Support of implementation of MSFD on Descriptor D11

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Summary

1 INTRODUCTION

1.1 Underwater noise and its impact on marine ecosystems

Noise in the ocean is the result of both natural and anthropogenic sources (Hildebrand, 2009; Popper & Hastings, 2009). Natural sources of noise include geophonic sounds such as breaking waves, rain, wind or earthquake and biological sounds produced by marine life for communication, mating behavior, detection of prey and predators, orientation, migration and habitat selection (Popper & Hawkings, 2019). Since the Industrial revolution, a third source of sound has appeared into the water: the anthropogenic one (Popper & Hawkings, 2019). There are several human activities carried out underwater or just upon the surface, that radiate sound into the water, some produced purposefully such as seismic exploration, sonar, acoustic deterrent devices and other unintentionally as commercial shipping, explosions, industrial activities and construction (Hildebrand, 2009; Farcas et al.,2015). The greatest part of these activities take place towards the shoreline, in the harbors and along the coasts, while offshore platforms and traffic lanes are more often found at greater distances from the coast.

Studies showed that anthropogenic noise can cause auditory masking, leading to cochlear damage, changes in individual and social behavior, altered metabolisms, hampered population recruitment, and can subsequently affect the health and service functions of marine ecosystems (Peng et al., 2015). The ways in which marine organisms respond to anthropogenic noise range from small temporary shifts in behavior all the way to immediate death (Popper and Hastings, 2009). When looking into the potential consequences of noise on the marine environment, both acute and chronic effects on animals should be considered. Short-term acute effects are generally associated with a specific activity, and are mainly related to intense noise of short lasting. This noise can potentially result in fatal injury due to physical damage or it can increase predation on affected animals due to its loss of hearing capability. Alternatively, long-term chronic effects (associated with many overlapping activities) of relatively low-intensity but continuous lasting (such as the shipping noise), alter the physiology and the behavior of exposed animals, resulting in a reduction of reproduction, an increase in predation, and a general decrease in their fitness (Hawkins et al. 2015). For this reason, interest from the entire scientific community and governments is raising about the potentially harmful effects of underwater noise on the marine species that use sounds as the most important sense for life underwater (Popper &Hawkings, 2019). More detailed information on impacts on target species chosen for the project are reported in the Deliverable 4.2.1 *Gap-analysis report based on existing knowledge of the sensitivity of target species (bottlenose dolphins, loggerhead turtles, and commercial fish sp.) to sound and the potential effects of noise*.

1.2 Marine Strategy Framework Directive (MSFD)

The Marine Strategy Framework Directive (MSFD, 2008/56/EC) requires European Member States (MS) to develop marine strategies to achieve or maintain good environmental status of EU marine waters by 2020. The Directive defines Good Environmental Status (GES) as: "The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive" (Article 3-5). GES means that the various uses of the marine resources are made at a sustainable level, ensuring their preservation for future generations. The Marine Directive (Marine Strategy Framework Directive MSFD 2008/56/CE) contains 5 main elements: i)initial assessment; ii) determination of good environmental status; iii) establishment of environmental targets; iiii) monitoring programme (enabling the state of the marine waters concerned to be assessed on a regular basis) and iiiii) the programme of measures to maintain and/or improve environmental status (Figure 1).

Figure 1 Marine Strategy Framework Directive (MSFD 2008/56/CE) five main steps

For determining good environmental status, 11 qualitative descriptors were defined, with descriptor 11 focusing on introduction of energy, including underwater noise (Figure 2). Underwater noise was formally defined as a pollutant in art 3(8) of the Directive.

BIODIVERSITY	Biodiversity	Descriptor 1: Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with
NON INDIGENOUS SPECIES	Non-indigenous species	Descriptor 2: Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem
COMMERCIAL FISH AND SHELLFISH	Commercial fish and shellfish	Descriptor 3: Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock
FOOD WEBS	Food webs	Descriptor 4: All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity
EUTROPHICATION	Eutrophication	Descriptor 5: Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom water
SEA-FLOOR INTEGRITY	Sea-floor integrity	Descriptor 6: Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected
HYDROGRAPHICAL CONDITIONS	Hydrographical conditions	Descriptor 7: Permanent alteration of hydrological conditions (i.e. physical parameters of seawater: temperature, salinity, depth, currents, waves, turbulence, turbidity) does not affect marine ecosystems
CONTAMINANTS	Contaminants	Descriptor 8: Concentrations of contaminants are at levels not giving rise to pollution effects
CONTAMINANTS IN SEAFOOD	Contaminants in seafood	Descriptor 9: Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards
MARINE LITTER	Marine litter	Descriptor 10: Properties and quantities of marine litter do not cause harm to the coastal and marine environment
ENERGY INCL. UNDERWATER NOISE	Energy incl. underwater noise	Descriptor 11: Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment

Sound Figure 2 The 11 Descriptor for the achievement of Good Environmental Status (MSFD)

To define and set up good environmental status, Member States are required to work with criteria and methodological standards for each descriptor in their marine strategies. In this regard, Commission Decision 2010/477/EU1, adopted in accordance with MSFD Article 9(3), provided criteria and methodological standards to ensure consistency in the determinations of GES, and to allow for comparison between marine regions or sub regions of the extent to which GES is being achieved. The 2010 Commission Decision was reviewed, and a new Commission Decision (EU)2017/8482 was published in 2017, following the Commission`s assessment of the marine strategies` first elements, as reported by Member States. In the 2017 Decision, for Descriptor 11 two criteria were defined:

i) The first criterion (D11C1) concerns anthropogenic impulsive sound in water and is described as follows: the spatial distribution, temporal extent and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect population of marine animals.

ii) The second criterion (D11C2) concerns anthropogenic continuous low-frequency sound in water and is described as follows: The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound sources do not exceed levels that adversely affect population of marine animals.

Commercial marine shipping is one of the main sources of human-made underwater sound and shipping's contributions to underwater noise have been increasing. Shipping vessels and other anthropogenic sounds (eg., dredging operations) can produce lower frequency sounds (20 to 1,000 Hz) that overlap the detectable frequency range of marine organisms (Figure 3).

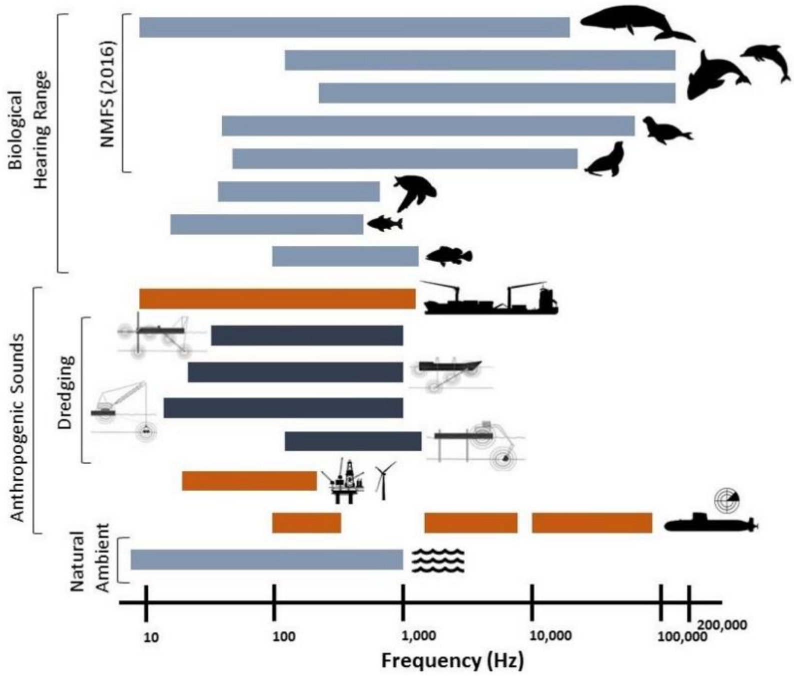

Figure 3 Frequencies produce by anthropogenic activities and marine species

Sounds propagates through water almost 4.5 times faster than in air (Urick, 1983). Long wavelength, low frequency sounds are relatively unaffected by absorption, scattering and reflection and may travel tens of kilometers, depending on local environmental conditions (Rogers and Cox, 1988).

Fish can detect frequencies ranges between 30 to 1,000 Hz (Erbe, 2011), and some fish can even detect infrasound (< 20 Hz; e.g., Clupeid spp.) and ultrasound (> 20,000 Hz; e.g., Atlantic herring; Normandeau Associates 2012). More commonly the 100 to 400 Hz frequencies are detected by a majority of fish studied (e.g., see Offutt 1974; Yan 2001; Codarin et al., 2009; Parmentier et al. 2011). Significant data gaps exist in terms of sea turtles' responses to underwater sound. Willis (2016) reports that the vocalizations and best hearing frequencies for turtles are around 300-500 Hz.

The spectrum of sounds and signals that are emitted and detected by marine mammals are in the much broader range of 7 Hz to 160 kHz.

Details on methodologies and frequencies used for the project are described in Deliverable

D-3.5.1 Report on the definition and implementation of the processing protocols and Deliverable 4. D-4.2.1. Gap-analysis report based on existing knowledge of the sensitivity of target species.

1.3 European Projects and other initiatives on underwater noise

For descriptor 11, a technical group was formed (initially called TSG Noise, later TG Noise) in 2010, that consisted of nationally-nominated experts with experience in different regions and relevant scientific expertise. Back then, anthropogenic underwater sound was an emerging topic, and little was known about the levels and effects of underwater sound and advice was needed to develop monitoring of underwater noise descriptors, as defined in the 2010 Commission Decision. In 2014, the EU Technical Group on Underwater Noise (TG Noise) delivered the guidance document: Monitoring Guidance for Underwater Noise in European Seas. Because of the overlapping of different marine species acoustic detection and sound emitted by shipping, frequencies suggested by the TG Noise for Descriptor 11.2 are 1/3 octave bands cantered at 63 and 125 Hz. Following this guidance, various EU-funded projects and other scientific work in the field of underwater sound were implemented as mentioned in the Management and monitoring of underwater noise in European Seas - *Overview of main European-funded projects and other relevant initiatives.* 2nd Communication Report. MSFD Common Implementation Strategy Technical Group on Underwater Noise (TG-Noise), December 2019 (Table 1).

QUIETMED	Joint programme on noise (D11) for the implementation of the Second Cycle of the MSFD in the Mediterranean Sea	2017 - 2018	*Spain*
CMEMS	Copernicus Marine Environment Monitoring Service and Quiet-Oceans initiative on Underwater Noise Mapping	2019 - 2017	*France*
SHEBA	Sustainable shipping and environment of the Baltic Sea region	2015 - 2017	*Sweden*
DEPONS	Disturbance Effects on the Harbour Porpoise Population in the North Sea	2012 - 2018	*Denmark*
UNAC-LOW	- Underwater acoustic calibration standards for frequencies below 1 kHz	2016 - 2019	*Turkey*
	Baltic BOOST	2015 - 2016	*HELCOM*

	Impacts of Noise and Use of Propagation Models to Predict the Recipient Side of Noise	2014 - 2015	*UK*
MaRVEN	Environmental Impacts of Noise, Vibrations and Electromagnetic Emissions from Marine Renewable Energy	2012 - 2015	*Denmark*
SONIC	Suppression Of underwater Noise Induced by Cavitation	2012 - 2015	*Netherlands*
AQUO	Achieve Quieter Oceans by shipping noise footprint reduction	2012 - 2015	*France*
BIAS	Baltic Sea Information on the Acoustic Soundscape	2013 - 2016	*Sweden*
JONAS	Joint programme for Ocean Noise in the Atlantic Seas	2019 - 2021	*Ireland*
QUIETMED2	Joint programme for GES assessment on D11-noise in the Mediterranean Marine Region	2019 - 2021	*Spain*
JOMOPANS	Joint Monitoring Programme for Ambient Noise North Sea	2018 - 2020	*Netherlands*
CeNoBS	Support MSFD implementation in the Black Sea through establishing a regional monitoring system of cetaceans (D1) and noise monitoring (D11) for achieving GES	2019 - 2021	*Romania*
RAGES	Risk-based Approaches to Good Environmental Status with case study on D2 (non-indigenous species) and D11 (underwater noise)	2019 - 2021	*Ireland*
AGESCIC	Achieve Good Environmental Status for Coastal Infrastructure Construction	2019 - 2021	*France*
	Underwater noise impact reduction of the maritime traffic, and real-time adaptation to ecosystems	2019 - 2022	*France*
LIDO	Listening to the Deep-Ocean Environment	2007 - ongoing	*Spain*

	JPI Oceans Action – Munition of the Sea	2011 - ongoing	*Belgium*

Table 1 European Projects and other initiatives on underwater noise in the last 15 years

1.4 Soundscape Project

The Interreg Italy-Croatia SOUNDSCAPE project had the aim of monitoring the soundscapes in the North Adriatic Sea and their impact on marine biological resources. SOUNDSCAPE started in February 2019 for supporting for the first time the implementation of underwater noise in the Mediterranean Sea, taking into account the North part of the Adriatic Sea, which stretches along the Italian, Croatian and Slovenian coasts. This cooperation aims to ensure an efficient protection of marine biodiversity and to develop a sustainable use of marine and coastal ecosystems and resources. The objectives of the project were to be pursued in three ways:

1) implementing a shared monitoring network for a coordinated regional and transnational assessment of the underwater noise
2) evaluating the noise impact on marine biological resources
3) developing and implementing a planning tool for straightforward management.

Four Croatian partners and four Italian Partners took part to the project: the Institute of Oceanography and Fisheries (IOF), Blue World Institute (BWI), Croatian Ministry of Environment and Energy, Teaching Institute of Public Health of Primorsko-Goranska County, National Research Council – Institute of Marine Sciences (Cnr-Ismar), Environmental Protection Agency of Friuli Venezia Giulia – ARPA, Cetacea Foundation (CF) and Marche Region - Service for Care, Management and Territorial Planning.

The SOUNDSCAPE project dealt specifically with monitoring continuous low frequency sound as covered by the MSFD indicator 11.2.1: the spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound sources do not exceed levels that adversely affect population of marine animals.

The 1/3 octave frequency bands of 63 and 125 Hz were recommended by TSG Noise as proxies for noise generated by ships. Therefore, these frequency bands were the main focus of the data processing and modelling within SOUNDSCAPE, although the sound measurements themselves covered a wider frequency range (10 Hz – 10,000 Hz).

In last years, different studies on underwater sound have been carried out in the Mediterranean Sea, both on SPL levels and Frequency analysis.

A long-term study of approximately 10 months in the Ionian Sea at a depth of 2100 m shows that the median of the SPL values exceeds 100 dB re 1 μPa in the standard 1/3 octave bands up to 250 Hz. In particular, the median values of the SPL in the 1/3 octave bands cantered at 63 Hz and 125 Hz, considered in the descriptor 11.2 of the MSFD, reach respectively 112 dB re 1 μPa and 107 dB re 1 μPa (Viola et al. 2017). From 2013 to 2014, a similar study has been run in the shallow waters of Lampedusa (Italy), in the middle of the Mediterranean Sea, inside a marine protected area. Lampedusa is characterized by heavy anthropogenic noise, with a mean of 13 vessel passages per hour over one year, and with a masking effect on the fish vocalizations below 2kHz during July and August for approximately 46% of the time. Noise levels at lower frequencies increased from November to March (from 97.8 to 103.7 dB re 1μPa) whereas the higher frequencies followed the opposite pattern (102.3 to 110.9dB re 1μPa), with lower values during the winter. This seasonal variability was mainly attributable to the sea state for the lower frequencies and to the activity of snapping shrimp for the higher frequencies (Buscaino et al. 2016).

In a study conducted by Picciulin et al. in 2019, the Northern Adriatic Sea was defined as a 'noisy' area: SPL wideband values range from a minimum of 88 dB re 1 uPa to a maximum of 154 dB re 1 uPa (recorded in the Losinj archipelago) with an average value equal to 125 ± 11 dB re 1 uPa. For 63 Hz and 125 Hz 1/3 octave bands SPL levels do not exceed 132 and 136 dB re 1 uP respectively, with and average value of 104±14 and 107±11 dB re 1 uPa.

On the other hand, taking into account the frequencies bands, as mentioned above, TG Noise suggested 63 Hz and 125 Hz as the representative frequencies for the ambient noise measures in particular for the anthropogenic noise radiated by shipping. However, in the study carried out by Picciulin et al., 2016, in the Northern Adriatic Sea, the noisiest band level was centred on 200 Hz. Therefore, authors suggest measuring a wider frequency band than those requested in Indicator 11.2.1.

In order to strengthen the ecological relevance of the results, two other frequency bands were added to those specified by the indicator; the 1/3 octave band centred frequency of 250 Hz (Turtles) and 4000 Hz (Dolphins).

1.5 The study area

The study area has been the North Adriatic Sea, a body of water separating the Italian Peninsula from the Balkans. The Adriatic Sea is the northern part of the Mediterranean Sea, extending as north as 45°47' N. It covers an area of about 138000 km2 and washes the coasts of 5 countries: Italy, Slovenia, Croatia, Albania and Montenegro. The Adriatic Sea is an elongated, landlocked narrow basin located on the East part of the Italian Coasts, it extends 800 km in length and 150 km in width (Poulain et al., 2001).

The Soundscape project monitoring and modelling is focused on the North Adriatic Sea (NAS) that covers the northern part of the Gulf of Trieste till the Middle Adriatic Pit, tracking an imaginary line from Alba Adriatica city on the Italian Coast to Neum city on the Croatian coast. The bathymetry of the North Adriatic Sea is characterized by relatively shallow waters, starting with a depth of 15 m along the Venice-Trieste coastline, increasing slowly southward, and then sharply reaching about 270 m in the Middle Adriatic Pit in front of Pescara (Poulain et al., 2001).

The northern and western coasts are generally sandy-muddy, shallow, presenting many marshes and lagoons and the nearby land is flat. In contrast, the Eastern coast is mountainous, including numerous islands, rocky shores, submerged reefs, bays and coves.

The Adriatic Sea is influenced by dynamic meteorological conditions and the continental characteristics are reflected by pronounced seasonal variations. Although, the middle Adriatic sill called Palagruza affects the current dynamic, salinity and temperature distribution of the basin.

As a whole the Adriatic is a temperate warm sea, at the same time is influenced by intense surface and lateral fluxes caused by the climatological dynamic characterized by bora wind, cold from north and sirocco wind, warm from south. The cyclonic and anticyclone movements influence significantly the distribution of the hydrological properties of the NAS. In winter time temperature salinity and density are characterized by a vertical homogeneity in the water column. The minimum sea surface temperature is about 8 °C close to the Po River delta, which is at a lower temperature compared to the sea water. In summer time, on the contrary, there is a strong vertical stratification with a thermocline at 5-10 m depth. Maxima temperatures are found along the Italian coast (23 -25 °C), and minimum on the other side (19-20 °C) where upwelling events prevail. In this season, river waters are warmer than the sea ones. Salinity values range from near zero close to the river's inflow to a maximum of about 38.5 on the east part of the basin, poor of freshwater inflows. However, maxima salinities are reached during winter and minima ones in summer, that is not perfectly matching Po River discharge, whose maxima are reached in spring-autumn and minima in summer. During summertime a slight decrease in the surface salinity values is observed (mean 36.79, median 37.60) together with a further propagation offshore of low salinity waters that now reach the whole northern part. This is most likely due to the strong stratification typical of this season, that is in short confining the relatively low number of fresh waters brought into the very upper layers of the sea. Water with relatively high salinity is now evident just in the central-south region, north of Gargano. The open Adriatic is an oligotrophic sea, while close to the coast where rivers are present is richer in nutrients (Poulain et al., 2001).

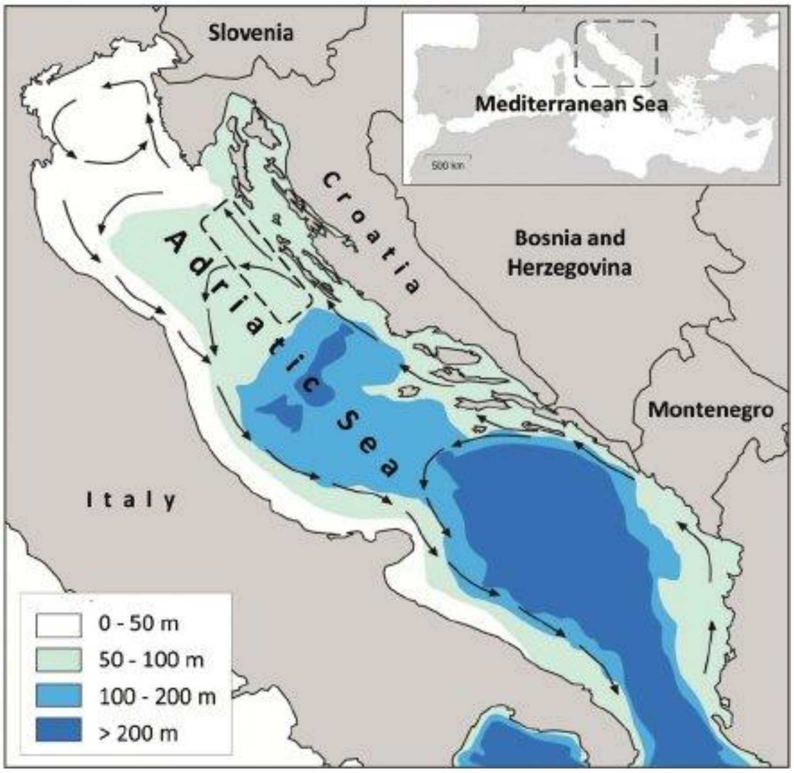

Figure 4 North Adriatic Sea (NAS) bathymetric and currents map (Gracan et al., 2014).

The entire NAS basin is also characterized by a high concentration of harbours and by many anthropic activities including fisheries, mussel and fish farms, commercial, urban and touristic activities (Picciulin et al., 2019).

Given its geographical location, the Adriatic Sea provides a priority maritime route from Asia, via Suez, to Europe. Northern Adriatic gateway multi-port system consists of the ports of Ravenna, Venezia, and Trieste, the Slovenian port of Koper and the Croatian port of Rijeka (Luipi et al., 2019). Although cruise industry is growing and the major traffic lane goes from Bari to Venice and Dubrovnik cities (Caric et al. 2014). The Northern Adriatic Sea is the area of the Mediterranean Sea with the highest increment of passenger traffic (cruises, ferries, catamarans and recreational boats) in 2016 compared to the previous years, and this trend is expected to continue (Adriatic Sea Tourism report, 2017). Many harbours (ports and marinas) are here concentrated, with highly touristic zones being exposed to high levels of recreational traffic. The Central-Northern Adriatic regions host old and important fishing traditions, and its fishing ports have always been a point of reference and innovation for sea fishing. More details on presence and characterization of naval and boat traffic in the NAS are described in the *Deliverable 5.4.1 Development of mitigation measures to reduce underwater noise and its effects on biological targets.*

2 Results

2.1 International monitoring network

The main objective of the project was 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. To achieve this goal a first standard on Underwater Noise monitoring has been set up at regional level 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. A definition of the appropriate technical equipment to be use has been developed, and to obtain quality underwater noise monitoring all partners utilized the same Sono.Vault autonomous passive underwater acoustic recorder (APUAR). 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 data collected could then be compatible and comparable between all stations for the elaborations of results. Locations of monitoring stations are displayed in Figure 5. Image and scheme of the Sono.Vault APUAR equipment and accessories are presented in Figure 6. More details on characteristics and variability of the different stations and the specifications of the APUAR equipment are presented in the Deliverable D-3.2.1 Definition of the underwater noise monitoring system set up and specifications for the system components.

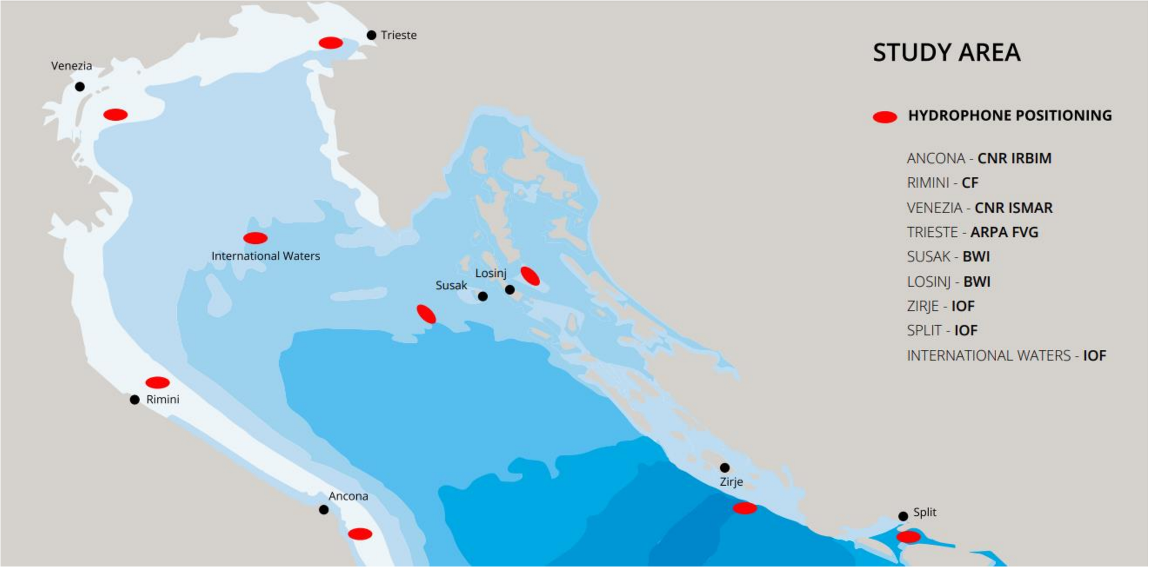

Figure 5 Hydrophones positioning in North Adriatic Sea

Pre and Post deployment and recovery procedures has been recommended for all partners as described in the Deliverable D-3.2.2 Recommendations for the underwater noise monitoring procedure.

Continuous underwater acoustic measurements generate relatively large amount of data, considering that one APUAR could generate about 500 GB of raw data per month. Therefore, for the safely data handling among project partners, special requirements for the data exchange protocols and data storage has been developed. Details on data processing and storage are described in Deliverable D-3.3.2 Underwater noise levels raw data database (and security protocols for data exchange).

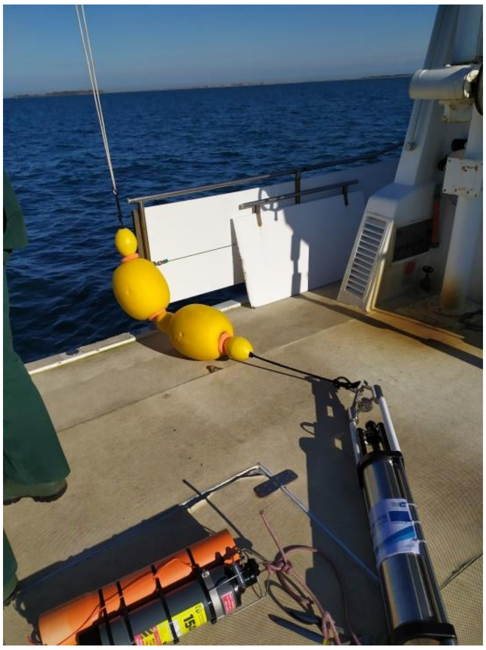
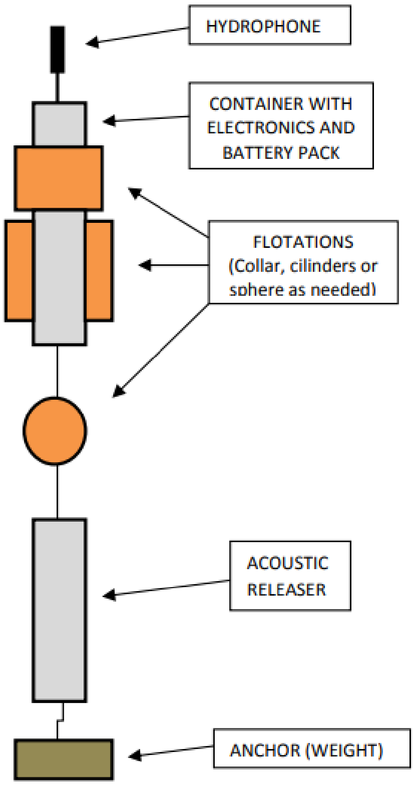

Figure 6 Equipment picture and scheme

2.2 Measurements Results

Underwater noise SPLs in NAS were calculated over 1 year of recordings (Details on methodological process is described in Deliverable D-3.6.2 Processing of data input for modelling and uncertainty analysis). Percentiles (5th, 25th, 50th, 75th, 95th percentile) values were obtained for each 1/3 octave bands. In the context of underwater noise, a percentile L_N is defined as the level that is exceeded for N percent of the time interval considered. As a consequence, L_{90} can be assumed to describe the lowest noise levels, being a value that is almost always exceeded along the time interval; L_{50} is the median level and L_{10} represents the values exceeded by rare levels characterized by the highest noise levels. Table 1 summarizes the descriptive values for NAS; a difference of about 20 dB re 1 µPa between L_{90} and L_{10} is found for the MSFD frequency bands.

Frequencies 1/3 octave band	Arithmentic Mean	50 EL L_{50}	75 EL L_{75}	25 EL L_{25}	90 EL L_{90}	10 EL L_{10}
63 Hz	82.7	82.6	77.3	96.2	68.9	105.0
125 Hz	87.5	88.2	75.00	86.13	68.3	92.40

Table 2 Underwater recorded noise SPLs in NAS (descriptive values; dB re 1 µPa) for MSFD frequency bands (one year data)

Figure 7 represents nine NA monitoring stations as circle with different diameter, sized according to their total 50th percentile calculated for the 1/3 octave bands centred at 63 Hz and 125 Hz, respectively, based on one year of continuous data recordings. This map represents the values dividing the noise distribution 50% of time over the threshold and 50% of time under this value.

Overall, for the MSFD frequencies, the stations MS3 (Ancona), MS6 (Losinj) and MS1 (Venice) show lower median annual SPLs (63 Hz and 125 Hz 1/3 octave bands) compared to MS4 (Trieste), MS5 (Susak), MS7 (Zirje), MS9 (Ivana), MS2 (Rimini), MS8 (Split).

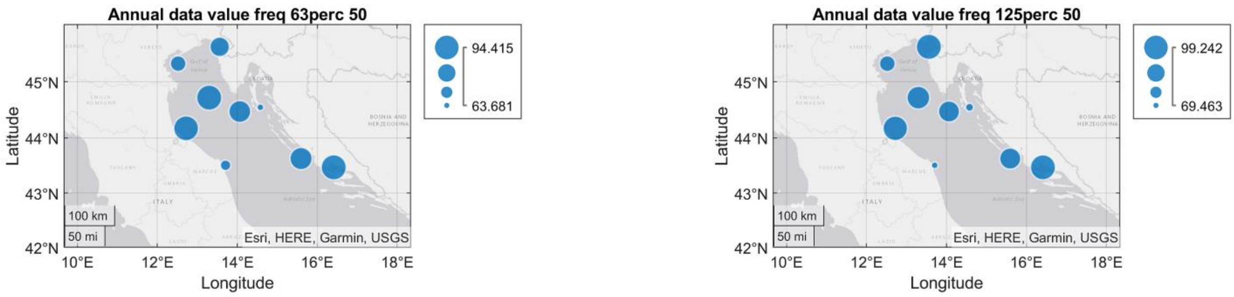

Figure 7 Representation of nine NA monitoring stations as circle with different diameter, sized according to their total 50th percentile calculated for the 1/3 octave bands centered at 63 Hz and 125 Hz on one year of continuous recordings.

Figure 8 and 9 show the monthly SPL values for the 1/3 octave bands centred at 63 Hz and 125 Hz calculated per each of the nine NA monitoring stations. Seasonal variations are evident for some but not all of the considered stations.

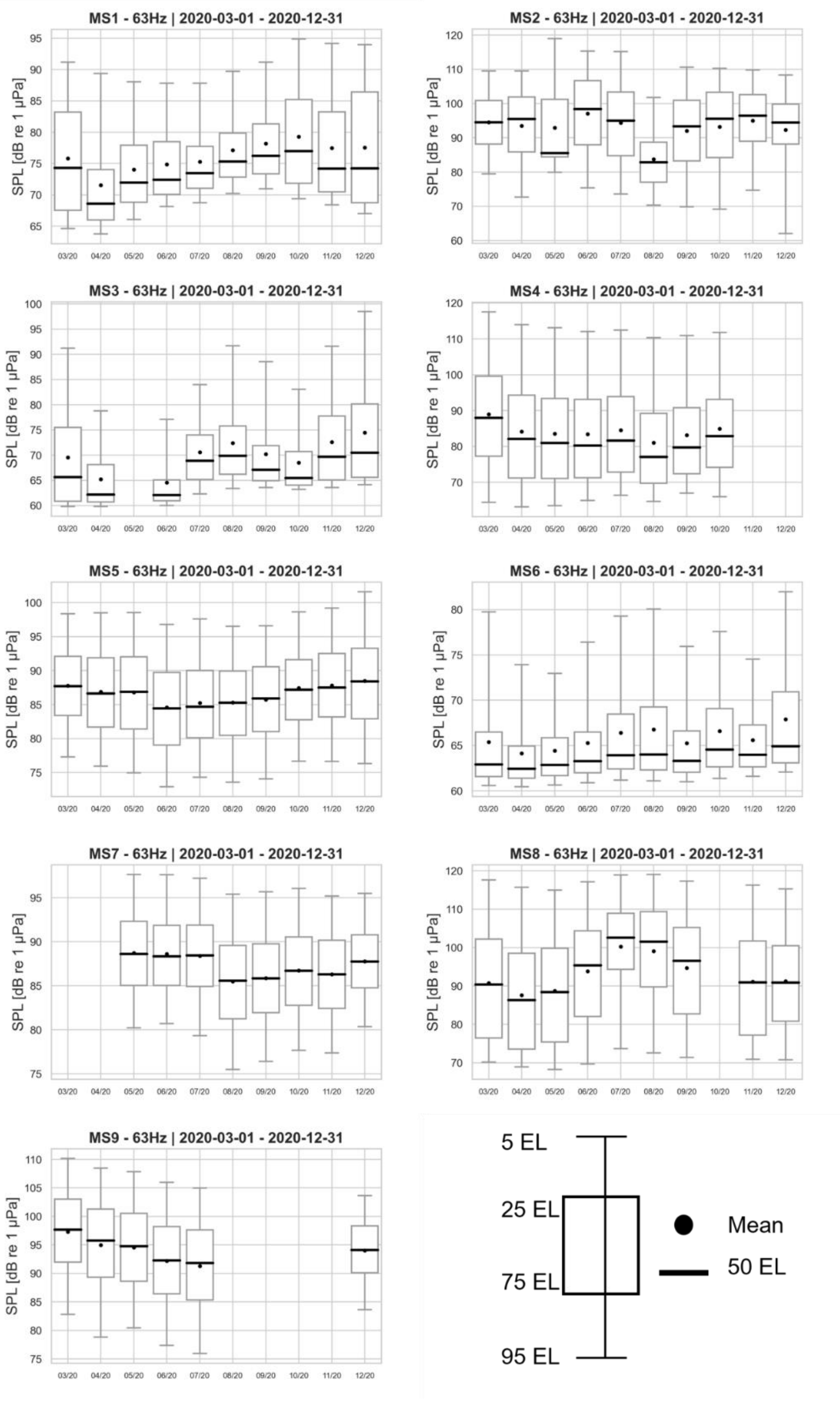

Figure 8 Monthly 1/3 octave bands centered at 63 Hz (Box Plots) for the nine NA monitoring stations

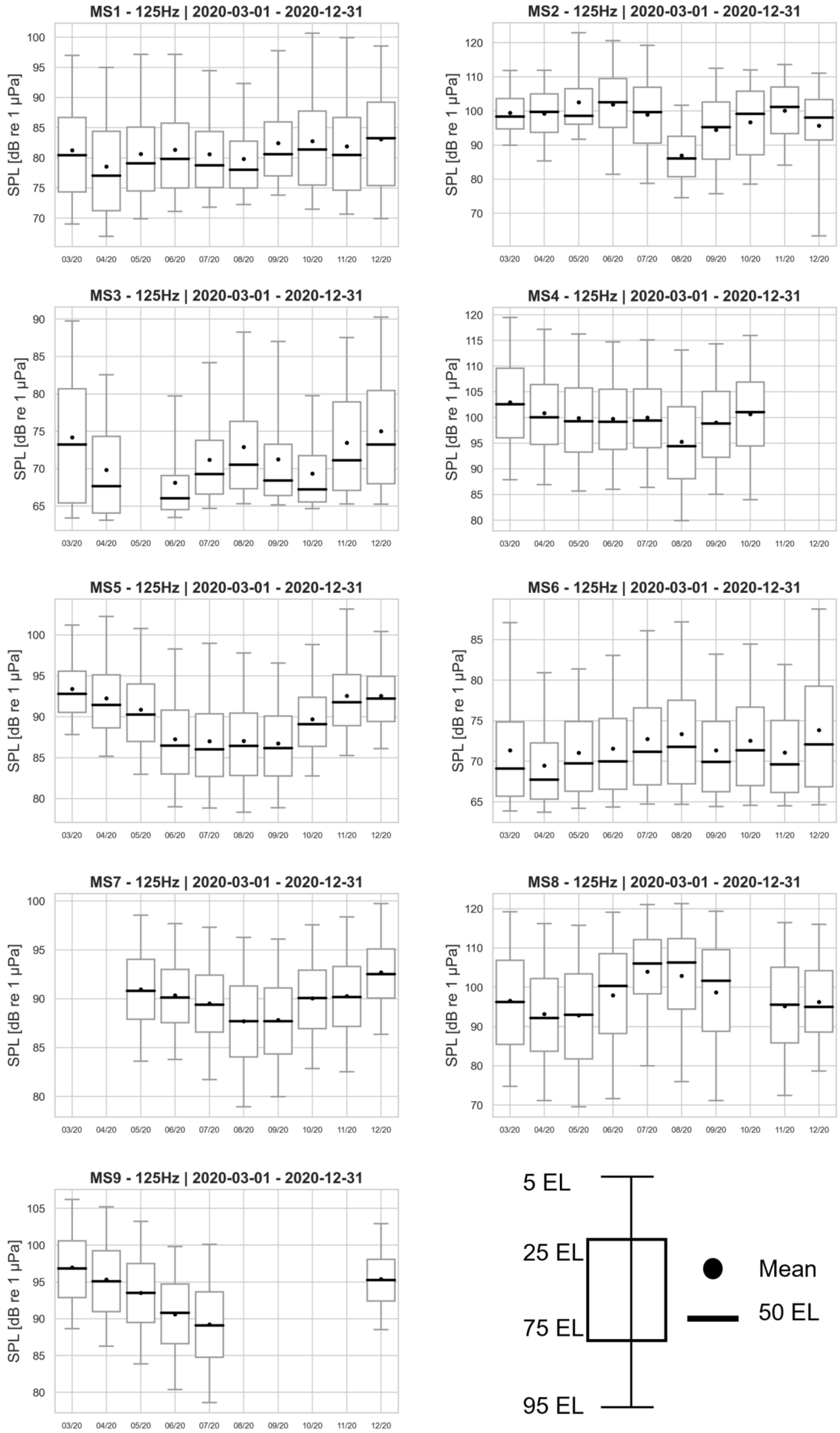

Figure 9 Monthly 1/3 octave bands centered at 125 Hz (Box Plots) for the nine NA monitoring stations

2.3 Modelling results

The underwater noise along the Northern Adriatic Sea was illustrated by monthly and annual maps made available through the QUONOPS online platform. Noise mapping enhances the local measurement providing a basin-scale description over the full area of interest taking into account of the sound propagation properties of the local environment and the noise input generated by Automated Information System network (Folegot, 2012). The modelling activity in the SOUNDSCAPE project considered four third-octave bands: two of them correspond to the MSFD control continuous 1/3 octave bands centred at 63 Hz and 125 Hz and the two other 1/3 octave band frequencies are centred at 250 Hz and 4000 Hz (see Deliverable D-4.2.1 Gap-analysis report based on existing knowledge of the sensitivity of target species for details). SPL values for these 1/3 octave bands were given by the model at three depth ranges (Surface to -15m, 30m to the bottom, and the full water column). For each noise map, seven percentiles (5th, 10th, 25th, 50th, 75th, 90th and 95th exceedance levels) were made available. (See Deliverable D-5.2.1 Monthly and annual Maps of soundscape and D-5.2.2 Interactive web interface with sound levels and probability to exceed some threshold in different timescale for details). Figure 10 shows the annual mean levels of natural and baseline noise for the 2020 year.

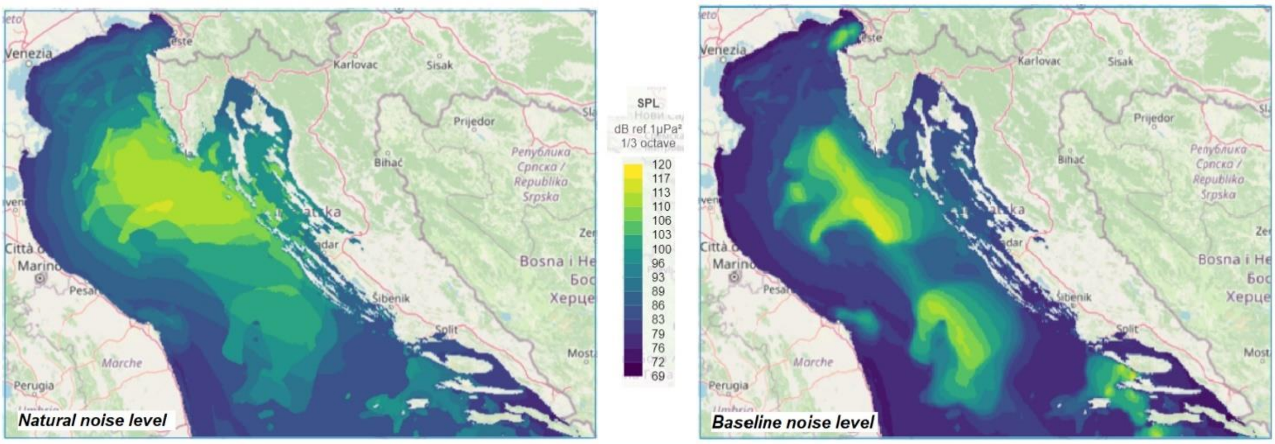

Figure 10 Natural and Baseline noise mean level maps for 2020, implemented by Quonops.

The maps gave valuable information on the noise spatial distribution along the whole investigated Northern Adriatic Sea; as a consequence, they were here used to interpret the obtained results. Both *natural* and *baseline* noise maps were provided by Quiet Ocean, assuming that this division refers to SPL values generated by (i) the natural noise generated by wind, waves and rain and (ii) the natural *plus* anthropogenic acoustic sources in the study area, accordingly. More in detail, the *baseline* noise maps were developed from information about shipping taken from the AIS vessels (D-5.1.3 Data on traffic collection and elaboration) and oceanographic data such as temperature, salinity, sea-state and bottom properties (D-5.1.1 Database of environmental data collected for modelling and D-5.1.2 Data resulting from hydrodynamic model (and wave) to integrate the environmental database).

3 Elaboration of Results

3.1 Excess noise spatial distribution

In the measured sound the natural and anthropogenic components exist often simultaneously. Therefore, the key question for quantifying the prevalence of anthropogenic sound is to estimate its excess over the underlying natural levels. By using the noise maps it is theoretically possible to describe the area for which the human-made noise exceeds the natural ambient noise level, subtracting the SPL values obtained from *baseline* to the one from *natural* noise maps. By repeating this process *per* each monthly couple of maps, an indication of the temporal trend of the anthropogenic pressure in the area could also be obtained.
The median (50th percentile) of the sound levels along the study area *per* the *natural* and *baseline* maps for the continuous 1/3 octave bands centred at 63 Hz and 125 Hz was considered, subtracting the SPL values obtained from *baseline* and *natural* noise maps. This gives the excess level distribution in the study area. Monthly maps highlighting the difference between the median of *baseline* and *natural* SPLs, expressed in dB, were generated *per* each month (Figure 4 and 5).

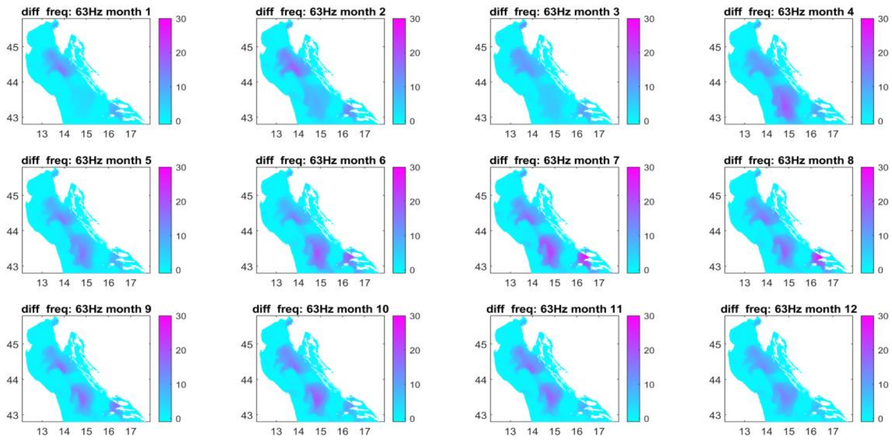

Figure 11 Excess noise spatial distribution (1/3 octave band centered at 63 Hz) from January to December 2020

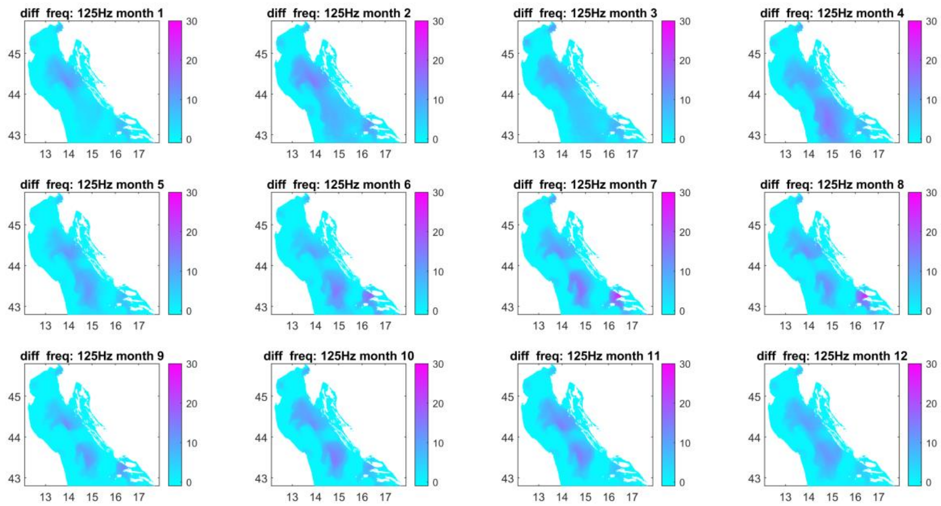

Figure 12 Excess noise spatial distribution (1/3 octave band centered at 125 Hz) from January to December 2020

Variation in the extend to the excess noise spatial distribution can be observed, with a larger amount of the study area affected by man-made noise pressure during spring and summer. The distribution of the noise along the central NAS and the Trieste Gulf, reflects the main cargo routes. In its turn, this result is related to the use of AIS as input data for the anthropogenic noise in NAS. On the other hand, MS4 (Trieste) was highlighted as very impacted by anthropogenic noise by using the recorded data, whereas MS2 (Rimini) and MS8 (Split) seem less influenced in the modelled data than the ones collected from the hydrophones. This could depend from the lack of calibration of the data for the modelling in these areas (see below).

3.2 Quonops model quality-control

A first quality-control system was developed by Quiet-Oceans on some pilot data before the modelling activity. The calibration of the model is based on the ground truth given by a number of time series of underwater acoustic measurement taken from a diversity of measurement stations. The calibration is a process that aims reducing the uncertainties for a number of model parameters.
The calibration process is based on the Cumulative Density Functions (CDF) that provide a description of the statistical content of the sound for the period considered similarly for both the measurement and the modelling regardless from the technical characteristics of the measurement nor the modelling. The CDF express the relationship between the sound level and the percentile, e.g., the proportion of time a given level occurs.

Calibration consists in finding the best set of model parameters that minimize the difference between the CDF provided by the measurement and the CDF provided by the model at the position of the measurement and for the same period of time.
In order to run the calibration process, Quiet-Oceans has decided to ignore certain measurement datasets for i) differences between the measurement depth available in the measurement file and the depth identified in the bathymetry layer used by QO, ii) measurement quality problems, i.e., Quiet-Oceans highlighted signal instabilities or unwarranted noise variations. As a result, the calibration of the model was performed on five stations (MS1, MS3, MS4, MS5, MS9), mainly distributed along the Italian sandy coasts, whereas four monitoring stations were not calibrated (MS2, MS6, MS7, MS8).
Calibration was performed globally using all data available till 1st October 2020; the quality of the calibration was measured using the Residual Mean Square Error (dB), defined as the quadratic difference between the measured and modelled Cumulative Density Function (CDF). The Residual Mean Square Error (dB) was computed on percentiles between 5 and 95 to exclude extreme events. The Residual Mean Square Error is always lower than 1 dB (Table 3) for the calibrated monitoring stations.

Residual Mean Square Error (dB)

	63Hz	126Hz	251Hz	4000Hz
MS1	0.82	0.4	0.42	-
MS3	0.5	0.61	0.98	0.35
MS4	0.48	0.44	0.66	-
MS5	0.41	0.36	0.48	-
MS9	1.00	0.32	0.3	-

Table 3 Residual Mean Square Error between the modelled and the recorded values for the calibrated stations.

3.3 Post-processing quality control

A post-process evaluation of the difference between the expected and the recorded noise levels on the recording stations has been also run by CNR. This further helped to evaluate where the modelling results were more reliable in space.
A root-mean-square error (RMSE) was further calculated over the seven available percentiles (5th, 10th, 25th, 50th, 75th, 90th and 95th exceedance levels) given by the model and the corresponding values obtained from the *in-situ* recordings according to the following equation 1, z_f being the measured percentiles and z_o the modelled percentiles:

$$\mathrm{RMSE}_{fo} = [\sum_{i=1}^{N} (z_{f_i} - z_{o_i})^2 / N]^{1/2}$$

eq.1

Modelled percentile values were extracted from the spatial cell provided by the maps, which was closest to the real hydrophone position; these values represent the noise levels estimated for the whole water column. RMSE was here used as a measure of the modelled data accuracy. In general, a lower RMSD is better than a higher on.

RMSEs reach 20 up to 40 dB for the non-calibrated stations (MS2, MS6, MS7, MS8), as expected from the Quonops calibration process; on the other hand, these values were generally below 10 dB for the calibrated ones (MS1, MS3, MS4, MS5, MS9). RMSEs values lower than 5-6 dB could reflect a reasonably good correspondence between model and recorded data.

The following map (Figure 13) classified the nine monitoring stations as low reliable, medium reliable and high reliable for their output in the modelling, based on the maximum RMSE calculated along the 12 months' study period.

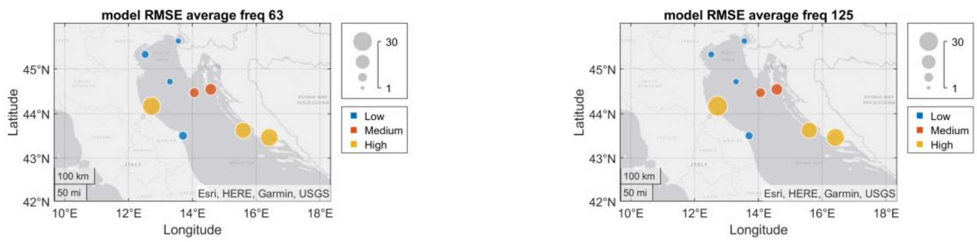

Figure 13 Monitoring station displayed by a circle, whose diameter is sized according to its maximum RMSE calculated along the 12-month study period for the four considered 1/3 octave bands; monitoring stations are classified accordingly, with different colours highlighting low, medium and high RMSE.

4 Considerations and Recommendations

SOUNDSCAPE INTERREG Project has been the first underwater noise project done in the Adriatic Sea. Important results have been achieved, first of all it was established a transnational collaboration between two different countries (Italy and Croatia), and 8 different partners, each one with self-skills in communication, management and technical field.

From this collaboration it was possible to create a unique monitoring procedure using the same APUAR instruments (Sono.Vault) for the initial assessment of D11.2 on underwater noise in Northern Adriatic Sea. Also, a same processing data method has been implemented, using the online server (Audio Noise Processing) for uploading all data, more than 30 Tb in total.

To evaluate the status of Sea Ambient Noise in Northern Adriatic Sea sub region, a comparison with scientific literatures of different areas of the World and of the European and Mediterranean regions have been made, taking into account the 1/3 octave bands indicated by the MSFD (63 and 125 Hz) (Table 4).

Zone		NA	NA	NA	NA	NA	NA	NA	MED	MED	MED	MED	MED	MED	MED	MED	MED	MED	MED
Area		Azores	Azores	Azores	UK	UK	UK	UK	Spain	Spain	Italy	Italy	Italy	Italy	Italy	It-Hr	Italy	Italy	It-Hr
Station		Açores	Gigante	Condor	CelticSea	NorthSea	SouthernNorthSea	FalmouthHarbour	CartagenaPort	CartagenaPort	CataniaPort	Civitavecchia	SZ-GulfofNaples	B1-GulfofNaples	B2-GulfofNaples	NAS	TriesteGulf-ARPAFVG	TriesteGulf-ARPAFVG	NAS-SOUNDSCAPE
63Hz(dB)	mean	70.2±9.2	73.6±12.	72.4±5.6	101.60	101.80	110.80	92.60	100.70	113.30	112.89	119±12	97.55	91.96	92.09	104±14	95.00	92.60	82.67
	5%							68.50											
	10%												87.58	83.76	85.00			84.68	105
	25%												92.37	87.51	87.90			87.85	96.2
	50%							78.30										91.59	82.6
	75%												102.24	96.33	96.04			96.92	77.3
	90%				93.20	100.30	102.00						106.79	100.09	99.61			101.69	68.9
	95%							95.30											
125Hz(dB)	mean	74.6±9.8	76.0±11	79.5±10.	102.30	103.80	113.10	96.00	102.30	114.50	107.83	111±11	95.76	90.77	90.93	107±11	97.00	89.16	87.55
	5%							81.30											
	10%												87.81	80.41	81.35			81.25	92.4
	25%												91.57	84.57	85.30			85.02	86.13
	50%							89.50										88.47	88.2
	75%												99.75	96.48	96.28			92.60	75
	90%				93.30	103.50	102.00						103.41	100.10	100.34			97.19	68.3
	95%							100.50											
Reference		Romagosaetal.,2017	Romagosaetal.,2017	Romagosaetal.,2017	Merchantetal.,2016	Merchantetal.,2016	Merchantetal.,2016	Garretetal.,2016	DeClippeleetal.,2021	RodrigoSauraetal.,2019	RodrigoSauraetal.,2019	Cafaroetal.,2016	Pierettietal.,2020	Pierettietal.,2020	Pierettietal.,2020	Picciulinetal.,2019	Codarinetal.,2015		

Table 4 Literature summary values of 63 and 125 Hz in different part of the World.

Values of the arithmetic mean at 63 and 125 Hz in the Northern Adriatic Sea are quite similar to the values of other study areas. In some cases, it looks lower. The monitoring has been started when the pandemic spread out in Europe and all over the world and the stop of marine traffic for the first months of the year could be reason of a lower value of the Sea Ambient Noise in the NAS in 2020. For this reason, it is rather important to continue the monitoring in the next months in order to evaluate changes in shipping traffic and/or noise underwater.

Regarding the implementation of the Marine Strategy Framework Directive, focusing on Descriptor 11.2 on continuous low frequencies sound, Soundscape proceed in achieving great amount of data on the 63 and 125 Hz 1/3 octave band as suggested by the document. Objective of Article 9 (MSFD 2008/56/CE) concerning the initial assessment for the underwater noise has been achieved during the monitoring of 12 months in continuous. A *Baseline* and *Natural noise level* of the Northern Adriatic Sea has been assessed.

Analysing results, different considerations could be made starting from the utility to have different monitoring stations for each sub region of the Mediterranean Sea. Because of the important variability between different areas of the basin, due to bathymetry, sediment characteristics, currents, temperature and wind variables, values obtained in the 9 stations vary between each other. The same variables determine the variability on a spatial and temporal scale, adding the different distribution of recreational boats during summer and winter, and the higher presence of fishing boats toward the Italian coast, compare to the Croatian Coast (more details on distribution of ships in the NAS are well described in Deliverable 5.6 D-5.6 Activity Title Transferability Plan at Adriatic basin scale). For these reasons recommendation on monitor different stations with different characteristics could be useful in order to determine modelling bias as well as understanding variables that influence the underwater sound propagation. In the same way monitoring and analysing data at a monthly or seasonal basis could be useful to estimate the incidence of ships, temperature and other variables on the sound speed profile and its propagation.

Evaluation of the Sea Ambient Noise for the initial assessment as described in art.9 of the MSFD, is essential to develop monitoring strategies, programmes of measures and achievement of Good Environmental Status. Collecting data for all the frequency bands from 0 Hz to 1 KHz is recommended in order to evaluate the noisier 1/3 octave band in the area and subsequently concentrate the effort in managing the mitigation measures on these frequencies and on biological species more impacted in a determinate region or subregion.

Another important result of the SOUNDSCAPE project is the production of modelling maps on underwater noise radiation (Deliverable D-5.2.1 Monthly and annual Maps of soundscape). Modelling will become one of the most important tools in implementation of analyses in the research filed. For this reason, it's of a great importance to increment the utilization of modelling software and algorithms, for the evaluation of extended areas. Field work measurements will become the modelling validations instruments, with the chance to diminished the effort of monitoring on site. Future will include spot measurements along the area and through a monthly or annual scale.

Modelling have been made using AIS data (D-5.1.3 Data on traffic collection and elaboration (automatic download from web)) on distribution of ships around the study area. Nevertheless, regulation requires AIS to be fitted aboard only for ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnages and upwards and all passenger ships. For this reason, majority of recreational, pleasure boats or other kind of vessels were not considered for the model implementation. To solve or diminished the issue, and give the model less bias on presence-absence of ships in the area, could be ideal to distribute and disseminate the usage of an AIS map, on all kind of boats, through a *Citizen science* initiative. An idea could be the Marine Traffic OnCourse - boating & sailing App.

Keep going with a long-term monitoring of Sea Ambient Noise in the Northern Adriatic Sea as well in other parts of the European Seas is necessary to evaluate the achievement of Good Environmental Status and take action with appropriate programmes of measures if the GES is not achieved. Next milestone on evaluation of GES is the identification of threshold of Sea Ambient noise in each marine sub region, as suggested by the TG Noise. Long term monitoring is therefore necessary for the protection and conservations of marine ecosystems.