Definition of the underwater noise monitoring system set up and specifications for the system components

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1 Abstract

Document describes all activities leading to the adoption of all understanding, knowledge and skills needed for the implementation of the recommended monitoring system, special operations with autonomous passive underwater acoustic recorder Sono.Vault. The report also contain all documentation and manuals provided with the equipment procured.

2 Introduction

The main objective of the project is to create a cross-border technical, scientific and institutional cooperation to face together the challenge of assessing the impact of underwater environmental noise on the marine fauna and in general on the Northern Adriatic Sea ecosystem. At this stage, in fact, there are no extensive data on underwater noise in the area and the knowledge on noise pollution and its impact on biodiversity is very limited.

Therefore, according to the project work plan, the network of the underwater noise monitoring stations will be set up in the Northern Adriatic Sea (Activity 3.2). The continuous underwater noise produced by anthropogenic activities such as marine traffic (both commercial and recreational) and hydrocarbon exploitation will be monitored.

The monitoring results will be used to fill the knowledge gap about underwater noise levels in the Northern Adriatic Sea but also to support setting up and validating the soundscape model (Activity 5.2).

3 Underwater noise monitoring network

To achieve objectives of the project mentioned earlier, the network of the underwater noise monitoring stations is developed and designed. The network for the monitoring of underwater noise will be set up by implementing 9 monitoring stations.

The locations of monitoring stations were determined after analysis, considering expected noise pressures, categorization of the monitoring according to TG Noise recommendations, deployment and servicing complexity, soundscape modeling requirements and cost.

Before the deployment of the monitoring station, all necessary permits for the deployment should be secured.

The locations of monitoring stations are displayed in Table 1 and in Figure 1.

Table 1 Approximate locations of monitoring stations

Monitoring station reference	Monitoring station name	Position		Depth (m)	Noise pressure foreseen
		Longitude (E)	Latitude (N)		
MS1	Aqua-Alta	12.514722	45.32306	16	Very high
MS2	Azalea	12.7142580	44.17177	20	Moderate / low
MS3	Ancona	13.71	43.5086111	15	Moderate / High
MS4	Paloma	13.5641	45.6188	25	Very high
MS5	Susak	14.06596	44.47237	55	Moderate / low
MS6	Lošinj	14.574283	44.54662	35	Low Moderate / high
MS7	Žirje	15.5984	43.6283	53	Moderate / low
MS8	Split	16.415594	43.46806	42	Very high
MS9	Ivana	13.30048	44.71964	35	High

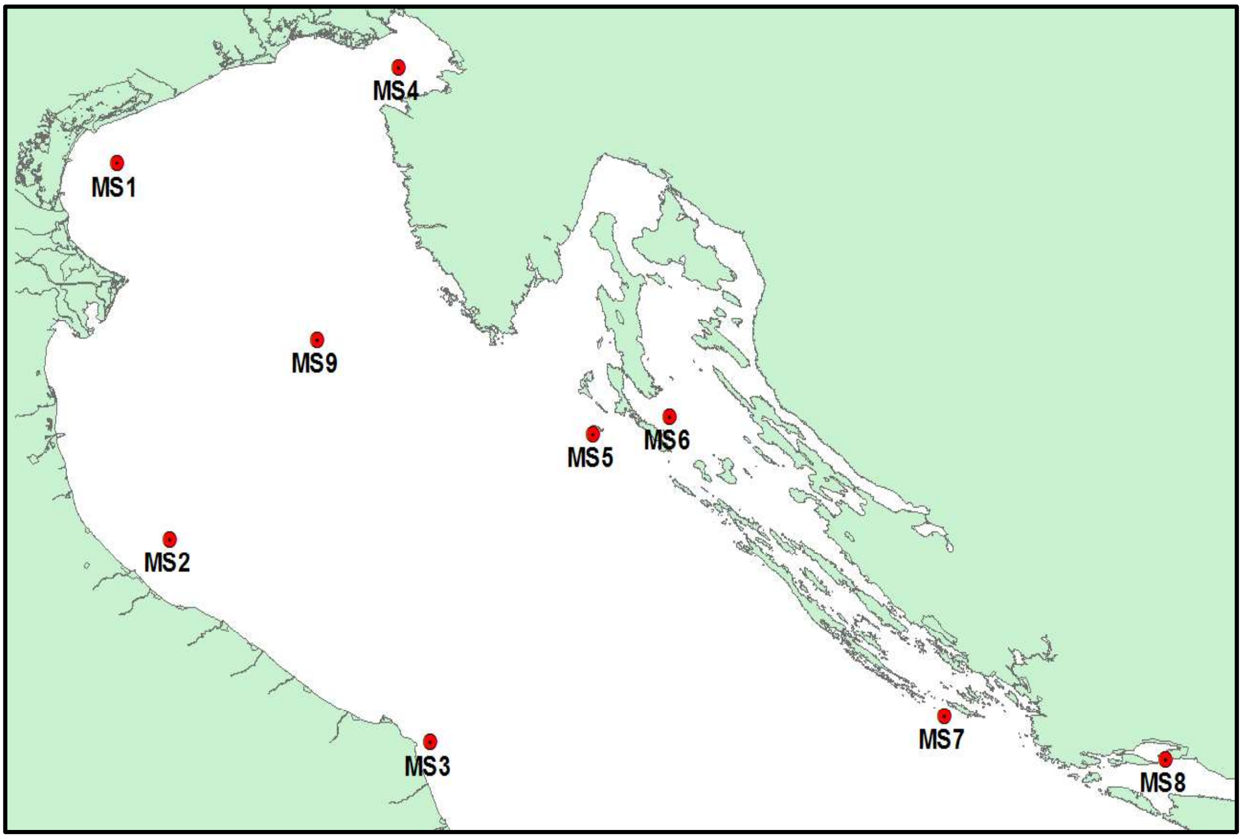


Figure 1 Tentative location of monitoring stations

The monitoring station MS1 Aqua-Alta is located near the entrance to the Venice harbor. The maritime traffic is very dense with all categories of vessels (cargo, passenger and recreational) and anthropogenic underwater noise pressure is expected to be very high. The monitoring station is located in vicinity of the oceanographic platform Acqua-Alta which is an offshore oceanographic monitoring station belonging to CNR-ISMAR where the meteo marine sensors installed include meteorological stations, ADCP systems for currents and waves, multipara metric probes at many levels. That additional sensors and data gathered on the location can be very useful in interpreting underwater noise data and building reliable model for underwater noise propagation.

The monitoring station MS2 Azalea is located near dismissed gas platform which provide protection again equipment damage owing to the trawling. The area is near the secondary shipping lanes and is a noteworthy passage of marine megafauna.

The monitoring station MS3 Ancona, managed by CNR-IRBIM of Ancona, is located south of the Ancona harbor. The maritime traffic is dense with all categories of vessels (cargo, passenger and recreational), and anthropogenic underwater noise pressure is expected to be moderated/high. The point is in shallow water in a Natura 2000 site coastal area, so it is an interesting area for monitoring the impact of underwater noise to marine fauna. As MS3 is very close to the shore which cannot be seen in Figure 1, close up of the position is displayed in Figure 2.

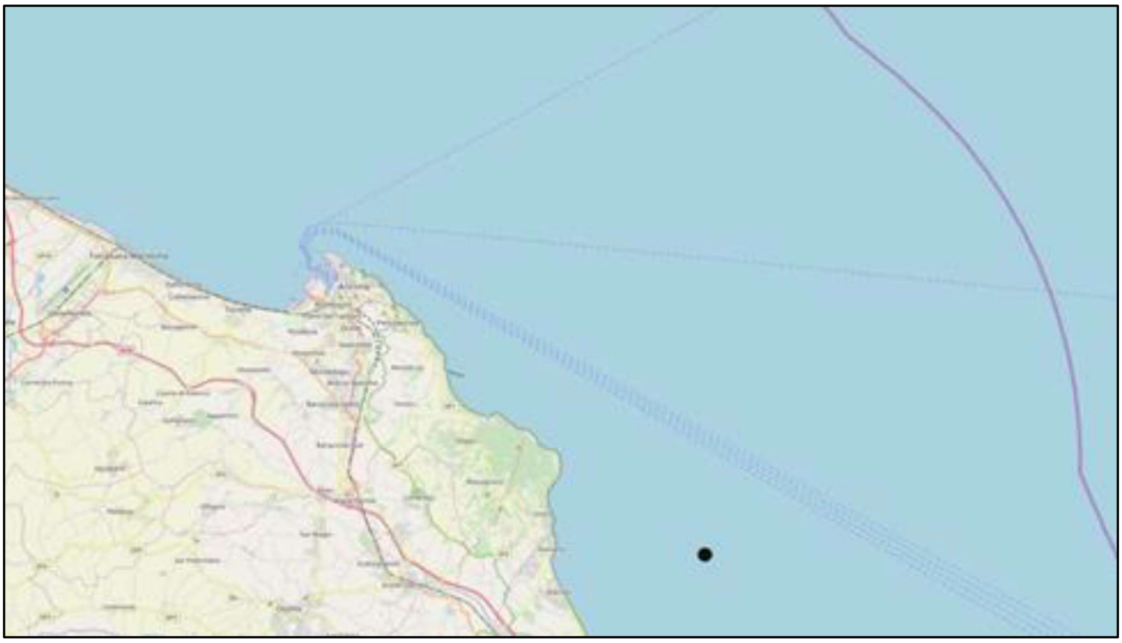


Figure 2 Close up of the position of MS3 Ancona

The monitoring station MS4 Paloma is located in the center of Trieste Gulf, near the entrance to the Trieste and Koper harbors. The maritime traffic is very dense with all categories of vessels (cargo, passenger and recreational) and anthropogenic underwater noise pressure is expected to be very high. The station is located in the vicinity of PALOMA Platform Oceanographic Laboratory. The PALOMA platform also include various sensors and provides meteomarine data including sea temperatures, wind speed and direction, air temperature, relative humidity, precipitation, solar radiation, air pressure, hydrological (CTD) and biogeochemical parameters (dissolved oxygen, pH, inorganic nutrients). That additional data gathered on the location can be very useful in interpreting underwater noise data and building reliable model for underwater noise propagation

The monitoring station MS5 Susak is located away from the shore and islands towards the open sea. The location is relatively close to one of the main shipping lanes to Rijeka port, but far away from the recreational boating hot-spots. The anthropogenic underwater noise pressure is expected to be low to moderate. It is an area of importance for sea turtles and a potential open - water Natura 2000 site.

The monitoring station MS6 Lošinj is located in the core of Natura 2000 SCI (Cres-Lošinj, HR3000161) of high relevance for the resident bottlenose dolphin community as their important feeding and nursery ground. The area is subjected to intense recreational boating during touristic months but is isolated from major shipping lanes. The anthropogenic underwater noise pressure is expected to be low but moderate/high during summer touristic season.

The monitoring station MS7 Žirje is located on the edge of Jabuka Pit which is very important fishing and spawning area and near Kornati National park which is also Natura 2000 area (HR 4000001). The location is far away from main shipping lanes but relatively close to fishing and recreational activities. The anthropogenic underwater noise pressure is expected to be low to moderate.

The monitoring station MS8 Split is located near the entrance to Split port. The maritime traffic is very dense with mostly passenger (ferries, cruisers) and recreational vessels. The anthropogenic underwater noise pressure is expected to be very high. As MS8 is very close to the shore which cannot be seen in Figure 1, close up of the position is displayed in Figure 3.

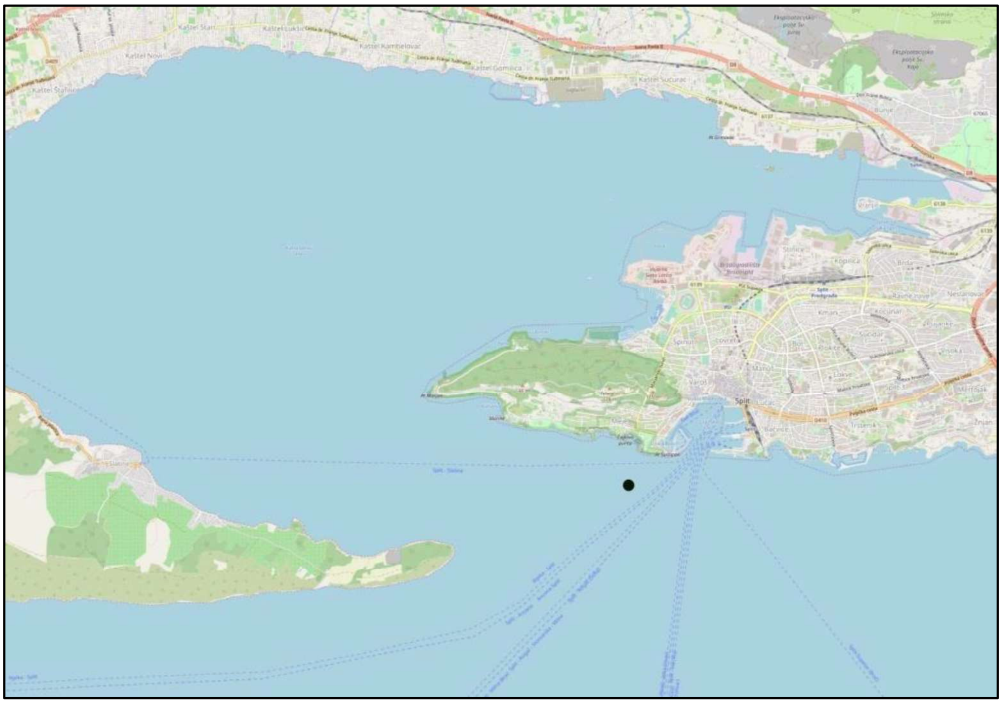


Figure 2 Close up of the position of MS8 Split

The monitoring station MS9 Ivana is located near Ivana gas platform in the middle of the Northern Adriatic Sea very close to the main shipping lanes to Venice, Trieste and Koper ports. The maritime traffic is dense with all categories of vessels (cargo, passenger and fishing). The anthropogenic underwater noise pressure is expected to be high.

As some of the monitoring stations will be deployed in shallow water it is important to bring to the attention the existence of **lower cut-off frequency**. The lower cut-off frequency is due to the propagation of the sound waves in the shallow water. It is not possible to measure and report underwater noise levels on the frequencies below cut-off. See Annex II for the guidelines on shallow water specific environmental dependence and cut-off frequency.

The locations of all stations are approximate. The final positions can vary slightly depending on the assessment of the threat for the equipment loss or damage during deployment period.

4 The assessment of the threat for the equipment loss or damage

The monitoring area of the Northern Adriatic Sea is busy with maritime activities. Apart from maritime traffic through the main shipping lanes, it specially goes for fishing and recreational activities. Owing to that, there is a reasonable possibility of the loss or damage of the equipment (and data). This has to be seriously considered by each partner and all effort should be invested in the minimization of that possibility.

There are different opinions regarding marking the equipment position with surface buoy. Some experience points out that surface marks attend unwanted curiosity which can cause intentional or unintentional damage, theft or banalization. On the other hand, as the system is left unattended and unmarked, there is possibility to be trawled up or caught by fishing gear.

Each partner has to analyse the situation in the monitoring site environment and to assess the treat of the equipment loss or damage. According to the assessment, the appropriate measures against the equipment loss or damage should be taken.

Two possible procedures have proven effective in practice. The first is to mark the site and establish the communication with local community (fishing, social and other) making the presence of the monitoring site known to all (or most of) maritime stakeholders and/or sea-goers. It can assure that site is undisturbed by local community. It goes without saying that all authorities (maritime police, harbour master or other depending on legal requirements) should be informed.

The good alternative is not to mark the monitoring site but to identify natural barriers to fishing (e.g., large outcroppings or shipwrecks) and locations that fishermen avoid for the deployment locations.

Protective anti-trawling housings (barnacles) are also used for the protection of various oceanographic equipment (e.g. ADCP-s). But in the case of underwater noise monitoring, hydrophone should be unobtrusive and free of all obstacles and therefore cannot be covered. Also it is recommended that hydrophone should be 2-3 m above the seabed to minimize reflection. Considering all that, use of the protective anti-trawling housings is not recommended as it is not an efficient protection for the underwater noise monitoring.

5 Technical specifications for the equipment used

To achieve objectives of the project mentioned earlier and implement quality underwater noise monitoring, appropriate equipment should be used. The specifications of the monitoring equipment were defined after analysis considering expected underwater noise spectral and dynamic characteristics, the duration of the deployment and the deployment environment.

The thorough market analysis was carried out and it was found that technical specifications required are realistic and several manufacturers are able to fulfill them.

5.1 Autonomous passive underwater acoustic recorder (APUAR)

To achieve objectives of the project mentioned earlier and implement quality underwater noise monitoring autonomous passive underwater acoustic recorder (APUAR) should fulfil the technical specifications as displayed in Table .

Table 2 Technical specifications for the autonomous passive underwater acoustic recorder (APUAR)

Recording file format:	.wav
Sensitivity:	In the range -165 to -185 dB re 1 V/µPa
Dynamic range	Minimum 16 bit
Frequency response:	10 Hz – 10 kHz flat within ±2 dB, 10 Hz – 20kHz flat within ±3 dB
Directionality:	Omnidirectional to within +/- 1 dB up to 20 kHz horizontal, and to within +/- 2 dB in vertical
Sampling rate:	Minimum 44 kHz at dynamic range requested
Data storage:	Minimum 512 GB (SD cards or SSD only)
System self-noise:	Better than 58 dB re 1 µPa2/Hz at 63 Hz; Better than 53 dB re 1 µPa2/Hz at 125 Hz
Battery life:	Alkaline: not less than 25 days Lithium: not less than 75 days Continuous recording 16 bit resolution, 24 kHz sampling
Calibration	The system has to be fully calibrated (hydrophone sensitivity and directivity, gain and self-noise) and the calibration documented for each instrument (no generic data)
Programmable or switchable input gain	Has to enable various sensitivities within range required
High pass filter	Cut off frequency In the range of 3 – 10 Hz
Maximum operating depth	500 m
Temperature range:	-5°C to +40°C
Dimensions (with mooring frame and batteries)	Diameter no more than 220 mm Length no more than 1100 mm Weight in water no more than 20 kg
Power up/down without opening of housing	
Start/stop recording without opening of housing	
Communication interface for control and setting up of system parameters	
Mooring frame: Frame to enable attachment of deployment equipment (flotation, acoustic releasers, moorings etc.) to the instrument	
Hydrophone protection: Mechanical protection of hydrophone against physical damage (e.g. cage)	
Possibility of start stop recording (duty cycling, on/off scheduling)	
Possibility to use both alkaline and lithium batteries	
Warranty	Not less than 12 months

Note: *The specifications above are only tentative. Final specifications will depend on the equipment acquired and can differ slightly.*

5.2 Acoustic releaser

The acoustic releaser is an oceanographic device used for the deployment and recovery of instrumentation from the sea floor, in which the recovery is triggered remotely by an acoustic command signal. The whole acoustic release system consists of the underwater unit (releaser itself) and the command (deck) unit with remote hydrophone. The acoustic releaser is assembled in the deployment rig (as described in deliverable D3.2.2) while the command unit is on the vessel. When the communication with the releaser is needed, the remote hydrophone of the deck unit is lowered in the water and the acoustic command instructing releaser to release the whole rig from the anchor is send.

The releaser and the deck unit should reliably communicate in the shallow water within the range of 1000 m.
Operating depth should be not less than 400 m, and release load not less than 120 kg.

5.3 Deployment gear

Deployment gear would include:

- *Anchor (weight)*
  The weight and shape of the anchor as recommended in deliverable D3.2.2
- *Flotation(s)*
  The buoyancy and the shape of the flotation(s) as recommended in deliverable D3.2.2
- *Rope(s)*
  Various ropes with suitable gauge and length for the assembly and the deployment of the rig. For the assembly of the rig wire ropes can also be used, if assessed necessary.
- *Assambly accessories*
  All accessories needed for assemble and fixing of the rig (e.g. shackles, eyes, bolts, nuts, clips etc.).

5.4 Batteries & memory cards

Battery type (alkaline or lithium) as recommended by the equipment manufacturer. Memory card type and size as recommended by the equipment manufacturer. Quantity will depend on the equipment acquired.

6 Equipment setup

To obtain quality underwater noise monitoring and the results that are compatible and comparable all APUAR-s should be set up in the same way. The setup should be as follows:

Dynamic range	16 bit	
Sampling rate:	48 kHz	
Type of recording	Continuous	
Duration of recording	n/a	
Duration of sleep	n/a	
Sensitivity	**Monitoring station**	**Gain setting**
	MS1	5
	MS2	6
	MS3	6
	MS4	5
	MS5	6
	MS6	7/6 (summer)
	MS7	6
	MS8	5
	MS9	5

ANNEX I Calibration of Sonovault autonomous passive underwater acoustic recorder

The calibration is the process of calculating calibration coefficient(s) in order to convert wav. units which will be recorded to SPL (dB/µPa) which should be reported.

The basic calibration equation is:

$$SPL = 20 \cdot \log_{10} U - \mathrm{S_H} \qquad (1)$$

where:

U is the electric voltage in V recorded by SonoVault

$\mathrm{S_H}$ is the sensitivity of the hydrophone in dB/V ref 1µPa

As U in V is not known but only the magnitude of recorded signal in wav. units (which is the fraction of 1, e.g. 0,335) it should be calculated from the equation:

$$U = \frac{10^{\frac{20\log_{10} U_{REC} - (LU_{CAL\,EL} - 20\log_{10}5)}{20}}}{1000\,.\sqrt{2}} \qquad (2)$$

where:

U_{REC} is the maximum of recorded wav. signal in wav. units (fraction of 1)

$LU_{CAL\,EL}$ is the level of the calibrated electric voltage for the corresponding gain setting in dB/5mVp (from the calibration sheet of SonoVault)

As the level of the calibrated electric voltage is in the reference of 5mVp (that is Developic's standard procedure) it should be recalculated to the reference of 1mVp and that is acomplished by term $20\log_{10}5$ in formula (2).

1000 is to convert U from mV to V and $\sqrt{2}$ is to convert max. values of sine waveform to RMS (this is required to have the same units as in $\mathrm{S_H}$).

Using all this and aplying logarithms on the both sides, equation (2) becomes:

$$LU = 20 \cdot \log_{10} U_{REC} - LU_{CAL\,EL} - 49$$

where:

LU is the level of the electric voltage recorded by SonoVault in dB/V

Then, the SPL recorded is:

$$SPL = LU - \mathrm{S_H}$$

where:

SPL is in dB/µPa and $\mathrm{S_H}$ is in dB/V ref µPa

If SonoVault is set to gain 5 and 16 bit sampling, $LU_{CAL\,EL}$ will be -28,65 dB/V and $\mathrm{S_H}$ is -192,7 db/V ref µPa. Then, SPL = $20 \cdot \log_{10} U_{REC}$ + 172,35

Checking the calibration with pistonophone Grass 42AC

Sound pressure level (SPL) inside the pressure chambre (adapter) attached on hydrophone D60 with pistonophone Grass 42 AC connected is 151,6 dB/µPa (factory data confirmed with indipendent measurements). The D60 hydrophone sensitivity is -192,7 db/V ref µPa (for serial number SN4142). The level of recorded wav. signal (in reference to 1) is then:

$$\mathbf{20 \cdot \log_{10} \mathit{U_{REC}} \ = SPL + \mathit{LU_{CAL\,EL}} + \ 49 + \ S_H}$$

or:

$$\mathbf{\mathit{U_{REC}} \ = 10^{\frac{SPL+\mathit{LU_{CAL\,EL}}+ S_H+49}{20}}}$$

The value of U_{REC} should be read from recorded calibration file.

As an example, for SonoVault serial number 1095, with D60 hydrophone serial number SN4142, 16 bit sampling, the values for U_{REC} are:

Gain	$LU_{CAL\,EL}$	U_{REC}
0	-58,3	0,003
1	-52,43	0,057
2	-46,48	0,012
3	-40,36	0,023
4	-34,65	0,044
5	-28,6	0,089
6	-22,48	0,179
7	-16,35	0,362

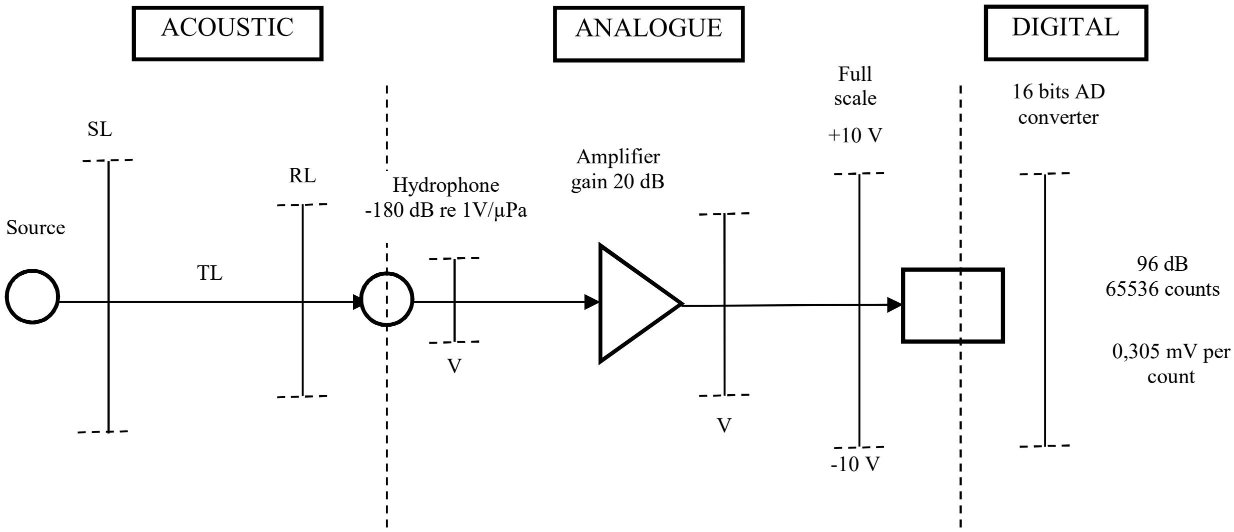
If SonoVault is set to gain 5 and 16 bit sampling, the maximum of UREC (the signal recorded with pistonophone Grass 42 AC) should be 0,089 wav. units.

The calibration is performed as follows:

- Assemble the pistonophone adapter SV.PA 60 as in user maual and mount it on the D60 hydrophone
- Screw the pistonophone to the adapter
- Connect SonoVault to computer and start Doclight (or similar terminal program) software (alternatively powering and activating recording can be done with external magnet)
- Power SonoVault on
- Start (switch on) the pistonophone
- Activate the recording for 30-40 seconds and then deactivate it
- Stop (switch off) the pistonophone
- Open the recorded file with Audacity (or similar) software and measure the value of the recorded signal maximum (This is UREC in wav.units).

ANNEX II Guidelines for the determination of the sensitivity and input gain

It is very important to note that overall system performance will depend on matching of system sensitivity, gain and conversion resolution. Poor signal to noise ratios and system overload and distortion should be avoided. The overview of the signal levels in the generic continuous underwater noise measuring system is shown in Figure AI-1. The source radiates sound with source level SL. The sound travels to receiver and, after being attenuated which is represented by propagation loss (PL), is received with received sound pressure level RL. After being converted to voltage by the hydrophone and amplified, it is imputed to 16 bit A/D converter. The electronics are supplied with the supply voltage enabling ±10 V of amplifier dynamics and full scale of A/D converter. Three scenarios are shown in the table below. If source level is 230 dB re 1µPa m, A/D converter will output and record ±10360 counts which is near the middle of the dynamic range of amplifier and A/D converter. If the source level of the radiated sound increases to 250 dB re 1µPa m, the signal on the input of the amplifier will overload the amplifier, input to A/D converter will be clipped, and final result of the conversion incorrect. If the source level decreases to 170 dB re 1µPa m, AD converter will output only ±10 counts which are 0,015% of the available dynamic range, and therefore the signal will be hardly recognizable in the noise.



SL (dB re 1µPa m)	TL (dB)	RL (dBre 1µPa)	Hydrophone output / Amplifier input	Amplifier output / AD converter input	AD converter output
230	60	170	±316 mV	±3,16 V	± 10360 counts
250	60	190	±3,16 V	clipped	incorrect
170	60	110	±0,316 mV	±3,16 mV	± 10 counts

Figure AII-1 Overview of the signal levels in the generic continuous underwater noise measuring system

If one, for example, has to perform category B monitoring or similar, where proximity of strong underwater noise source levels are probable, it is recommended that system could withstand noise pressures (received levels) of at least 180 db re 1 μPa. If high sensitivity hydrophone (-165 dB re 1 V/μPa) is used, with no additional gain it will output voltage of 15 dB re 1V (approx 5.62 V). With realistic supply voltage it will probably not overload (but will be very close to the upper dynamic limit) the amplifier and converter and cause no significant distortion. However, in that case it is better to be on the safe side and use less sensitive hydrophone and certainly no gain.

On the other hand, if low noise levels are expected high sensitivity hydrophone will substantially increase signal to noise ratio.

It is highly recommended that, prior to specifying the system setup, even a rough estimate of underwater noise levels expected is made. It will greatly help to ensure the right system performance.

ANNEX III Shallow water specific environmental dependence and cut-off frequency

When considering underwater sound propagation models, one effect not always appreciated is that shallow water channels do not allow the propagation of low frequency signals due to the wave-guide effect of the channel. This effect means that there will be a lower cut-off frequency, below which sound waves will hardly propagate in the water column, but will be radiated into the sea-bed instead. In this case propagation in the water column is poor and the acoustic field decreases rapidly with range.

Shallow water channel cut-off frequency can be explained and predicted by a normal mode analysis. This is complex problem which involves entire system of sound frequency, source/receiver depths and environmental parameters (water column, bottom).

However, for a realistic seabed, a simplified formula for the assessment of cut-off frequency depending on the ratio of sound speed in the bottom to that in the water can be used.

$$f_0 = \frac{c_w}{4 \cdot D\sqrt{1-(c_w/c_b)^2}}$$

where D is the water depth, cw is the sound speed in the water and cb is the sound speed in the sea-bed.

The expression is valid only for homogeneous water column depth D. The result of plotting this formula is shown in Figure AII-1. The sound speed in water is assumed to be 1490 m/s while sound speed in sea-bed to be 1700 m/s.

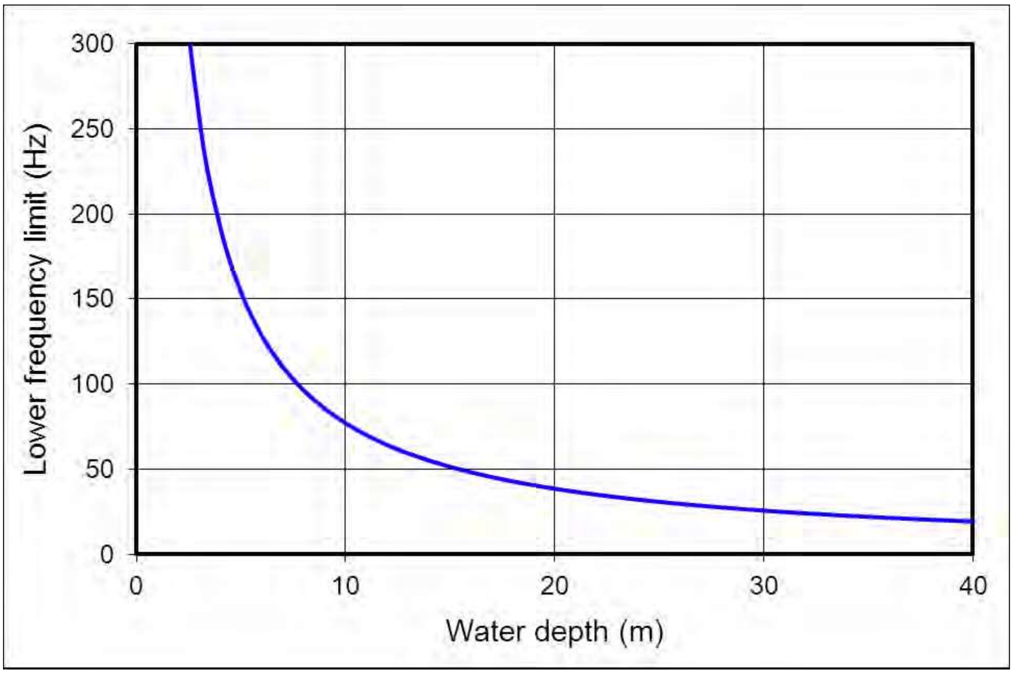


Figure AIII-1 The lower cut-off frequency as a function of depth for a shallow water channel

From Figure AII-1 one can see that, for example, frequencies below around 80 Hz would not be expected to propagate through the water in an approximate water depth of 10 m.