, t_2]$ is an integration interval of length T [sec.]. The $SPL_{1/3}$ indicator is given in logarithmic units refered to a reference pressure $p_0 = 1\ \mu Pa$.

There are two different ways of filtering the acoustic pressure, $p(t)$, to obtain the filtered version $p_{1/3}(t)$: in the time domain using a 1/3 octave filter bank and a much faster and simpler way employing the Fast Frequency Transform. Frequencies of the 1/3 octave filters as well as bandwidth corrections to avoid bandwidth approximation of the real 1/3 octave bandwidth were computed following the IEC 61260 (1995) in the same way done in similar projects [1].

Althought this is not required by the MSFD, additional signal processing for the detection of some cetacean species might be done. In the Appenidx A, we make a short review of the state of the art of algorithms traditionaly employed for the detection of cetaceans in acoustic passive acoustic monitoring.

4 Particularities on pre-processing and processing in the QUIETMED project.

Pre-processing and Signal processing is recommended in the QUIETMED project. In the former we check for undesired situations that can produce inaccurate ambient noise levels whereas in the later we obtain the different MSFD indicators. The process is illustrated in the Figure 4.

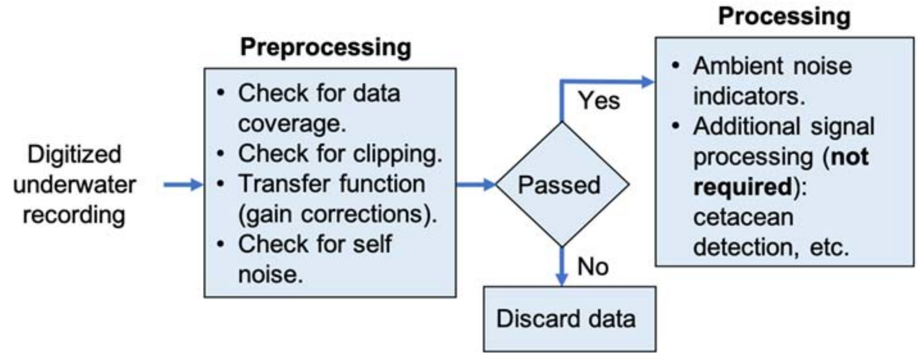

Figure 4: Pre-processing for ambient noise indicators in the QUIETMED project.

4.1 Pre-processing in the QUIETMED project.

Clipping detection in QUIETMED:

Clipping detection should be carried out by histogram analysis (see Section 3). Clipping tests should be performed for each integration interval and if clipping is detected the corresponding data fragment is flagged and not used for ambient noise estimation.

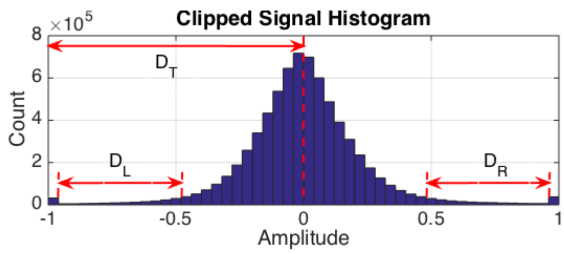

Figure 5: Meassure clipping using histogram analysis.

The particular metric employed in the QUIETMED project for testing data for clipping using histogram consist in measuring the distance from the local maxima in the left and right hand side of the histogram to the centre or mean value (see Figure 5). The maximum of this distance can be normalized by the total distance giving a Clipping Indicator (C_i) that ranges from 0 (no clipping) to 1 (heavy clipping). The Eq. (2) illustrates the procedure to obtain C_i.

$$C_i = \frac{max\{D_L, D_R\}}{D_T} \quad (2)$$

A Matlab function “*clipp_test.m*” has been created to perform the clipping detection using histogram analysis. This function gives a score from 0 to 1 based on C_i. This function has been used in the Cabrera and Malta Pilot to check the raw data for clipping prior to applying any signal processing algorithm. If the score was above 0.25 data fragment is considered to be clipped and no further processing is done.

4.2 Processing and obtention of noise indicators in the QUIETMED project.

Once recorded data has been validated by data checks the SPL ambient noise indicators may be calculated. For that purpose, Eq. (1) can be used. However, we need to take into account the discrete nature of the data. Digital filtering with the corresponding 1/3 octave bandpass filter needs to be computed as well as the discrete average power. The filtering process can be done in the time and in the frequency domain. If calculations are made in the frequency domain, Parseval´s theorem for a real signal can be used. This relates the discrete averaged signal power in the time and in the frequency domain (Eq. (3)).

$$\frac{1}{N}\sum_{n=n_1}^{n_1+N-1} p'(n)^2 = \frac{1}{N^2}\cdot\sum_{k=0}^{N-1}|P'(k)|^2 \tag{3}$$

In Eq. (3), $p'(n)$ is the acoustic pressure referred to the reference pressure level $p_0 = 1\ \mu Pa$, N is the number of samples of the integration interval $N = round(T * fs)$ and $P'(k)$ is the Discrete Fourier transform of $p'(n)$ of length N.

The process of obtaining the ambient noise indicator for a 1/3 octave band using Parseval´s theorem for a fragment of length N of the recorded signal $p'(n)$ can be summarized as follows:

1. Compute $P'(k)$, the Discrete Fourier Transform of $p'(n)$ refered to $p_0 = 1\ \mu Pa$.
2. Obtain the bins corresponding to the lower and higher cut-off frequency of the desired 1/3 octave band $[k_{low}, k_{high}]$.
3. Compute the ambient noise indicator $SPL_{1/3}$ as indicated in Eq. (4). Be aware that the factor 2 in Eq. (4) appears due to the fact that we are only adding the positive frequencies.

$$SPL_{1/3} = 10\cdot\log_{10}\left(\frac{2}{N^2}\cdot\sum_{k=k_{low}}^{k_{high}}|P'(k)|^2\right) \tag{4}$$

A Matlab batch processing has been created to compute SPL ambient noise indicators following Parseval´s approach. This script "QUIETMED_*ambient_noise_level_analysis*" has been used to obtain ambient noise indicators in the Cabrera and Malta Pilot Projects.

The integration interval ($T = N/f_s$ [seconds]) in the computation of ambient noise indicator determines the temporal resolution of the indicator. A trade-off between the capacity of identifying short acoustic events and obtaining compact and meaningful representations exist. In QUIETMED it was decided to use $T = 30$ [seconds] as the standard averaging interval.

Althought this is not required by the MSFD, the authors of this deliverable have employed different signal processing algorithms for the detection of: impulsive and tonal sounds, dolphin whistles and echolocation clicks. The Appenidx B summarizes how this was done in the framework of the project.

5 Guidelines on the representation of noise indicators in the QUIETMED project.

5.1 Traditional graphical representation techniques of ambient noise indicators (D11C2).

Long-term acoustic recordings result in large datasets that need to be stored and processed in order to obtain graphical representation of the different ambient noise indicators. In addition, sometimes we need to select a particular set of audio files taking into account a given variable such as: time of the day, weekend/weekday, etc. This allows the creation of comparative graphical representations of ambient noise under different circumstances. Figure 6 schematically illustrates the different elements involved in the process of graphical representation of noise indicators: sound database, querying of the database, and processing of the data files to obtain the graphical representations.

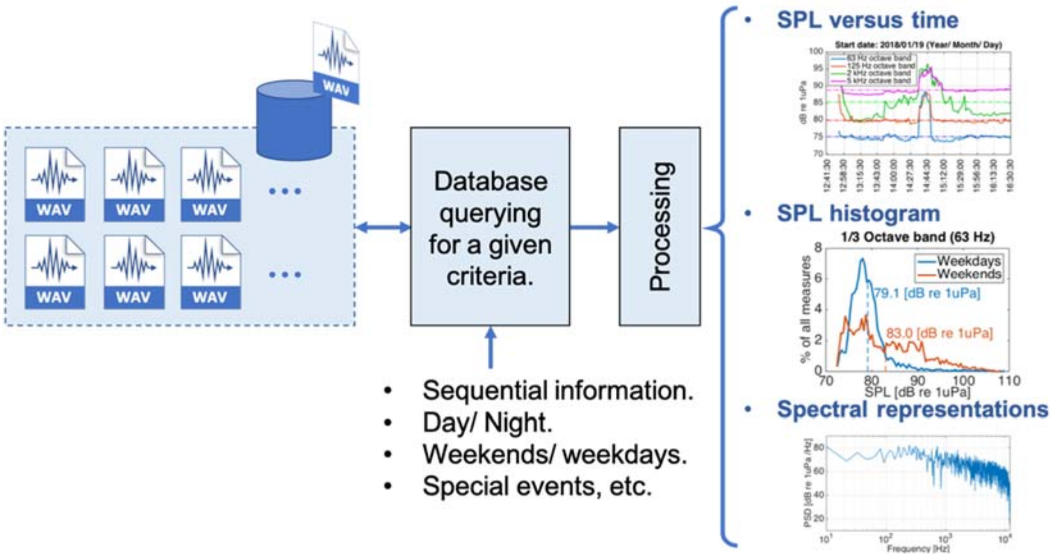

Figure 6: Different elements and stages involved in the creation of a graphical representation of ambien noise indicators.

There are three common graphical representation techniques for ambient noise indicators: SPL versus time, SPL histograms and Spectral representations (1/3 octave and narrowband). All three have been used in the QUIETMED project.

The processing stage in Figure 6, although typically used to compute ambient noise indicators, can be also used to obtain other indicators (detection of a cetaceans or ship noise for example). This, combined with the different representation techniques, allows a broad range of representations which may be used in future management of underwater sound.

SPL versus time:

Figure 7 shows an example of the 1/3 octave indicators (63 Hz, 125 Hz, 2kHz, and 5 kHz) computed during the first day of the QUIETMED Cabrera Pilot project deployment. The figure also shows the 66th percentile (L33) for each one of the 1/3 octave indicators as a dash-dot line.

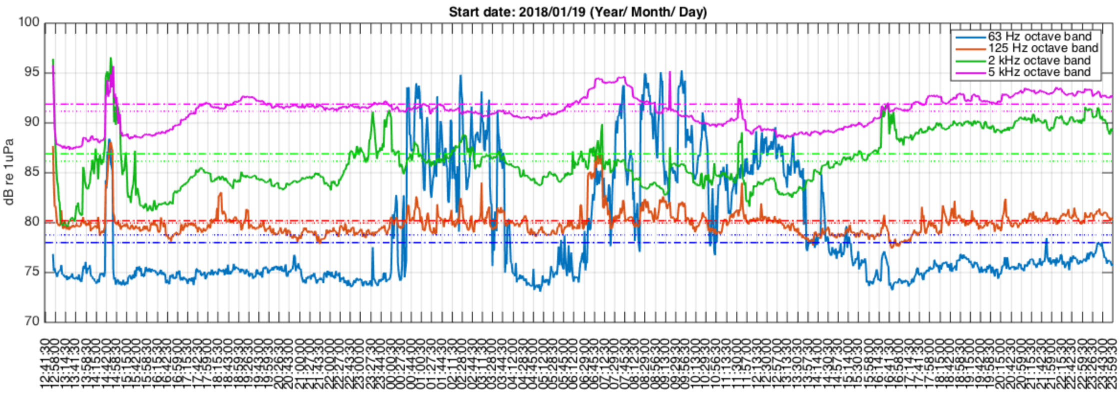

Figure 7: Ambient noise indicators vs time for the first two days of the Cabrera Pilot Project (Integration time T=30 seconds).

Representing a large number of 1/3 octave ambient noise indicators might be done by means of pseudo color representations. As an example we show in Figure 8 the noise levels at the central frequency of each 1/3 octave band up to 1 kHz for the Greece South pilot project.

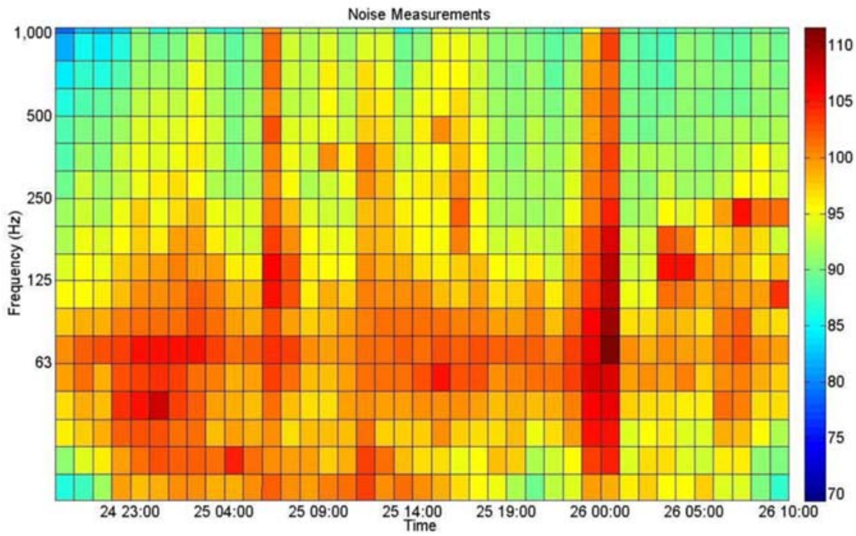

Figure 8: Octave noise levels calculated using data recorded by FORTH's UL1 for south 1 (Greece south Pilot project).

In some situations the averaged trends over one year are needed. The Figure 9 illustrates one of these representations for the deployment site in the Cabrera Archipelago Maritime National Park using estimated data. The only real values in the The Figure 9 corresponds to the ones from the QUIETMED Cabrera Pilot project (January-February 2018). The averaged trends for the rest of the months have been estimated using non-calibrated data from previous deployments (years 2013-2016). It is importan to emphasize that this representation should only be used as an example of year trend representations.

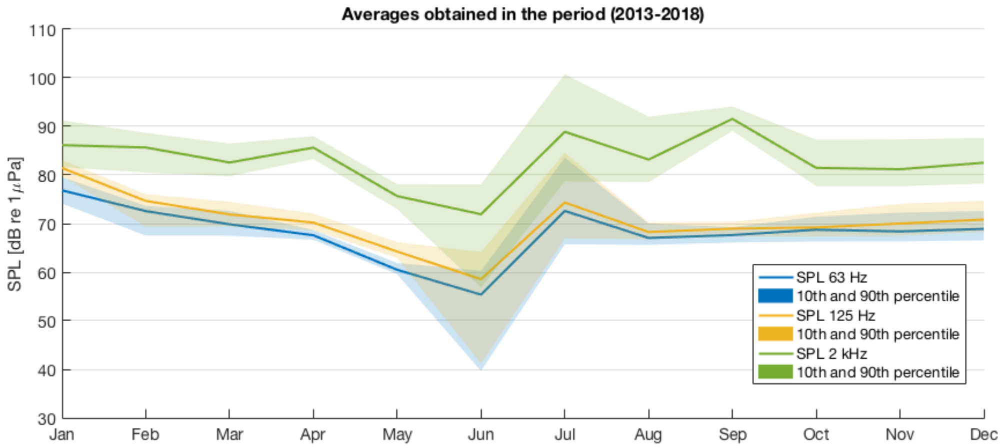

Figure 9: Ambient noise averages estimations in a year for the Cabrera Archipielago.

SPL histograms:

Regarding the SPL histogram representations, Figure 10 shows a level histogram for the 2 kHz 1/3-octave band during the weekend (blue line) and during the weekdays (red line) for the deployment site in the Cabrera Archipelago Maritime National Park. The figure shows how noise levels in the 2kHz band are higher during the weekends than during the weekdays. This might be due to the recreational use of the marine park.

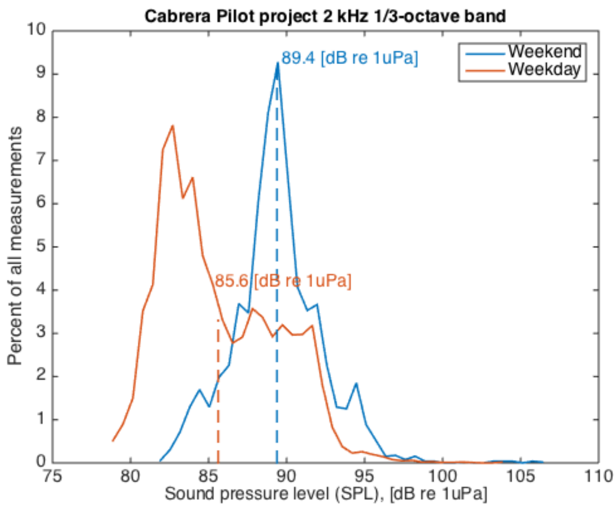

Figure 10: Level histograms for 2 kHz 1/3-octave band (Integration time T=30 seconds). Comparative for the overall weekdays and the overall weekends of the Cabrera Pilot Project.

Spectral representations:

Whether in the form of 1/3 octave bands or in any other constant resolution bands spectral representations play an important role when analysing the energy distribution of the different components. This might be needed to better understand sources of underwater sound. In many situations 1/3 octave bands spectral representations provide enough resolution to distinguish among different acoustic events. However sometimes a higher resolution is needed to analyse specific and very similar acoustic events such as different ship noise signatures. We can plot acoustic spectral levels for a given narrowband resolution (typically a few Hertz). Figure 11 shows an example of the acoustic spectral levels from the Cabrera Pilot project. The figure represents the averaged data in the 21 January 2018 at 6AM compared to the averaged of the same day at 12AM. The 10th and 90th percentiles have been represented as shadowed areas using a different colour for each time of day. Sharp peaks in sound can be seen at 150Hz and 300 Hz in the 6AM data.

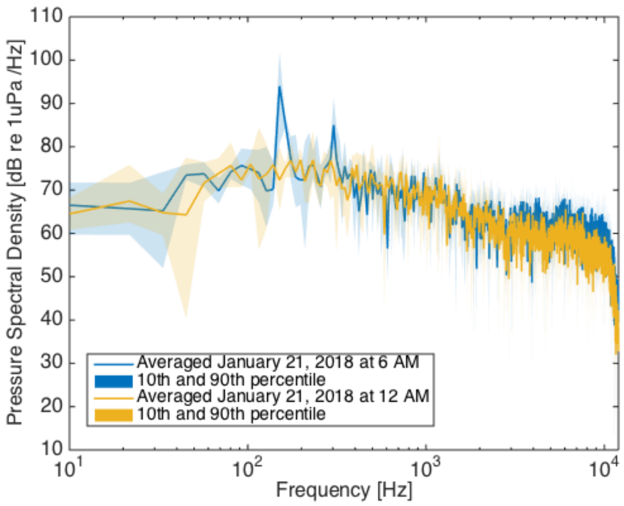

Figure 11: Acoustic noise spectral density for the averaged 21 January 2018 at 6 AM and at 12 AM. Statistical variance include as a shadow region the 10th and 90th percentiles as well as the mean in continuous line.

5.2 Representation techniques of ambient noise indicators in long temporal series (D11C2).

As the Technical Subgroup on Underwater Noise (TSG Noise) acknowledged, sometimes it is not possible to store the full time series and traditional representation as a function of time using XY graphs. These graphs may have a limited interest due to the large volume of data to be represented and, as a result many times percentage exceedance levels are used to provide local or basin scale statistics [6]. Averaging over a large time span is also recomended (see Figure 9).

An alternative representation technique that has been used in the QUIETMED project, consists in arranging data in two dimensions such as (Hour,Day) or (Minutes,Day) and employ heat maps such as those employed in Geospatial visualizations [7][18][17][16]. Each bin of the heat map corresponds to a previously determined time span (T_{bin}) and can be obtained averaging all $SPL_{1/3}$ (obtained for a given integration interval T) in the determined time span. The colour of the bin is representative of the $SPL_{1/3}$ in the time span T_{bin}. An example is given in the Figure 12. Regions were the data has been flagged due to clipping and cannot be used to obtain valid ambient noise statistics appears in black.

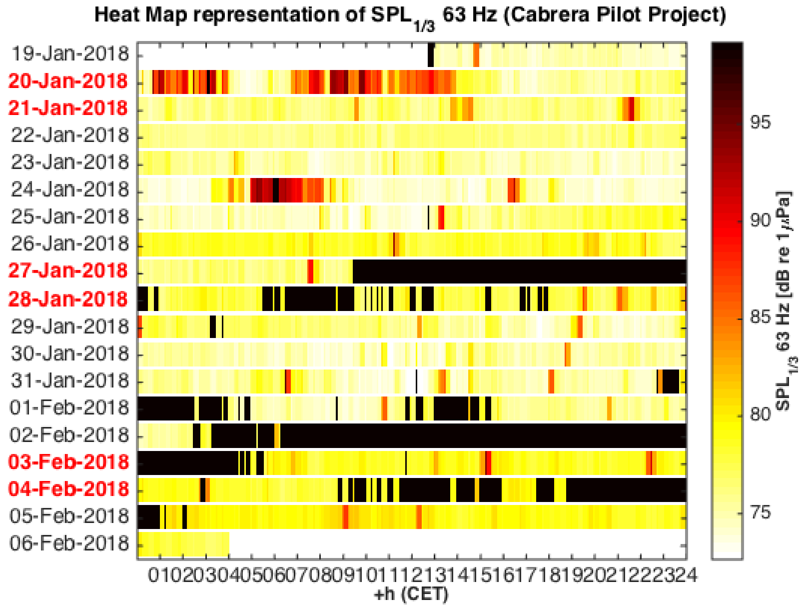

Figure 12: Example of a representation of the Cabrera Pilot project experiment (T_{bin}=15 minutes and T=30 seconds). The variable represented is the $SPL_{1/3}$ in the central frequency of 63 Hz (weekends are shown in red).

This graphical representation technique provides an acoustic panorama of a campaign which may last several months while at the same time allowing detection of short and repetitive events. Acoustic events happening consecutive days at the same time appear in the heat map as vertical lines and so can be easily identified. As an example we can see in the Figure 13 the vertical diel migration of some species clearly marked around sunrise (8:00) and sunset (18:00).

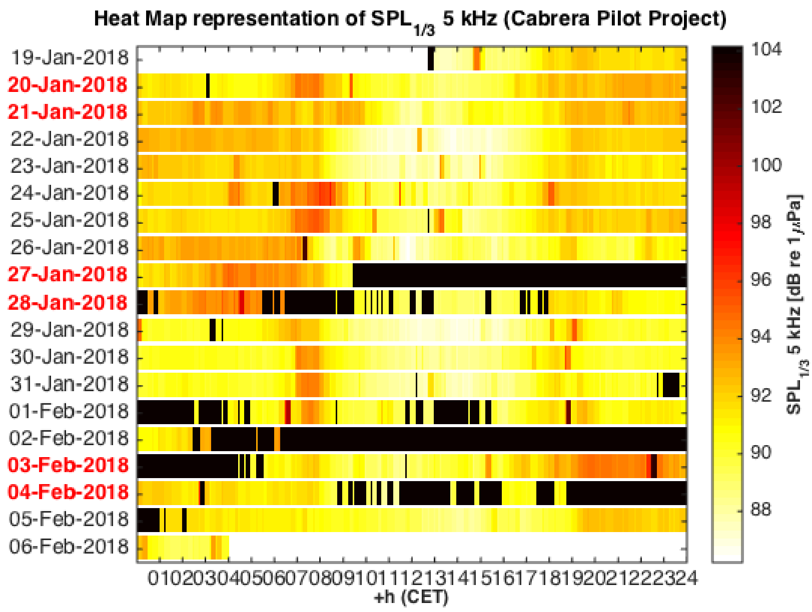

Figure 13: Example of a representation of the Cabrera Pilot project experiment (Tbin=15 minutes and T=30 seconds). The variable represented is the SPL1/3 in the central frequency of 5 kHz (weekends are shown in red). The figure allows to visualize the presence of vertical diel migrations of some fish species at sunrise/ sunset.

An additional benefit of this representation technique is that it can be employed for visually querying the sound database allowing intuitive access within the large number of sound files.

5.3 Representation of impulsive noise indicators (D11C1).

The criteria for Anthropogenic impulsive sound in water recommended by the MSFD is mainly focused in the the duration per calendar year of impulsive sound sources and their distribution within the year as well as spatial distribution. This suggests using different graphical representations for this indicator. One of these possible representations consist in plotting the Sound Expossure Levels (SEL) versus time alongside with the number of days exceeding a given threshold. The Figure 14 gives an example with estimated values.

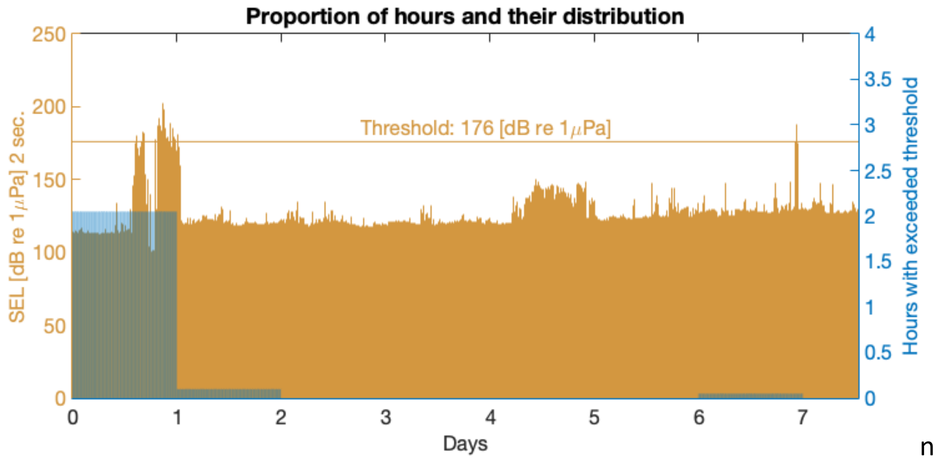

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Figure 14: Time graph representation of the Sound Expossure Level and the proportion of time (hours in the day) above the given threshold. In the Figure TH=176 [dB re 1 μ Pa].

These graphs show, alongside with the SEL, how much time the threshold has been exceeded. Depending on the length of time series this can be given in hours, for a short data series lasting only a few days, or it can also be given in days, for a long data series lasting months or even years.

5.4 Representation of ambien noise indicators using polar area diagrams (D11C2).

Averages of ambient noise indicators over a time period very often have a cyclical nature. This may make polar area diagrams an appropriate technique for their representation. Polar area diagrams look like a traditional pie chart, but the sectors differ from each by how far they extend out from the centre of the circle. As an example, the circle can be divided into 24 equally spaced sectors and represent the daily changes (by hours) of a specific ambient noise indicator.

This can be used to detect the presence of daily repeating events always happening at the same time of the day as well as to determine how the values of some ambient noise indicators may be related to circadian rhythms (see again Figure 13). Examples of ambient noise indicators polar area diagrams for the Cabrera Pilot Experiment are given in the Figure 15 and Figure 16. Both figures include the sunrise and sunset variations within the deployment period as a light grey sector as well as the night time as a dark grey sector.

The figures show that an ambient noise indicator at 5 kHz has a higher level during the night that it has during the days, producing a circle shape slightly flattened during sun hours. This may be due to noise produced by organisms as a result of the diurnal (or diel) vertical migration induced by light. Figure 15 and Figure 16 also show that noise levels in the Cabrera National Park are lower and present less variance during the weekdays than they have during the weekend. This again evidences the recreational use of the marine park.

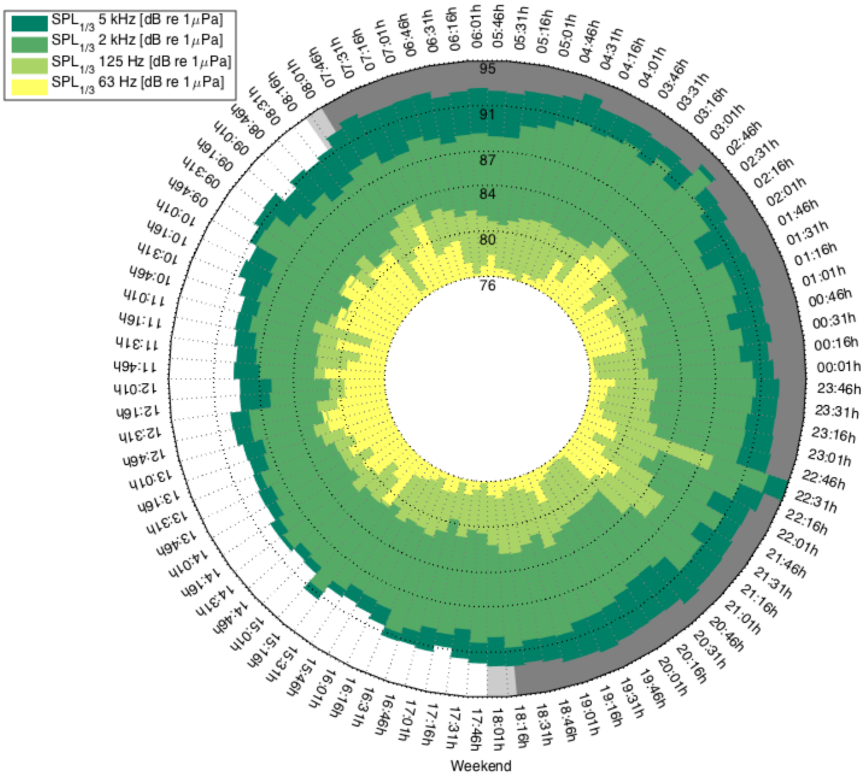


Figure 15: Polar area diagram of the Cabrera Pilot Project experiment. Ambient noise indicators averaged over the weekend. White/ grey sectors indicate day/ night calculated for longitude, latitude, and for all deployment dates using a generic astronomy calculator.

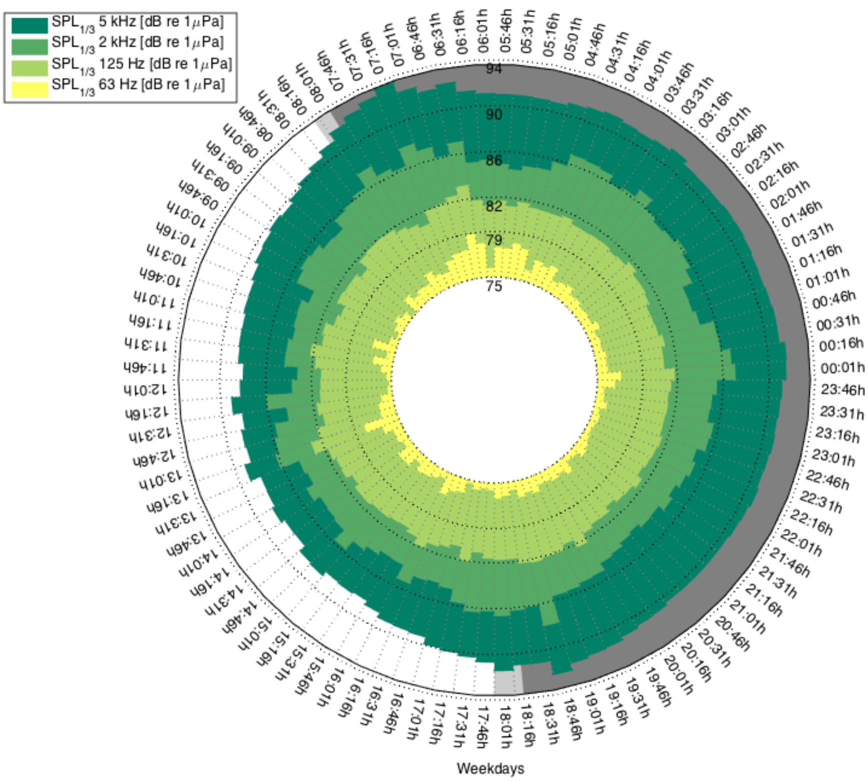


Figure 16: Polar area diagram of the Cabrera Pilot Project experiment. Ambient noise indicators averaged over the week days. White/ grey sectors indicate day/ night calculated for longitude, latitude, and for all deployment dates using a generic astronomy calculator

6 Recomendations for quality control and preservation of the data in the QUIETMED project.

Calibration of the different acoustic recorders do not guarantee that results obtained by individual partners are completely equivalent. “Round Robin” tests are one way to guarantee that the extracted noise indicators do not depend, for instance, on the particular implementation of the signal processing algorithm. In addition, systems and guidelines are needed to store the data in a universal and uniform way ensuring that data can be used to obtain noise indicators and for modelling. Quantities of acoustic data can be very high, so meticulous organization is required. In the case of the QUIETMED project, not all data has been acquired using the same device and so, differences in the naming convention of the acoustic files as well as in the device configuration may exist. Some recommendations on how to structure the data are:

- Raw acoustic recordings must be broken into fragments of a reasonable size so that a computer can process the file. The size of the fragments will depend on the sampling frequency used.
- Each of the sound fragments should be named in such a way that the date, time deployment location and project could be extracted. This is of special importance in the QUIETMED project where some partners are employing acoustic recorders which are prototypes or non-commercial research devices. A recommendation for the naming convetion of the audio files is given in the Appendix C.
- Non-acoustic parameters such as: deployment location, starting day and hour of the deployment, hydrophone sensitivity, internal gain, etc. should be registered and stored alongside with the acoustic recordings using always a similar format. The chosen data format should be agreed among the different partners and should incorporate the particulars of the different recording devices to allow repeatability and reproducibility of the measurements even with a different device (see Appendix D).
- Processed results and graphs should also be stored alongside with their corresponding parameters employed for the generation (Integration time, units,…). See Appendix E.
- Processed results (ambient noise indicators) should be stored alongside with their corresponding date/time variable (preferably in UTC). The format of date/time variable should be the same for all devices employed.

The Round Robin tests should share a sample of the raw acoustic recordings (under different noise level situations) as well as the signal processing algorithms used to obtain the different noise indicators. The tests should allow cross-validation of all the algorithms with all the data among the different Pilot projects. If a biased result is obtained, this particular combination should be investigated for possible errors.

Recommendations the signal processing algorithms and Round Robin tests:

- Use platform independent functionalities of the programming language to assure all algorithms work in the different operating systems ("filesep" for directory separator character in Matlab or "os.path.join" in Python for example).
- Use always lowercase or uppercase in filenames and extensions, and employ the corresponding functions to make case-insensitive search of files.
- Indicate minimum requirements and software versions to be used in order to guarantee the algorithms give the expected results.

APPENDIX A: Brief review of the different approaches for the detection of impulsive noise and cetaceans.

The detection and classification of marine mammal vocalisations is an important component in the tracking of animals for research purposes as well as in some noise mitigation strategies. Acoustic Monitoring systems can be deployed for long periods and can collect large volumes of data. Listening to the recordings to look for the presence of marine mammals is not practical and automatic detection algorithms are needed. These algorithms reduce the effort needed to analyse the recordings and provide results less dependent to human intervention.

The design of automatic algorithms for the detection of species is not an easy task due to the broad range of species and the different frequencies present in the vocalisations. In addition, differences may appear within species, and with temporal and geographical variations adding further complexity. Many signal processing algorithms have been created to automate this process with mixed results. Currently no single algorithm achieves the detection and classification of all species, so any automated system requires a combination of different algorithms and techniques.

There are several stages in the process of marine species detection (see Figure 17).). The first stage consists in a initial detection based on different techniques that can range from very simple detectors (energy detectors, filter banks,…) to more sophisticated detectors based on adaptive filters. In the second stage (classification stage) different features from the sound fragments obtained in the detection stage are extracted. These features are feed into different types of classifiers.

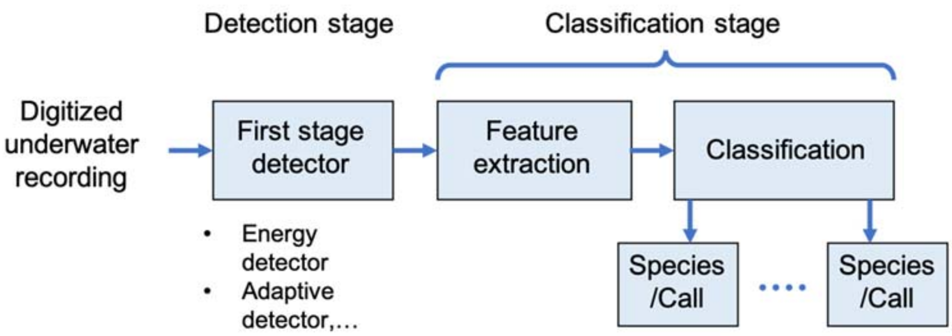


Figure 17: Different stages of a standard species/ call classification algorithm.

First attempts to classify species were done by looking for increased energy levels in certain frequency bands specifically selected to the species of interest. As an example we can mention the sperm whales detectors created using an energy detector on 6 narrowband frequencies below 12 kHz [8]. Similarly, a Fin whale detector was created comparing the power in three bands (80 Hz, 89 Hz and 98 Hz) using the relative amplitude of the signals in these bands [9]. The simplicity of these approaches makes them adequate for real time processing although they do not give good results in noisy environments.

More recent approaches use feature extraction by means of modelling the cetacean sounds in a similar way it is done with human voice. The extracted features of the modelled cetacean sounds are used as inputs in a classification algorithm. This idea was initially used by Clemins and Johnson in 2006 when they adapted the perceptual linear prediction (PLP) model to create a generalised perceptual linear prediction (gPLP) and apply the model for wild beluga whales (Delphinapterus leucas) among other animals [10]. Other authors have employed Mel Frequency Cepstral Coefficients (MFCC) as well as Greenwood Function Cepstral Coefficients (GFCCs) for parameter extraction in order to classify different cetacean species.

A different method consists in extracting temporal and frequency features from the spectrogram of the cetaceans sounds, such as the signal duration, the slope of frequency change, time-frequency profiles, etc. All these features can be feed in many of the different classification techniques to automatically detect different species and sounds: whistle detection using discriminant function analysis [11], classification within odontocetes species using regression tree analysis [12], beaked whale clicks detection using linear discrimination analysis [13] and sperm whale clicks detection using neural networks [14] are some examples.

Finally, a promising research line that might increase the detection percentage of cetaceans in the future is based on deep learning [15]. The use of neural networks with multiple hidden layer has given excellent results in different areas such as image recognition and voice identification [16]. It is expectable that we can achieve similar results for the detection of species and subspecies as long as we are able to find the adequate training sets.

APPENDIX B: Algorithms for the detection of tonal, impulsive events, whistles and clicks in the QUIETMED project.

As suggested in [6], the Cabrera and Malta Pilot projects used a sampling frequency high enough to cover the frequency range from 10 Hz to at least 10 kHz. This additional range provides extra data that may contribute to the knowledge base and may assist future evaluations.

In order to illustrate how this additional bandwidth can be used the UPV partner has employed in some of the pilot projects an automatic detection algorithm of pulsed and tonal events as well as whistles and echolocation clicks. The impulse & tonal detector is based in a ratio that serves to determine how much energy of an acoustic signal is in the form of short and high bandwidth components (pulsed) with respect to the long and narrowband components (tonal) [17]. This ratio, named Pulsed to Tonal Ratio (PTR), allows to design robust and computationally efficient algorithms for passive acoustic monitoring and may serve as a first stage detector [18].

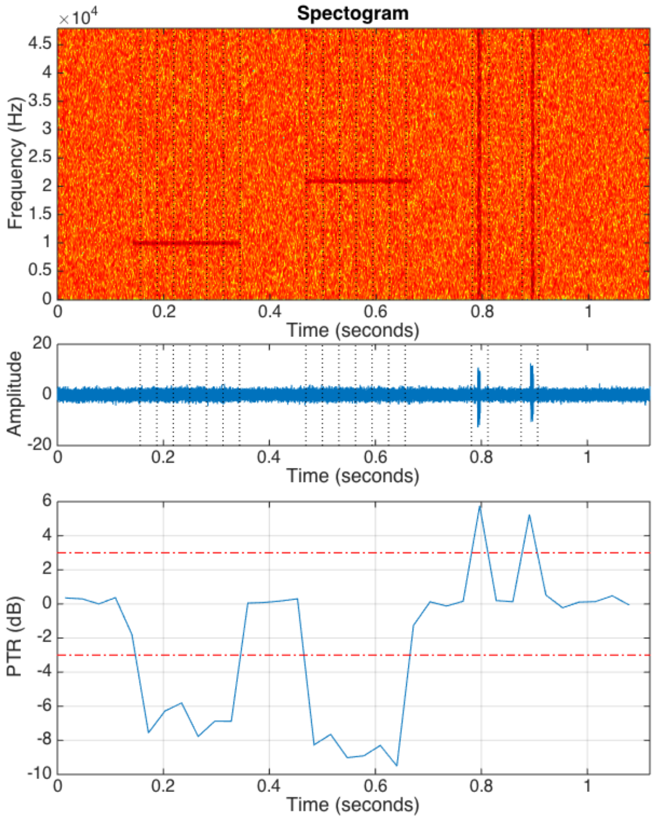


Figure 18: Top panel: spectrogram of an acoustic recording. Medium panel: temporal representation of the acoustic recording. Bottom panel: PTR of the acoustic recording.

The Figure 18 shows an example of how establishing a threshold in the PTR curve (± 3 dB) allows the detection of pulsed and tonal events in an acoustic recording. When the PTR is above a threshold, it indicates the signal has a pulsed component in the spectrogram. On the other hand, when the PTR is below a threshold, it indicates the signal has a tonal component in the spectrogram. Although this is a robust technique that works in situations with low Signal to Noise Ratios, this technique may give some false alarms in complex scenarios that have a large number of pulsed and tonal components.

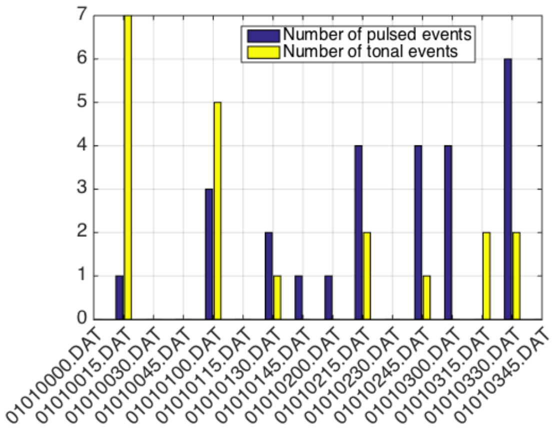


Figure 19: Results of the script that analyses the different files computing the number of pulsed an tonal events.

A Matlab batch processing (script) has been created to analyse all files in the Cabrera and Malta Pilot project deployments. The script "QUIETMED*_pulsed_tonal_detector*" looks for pulsed and tonal components and generates a graph as well as an Excel table with the fliename and the number of pulsed and tonal events detected in each file (see Figure 19).

Whistle detector is based in the algorithm proposed in [19], whereas the echolocation click detection was done applying the PTR detector after filtering the recordings with a high pass filter of 2 kHZ cutoff frequency. Isolated pulsed detections were removed and the Inter Click Interval (ICI) was computed to check that the value was in the range of typical ICI of dolphin species (0,035-0,155 sec) [20]. The Figure 20 shows the number of detected whistles and their distribution in the time within the whole deployment period.

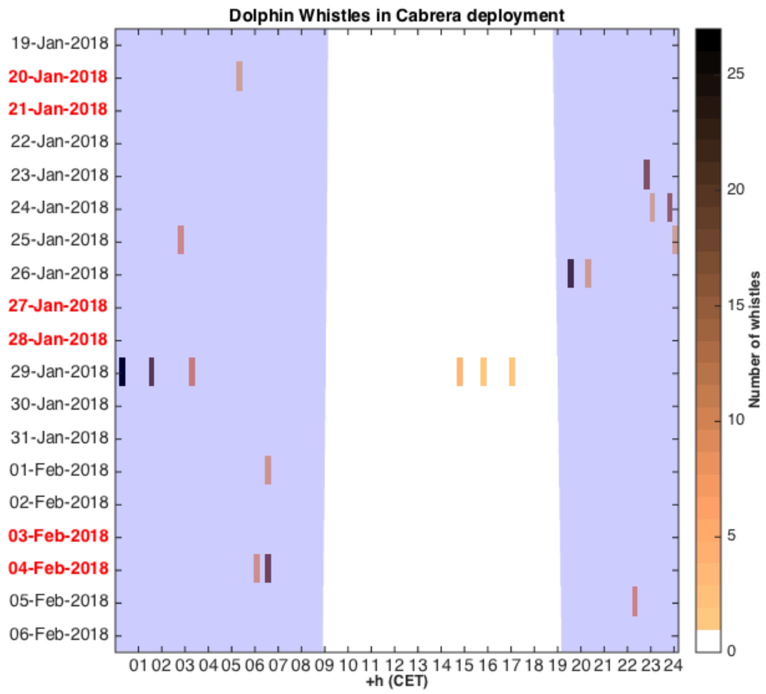
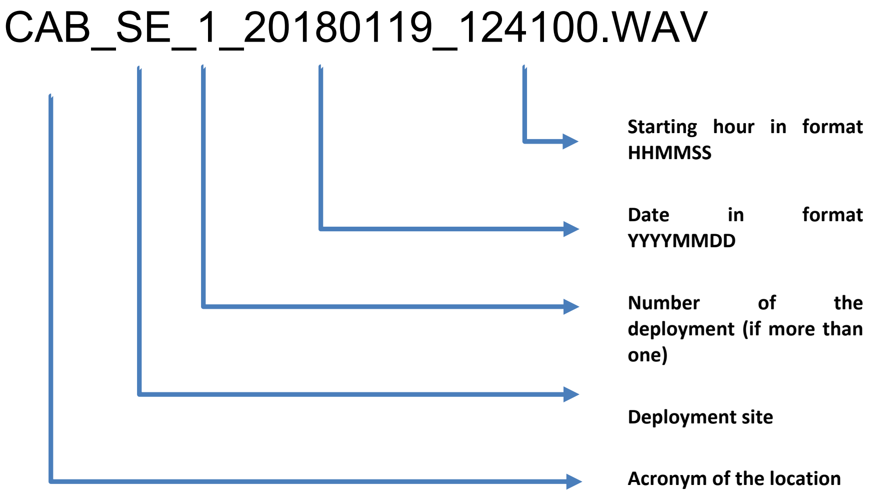


Figure 20: Representation and distribution in time of the dolphin whistle detection in the Cabrera Pilot Project. Shaded blue regions correspond to the night according to the sunset/ sunrise obtain with a generic astronomy calculator.

APPENDIX C: Recommendation for the naming convetion of the audio files.

We recommend a naming convetion for each one of the audio files that allows a unique identification of the project, location and starting time of the file. An example is given as follows:



In this way, the file "CAB_AA_1_20180119_124100.WAV" corresponds to the first deployment at site SE (South East), within the Cabrera (CAB) Archipiealgo (CAB_SE_1). Recording started the 19th of January 2018 at 12:41:00 UTC time.

APPENDIX D: Recommendation for minimum non-acoustic variables to be stored.

Non-acoustic variables need to be stored alongside with the acoustic data. Among some others we propose storing as Matlab variables the following information:

Variable Name	Description	Data type
project_acronym	Acronym of the location, deployment site and deployment number (see Appendix A).	Character vector containing the unique deployment identification (CAB_SE_1)
deployment_location	GPS coordinates of the deployment location	2-D number array with latitude, longitude in decimal degrees
deployment_start	Time in UTC format when the acoustic recording starts.	Character vector containing the date in the format YYYY-MM-DD-HH:MM:SS
duty_cycle	Duty cycle: minutes recording-minutes in standby	2-D number array with minutes recording and minutes in stand-by.
number_of_bits	Number of bits of the ADC	Integer with the number of bits
fs	Sampling frequency [Hz]	Integer with the sampling frequency
hydrophone_sens	Hydrophone sensitivity [dB re 1 V/µPa]	Decimal number with hydrophone sensitivity.
system_gain	Internal gain/ attenuation of the acoustic recorder [dB]	Integer with the gain (positive) or attenuation (negative) of the acoustic recorder.
system_ID	Acoustic rcorder employed (RTSyS, SAMARUC, FORTH)	Character vector with the iD of the system employed in the pilot project.
additional_info	Any additional information related to the deployment that might be useful in the future.	Character string.

APPENDIX E: Recommendation for the signal processing related variables to be stored.

Variables involved in the generation of the ambient noise indicators graphs and tables need also to be stored alongside with the raw data. The following are the minimum number of variables that were stored in the project:

Variable Name	Description	Data type
integration_time	Integration time in seconds.	Integer with the number of seconds.
spl_1_3_id	Central frequency of each one of the SPL 1/3 octave bands	Character array containing the central frequency of each one of the 1/3 octave central bands
starting_time	Time in UTC format when the first 1/3 octave ambient noise indicator was obtained.	Character vector containing the date in the format YYYY-MM-DD-HH:MM:SS

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