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THE EUROPEAN PROJECT 'DEUTERONOISE' - CHARACTERIZATION OF MARITIME NOISE IN DIFFERENT EUROPEAN BASINS AND ITS IMPACT ON ECOLOGICAL RELEVANT DEUTEROSTOME INVERTEBRATES

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ABSTRACT

DeuteroNoise is an European project founded by JPI Oceans intergovernmental platform. The project aims to characterize the noise pollution caused by maritime traffic in selected sites of the North Adriatic Sea, Lagoon of Venice, North Sea, Black Sea, and Barcelona shore, and to investigate its impact on behavior, nervous system and sensory organs, immune system, and resilience in marine invertebrates deuterostomes. These animals are closely related to vertebrates and can be easier studied in laboratory and on-site. A behavioral, morphological and genetic survey will be conducted on sampled animals living in polluted *vs* non-polluted areas. Moreover, animals will be exposed to noise in laboratory-controlled conditions. The noise level will be measured on-site and simulated in the laboratory using experimental layouts

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specifically designed for the project. In this work, these layouts will be described (equipment used and protocols) and the results of the first measurements will be reported. Comparative studies will allow us also to highlight levels and characteristics of noise pollution in the different basins, to predict noise pollution and to infer the best practices to reach the Good Environment Status of European basins.

Keywords: *underwater acoustics, underwater noise measurements, laboratory underwater measurements, biological noise effect*.

1. INTRODUCTION

1.1 Project Objectives

DeuteroNoise is an international collaborative and interdisciplinary project whose the main goal is to contribute to reach a Good Environmental Status (GES) of European seas and oceans, within the Marine Strategy Framework Directive (MSFD, 2008/56/EC) [1] Task Group 11, by characterizing noise pollution caused by maritime traffic in selected sites of the North Adriatic Sea, Lagune of Venice, Barcelona shore, North Sea, and Black Sea, and testing its effects on animal behavior, nervous system and sensory organs, immune system, and resilience in MIDs (Marine Invertebrates Deuterostomes). To reach this goal, the consortium, formed by a team of experienced researchers from four countries and with diverse backgrounds, will undertake a comprehensive analysis of noise level caused by maritime traffic in the selected sites and will analyze from different points of view a panel of ecological relevant invertebrate species.

1.2 State of art

In the last century, the level of noise in the sea worldwide has risen considerably due to increased human activities, thus generating a growing international concern regarding its impact on marine organisms [2], [3]. In the European Commission document “Proposed Mission Starfish 2030: Restore our Ocean and waters – Report on the Mission Board healthy Oceans, Seas, Coastal and Inland Waters”, the reduction and the regulation of underwater noise is identified as one of the four targets to achieve the ambitious objective of “Zero Pollution”. The Marine Strategy Framework Directive (MSFD, 2008/56/EC) [1] was just put in place with the aim to achieve a Good Environmental Status (GES) of EU marine waters based on 11 qualitative elements, the descriptors. Amongst them, the Descriptor 11 relies on the introduction of energy (including underwater noise) that does not adversely affect the ecosystem. Underwater noise is associated with anthropogenic activities such as shipping, dredging and drilling operations, seismic surveys, and cabling. These sources of noise overlap the natural ambient (animal communication, defense, hunting, partner search), physical (ocean turbulence), atmospheric (meteorological), and geophysical sounds. The impact of the sum of underwater noises on marine animal health is still far from being fully understood [3]. In the MSFD Task Group 11 Report (Underwater noise and other forms of energy - April 2010) [4] three underwater noise indicators are presented. Among them, the most suitable for the characterization of marine traffic noise is the “Indicator 3" (low frequency, continuous sound) which essentially consists of the sound pressure level corresponding to the 1/3 octave bands of 63 and 125 Hz. These frequencies well characterize the anthropic noise without overlapping the natural one too much. To date, underwater measurements on sound pressure levels have been carried out and the effect on vertebrates has been evaluated. On the contrary, very little is known on invertebrates [5].

1.3 Marine Invertebrates Deuterostomes (MIDs) studied in DeuteroNoise

The MIDs proposed for this project are present in marine waters worldwide and scientists are increasingly interested in their ecological roles in the marine ecosystem. They can be found in the sea basins studied in DeuteroNoise. They are represented by hemichordates, echinoderms, cephalochordates, and tunicates, the latter being dominant in distribution and number of species with respect to the other taxa. Their reproductive cycles and life histories are adapted to different environmental conditions. Bacteria and phytoplankton represent their staple food which is insured through suspension feeding. As components of zooplankton-meroplankton (during at least part of their life cycle), they play an important role in marine food webs, acting as carriers of energy from phytoplankton to higher trophic levels.

1.4 The studied basins in DeuteroNoise

The selected basins are geographically distant from each other (distributed at very different longitudes and latitudes) and with features representative of other European sea-basins. They involve Italy, Norway, Romania, and Spain; they belong to basins with different

features (below introduced), and are all affected by anthropogenic noise (shipping, maritime for commercial and recreation purposes). Moreover, they are populated by a number of MIDs that will be the DeuteroNoise subject of study. Noise pollution was partially studied in these basins and its impacts have never been comparatively investigated. The general topographic and physico-chemical features of the basins are below. In each basin, two sites have been selected: a polluted one and an unpolluted (or less polluted) one. Noise measurements will be done in the two sites, in order to evaluate the pollution level and its impact on MIDs.

The North Adriatic Sea and the Lagoon of Venice. The North Adriatic Sea is the northernmost part of the Adriatic Sea. Here there is the largest Italian port, Trieste, the main source of underwater noise in the area. The Lagoon of Venice is the largest lagoon in the Mediterranean, has an area of about 550 km^2 covered by water for the ~85%, islands for the 6% and salt marshes for the 7%. During the summer, tourists and recreational activities increase the amount of underwater noise. Moreover, in the lagoon a port for cargo and cruise ships and a petrochemical industry are housed.

The Black Sea. The entire north-western sector of the Black Sea receives 80% of the total freshwater input, originating from the Danube, Dnieper and Dniester rivers. Almost the entire coast of the Romanian Black Sea is highly urbanized and subject to multiple anthropogenic and natural stressors. Three major harbors found in Constanta, Midia - Navodari and Mangalia are responsible for over 80% of naval traffic activity in the region. In addition, there are three marina port facilities (Constanta, Eforie Nord, Mangalia) which contribute also seasonally to the general background noise in the coastal area. Opposite to these, the southern Eforie with the two SCIs belonging to Natura 2000 Network (Cape Tuzla, 2 Mai - Vama Veche) are almost free of noise and therefore will be used as unpolluted seascapes.

The North Sea is the shallower, northeastern arm of the Atlantic Ocean, situated between the British Isles and the mainland of northwestern Europe. Some parts of the North Sea coast along Norway are urbanized and subject to multiple anthropogenic and natural stressors. Bergen is the second largest city in Norway, featuring a large harbor serving commercial shipping related to cargo transport, off-shore activities, cruisers and others. It is also home to the Royal Norwegian Navy's largest base (Haakonsvern). In addition, it features numerous marinas for recreational crafts. Some areas, such as that one close to the Bergen Sailing Association, exhibits high marine traffic and human activity, especially in the Spring to Autumn period characterized by increased levels of underwater noise pollution from boats and nearby social establishments. On the other hand, there are remote marinas with extremely low marine traffic and human activity (such as Telavåg), that can be sites under study in DeuteroNoise.

The Barcelona shore. The Catalan Sea is the area of the western Mediterranean Sea located in the western Balearic Sea, between the east coast of the Iberian Peninsula - mainly Catalonia - and the Balearic Islands. It has an area of approximately 74,000 km². Especially in the surroundings of Port of Barcelona, it is a highly noise polluted area, impacting the biodiversity of the zone. The highly noise polluted site is supposed to be just in front of the coast of the Port of Barcelona, allowing to gather the maximum amount of vessel noise. The less polluted area is around 20 km North-East distant from the Barcelona port, on the shore of Badalona. The latter corresponds to Pont del Petroli, a structure that enters 250m inside the sea and facilitates the installation of the equipment to gather information from the bottom in a static solid structure from inland.

2. PROJECT DESCRIPTION

Partners belong to four countries and will study in collaboration five basins (see Tab. 1).

Table 1. Consortium partners and basins they will study.

Country	Partner	Studied basin
Italy	1.UNIPD *Subcontractor:* ISMAR-CNR UNIGE	North-Adriatic, Lagoon of Venice
	2.UNIMIB *Subcontractor:* UNIMI	North-Adriatic, Lagoon of Venice, North Sea
	3.SZN *Subcontractor:* UNI Insubria	North-Adriatic, Lagoon of Venice
Norway	4.UiB *Subcontractor:* Ocean Tunicell	North Sea
Romania	5.GeoEcoMar	Black Sea
Spain	6.LS-URL	Barcelona shore- Mediterranean Sea, Black Sea
	7.UB	Barcelona shore- Mediterranean Sea

To reach the objectives, all the partners will work in tight collaboration through seven common integrated Work Packages (WPs). Work Packages with specific objectives and tasks will be dedicated to distinctively develop a holistic approach by combining field data with laboratory experiments.

An integrated overview of the DeuteroNoise project is reported in Fig. 1, showing the interdisciplinary integration of the seven WPs (in different colors), the flow of milestones and deliverables (blue arrows), the distribution of the participation (grey cells) and leading responsibilities (thick cell borders) among partners, and the geographical distribution, area of knowledge, technical and species partner expertise across basins. WP2 is the first that deals with scientific activities to be carried out both in the field and in the laboratory and is preparatory to all the other WPs. This paper will deal in particular with WP2: *Identification of soundscapes in five different basins by means of measurements and simulations and their reproduction in laboratory.*

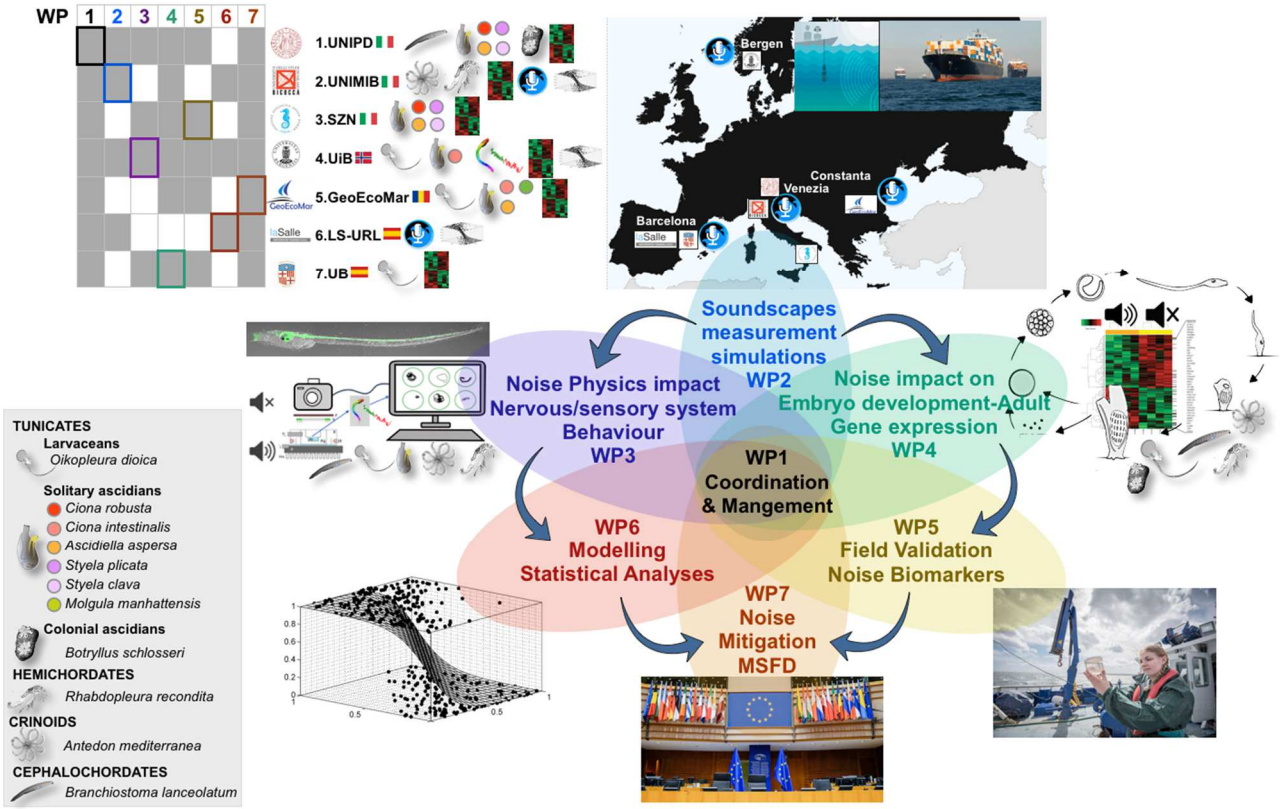

Figure 1. Integrated overview of the DeuteroNoise project.

3. IDENTIFICATION OF SOUNDSCAPES IN FIVE DIFFERENT BASINS BY MEANS OF MEASUREMENTS AND SIMULATIONS AND THEIR REPRODUCTION IN LABORATORY

3.1 Selection of measurement points in the five basins

One of the objectives of WP2 is to identify soundscapes in selected sites of the five basins affected by maritime traffic: the Mediterranean Sea, North-East Atlantic Ocean, and Black Sea. Within each basin, at least 2 measurement points will be selected: 1) In non-noise (or very little) polluted area; 2) In heavily noise polluted area. The first point typology, called in the EC guidelines of "Category A", is meant to establish information on the environmental noise in a location away from the noise produced by ships and to ground truth noise prediction. The second point, called in EC guidelines of "Category B", is necessary to characterize the anthropic noise of the site and to reduce uncertainty in noise models.

Measurement points have been selected by the partners. Anyway, detailed sites will need to be defined locally following specific on-site surveys to assess the feasibility and significance of measurements.

3.2 Measurement campaigns

For each site at least 2 measurement campaigns lasting from one day to two weeks will be carried out: one during the summer season, the other during the winter season. The choice of seasonality is due to the relevant difference in presence of both ship traffic and MIDs to be studied.

Monitoring at sea involves the measurement of sound pressure level, using hydrophones, and particle velocity. This second measurement will be achieved by using underwater accelerometers or velocimeters that are to date still being optimized.

To date, two measurement campaigns have been carried out: one in the Lagoon of Venice and one in the North Adriatic off the coast of Bibione (VE). In the following figures (Figs. 2, 3) the outdoor measurement point location is represented on a map:

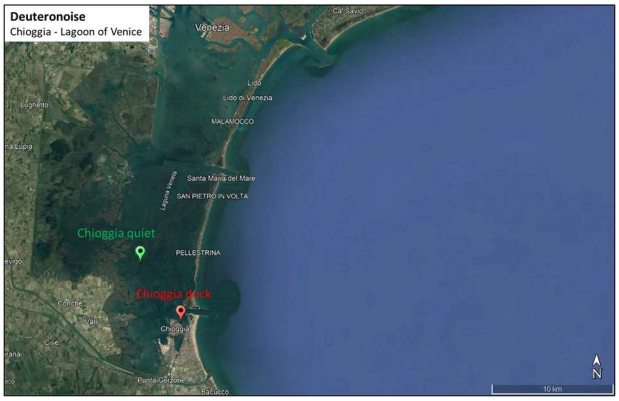

Figure 2. Lagoon of Venice, location of measurement sites close to the town of Chioggia in the Southern lagoon. Red spot: noise polluted site; green spot: unpolluted site.

Figure 3. North Adriatic Sea (Bibione), location of measurement sites. Red spot: noise polluted site; green spot: unpolluted site.

Two autonomous battery-powered hydrophones were used to carry out simultaneous measurements in each basin. Acoustic underwater recorder is a URec384k model, a programmable digital recorder, with an Aquarian Scientific AS-1 hydrophone connected. The sensor is calibrated by manufacturer.

A measurement setup, using two buoys and two ballasts, was defined to reduce the influences of the sea current and waves on the stability of the underwater recorder.

In Fig. 4, the measurement layout that was used in the Northern Adriatic Sea is represented. As regards the

measurements in the Venice Lagoon, due to the low depth of the water, only the part enclosed in the box on the right of the image was used.

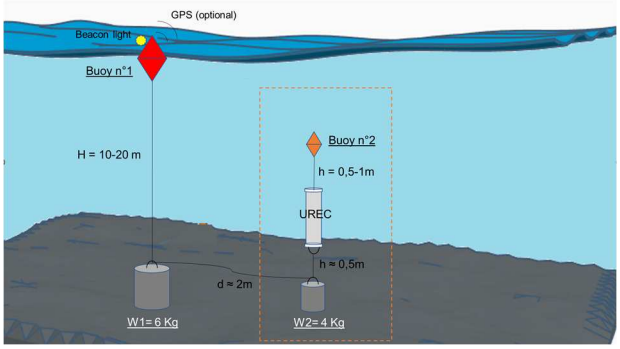

Figure 4. Outdoor measurement experimental layout.

The measurement campaigns included the continuous recording over the monitoring period of the raw audio data, producing a sequence of 10-minute.wav files. Sampling rate has been set up to 48 kHz.
In the following figure (Fig. 5), an example of a vessel in transit has been detected by the hydrophone in the quiet site of Chioggia (Lagoon of Venice). As it can be calculated by time series of sound pressure, average SPL background level (dB re 1µPa) results about 125-130 dB, while the peak level reached by the ship transit is around 155 dB. The spectrogram shows that the noise event has a broadband spectrum, typical of a small boat pass-by.

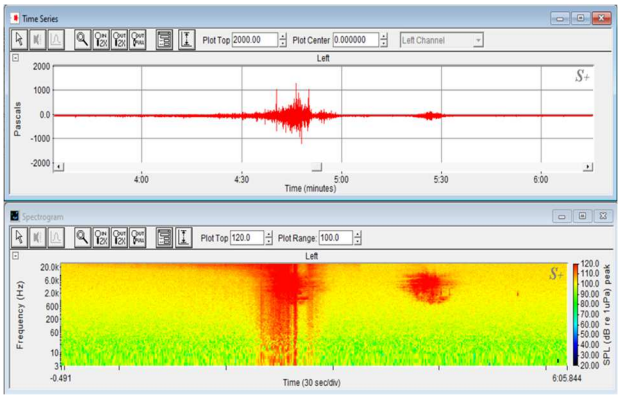

Figure 5. Analysis of a recorded .wav file, Lagoon of Venice.

For each site, throughout the measurement period, the data of the ships and the routes have to be collected by means of an AIS (Automatic Identification System) station that was installed in the site of Chioggia. This allows to monitor the vessels in the area. Moreover, the system can be connected to specialized web services (Vessel Monitoring System) to share data and access to historical or even remote data, such as vessel tracks and characterization, in order to evaluate acoustic monitoring results or to do simulation studies with respect to specific reference scenarios.

3.3 Analysis of noise sampled data

The data acquired in each point will be subjected to statistical analysis in order to obtain the characteristic spectrum and the levels of both the noise and the velocity of the particles.
The analysis of the recorded data (raw acoustic data) in the five basins will include the design of a taxonomy of anthropogenic noise sources, *e.g.* big ships, small vessels, water motorbikes, or any other noise sources existent. The data recorded will be labeled with those sources, describing their main audio characteristics (spectral pattern, time evolution, etc) for their characterization and future blind identification.
This analysis and labeling, together with the data of the ships and the routes, will allow the reproduction of anthropogenic noise environments in the laboratories and will be an input dataset in a commercial software ("dBSEA by Marshall Day Acoustics and Irwin Carr Consulting") with the purpose to produce underwater noise maps.

3.4 Experimental set-up to simulate anthropogenic noise in laboratory

The development and improvement of measurement standards and methods for laboratory noise reproduction is another WP2 objective.
For each basin, partners 1-5,7 (Tab. 1) will collaborate to artificially reproduce the noises in the aquarium with noise level and physico-chemical parameters (temperature, salinity, ph) similar to those present in the natural measurement sites.
For each laboratory, animals will be maintained in two tanks: one in which they will be exposed to noise and another one as a background comparison in which there will be no direct source of noise.

Both the tanks will be furnished with hydrophones and a sensor to detect the speed of the particles. The latter will monitor the characteristics of the noise to which the animals will be subjected. In the tank where the MIDs will be treated, at least an underwater loudspeaker will be placed. The standard experimental layout for indoor measurements is shown in Fig. 6.

Experiments using airborne generated noise with a loudspeaker over the tank will be also conducted to verify its effectiveness and potential effects on MIDs.

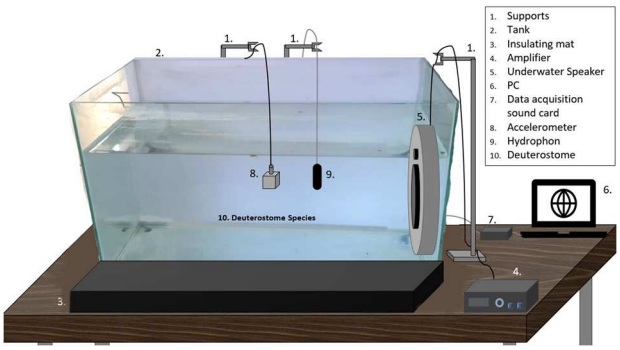

Figure 6. Indoor measurement experimental layout.

4. FIRST RESULTS IN THE LABORATORIES

At the time of writing this article, the measurements were carried out in three biology laboratories: at the University of Milan, at the University of Genoa and at the University of Padua. In these Universities different organisms are studied, in particular crinoids, tunicates and amphioxus.

The three laboratories have different characteristics with regard to: laboratory room size and properties, tank dimensions and material, tank positioning in laboratories, presence of technical equipment that generates airborne noise, and insulation of solid structures.

As a first step, in absence of hydrophonic results at sea, artificial noise, consistent with the Marine Strategy Directive guidance, was produced in the laboratories. The type of selected noise is a low-frequency continuous noise, according to Indicator 3 [4]. In particular, a .wav source file was produced from pink noise equalized so as to amplify only the two 1⁄3 octave bands centered in 63 Hz and 125 Hz (see Fig. 7).

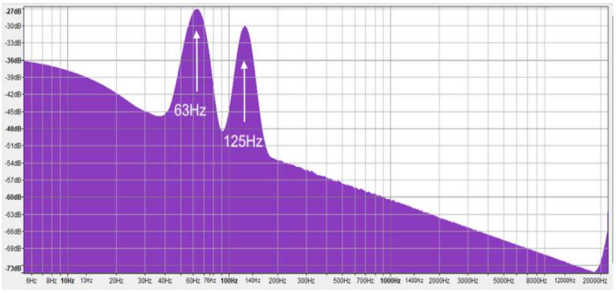

Figure 7. Artificial noise source spectrum for labs measurements

Before starting with the subaquatic noise treatment phases for the different species, the acoustic characterization of the tanks was carried out by means of a series of hydrophonic recordings performed in a grid scheme. Specifically, for each laboratory, sound levels in the background tank were checked to determine how ambient noise affects the underwater sound field. Secondly, the propagation of the noise generated by the underwater loudspeaker within the tank was mapped, setting a specific output level. In this regard, a high noise gradient was surprisingly observed at increasing distance from the source, which is also a function of the material the tank is made of. The experimental noise maps of the background and treatment tanks for the University of Padua laboratory is shown in Fig. 8 as an example. The background levels (image on the left) are around 100 dB, vice versa the gradient during noise exposure (image on the right with loudspeaker placed on the bottom) can exceed 30 dB.

The tanks used in the Padua laboratory are made of reinforced plastic. Preliminarily, it was observed that stiffer materials tend to reduce the sound level gradient in tanks of the same size, also changing the sound effect at the edges. As a consequence, biological treatments on sessile species require that the location of the sample within the tank is exactly determined. This can be done tracing a map on the tank edges.

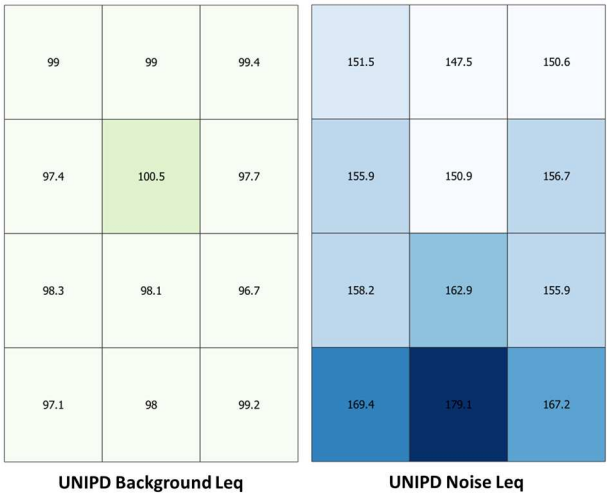

Figure 8. Noise mapping of the tanks, University of Padua laboratory.

In this respect, Fig. 9 shows the placement of a colony of the tunicate *Botryllus schlosseri* on a slide at a fixed position in the tank in Padua laboratory. Thus, the tank acoustic mapping gives the exact level of noise exposure to which the treated individuals are subjected and represents an important prerequisite for any experiments of noise exposure in the laboratory.

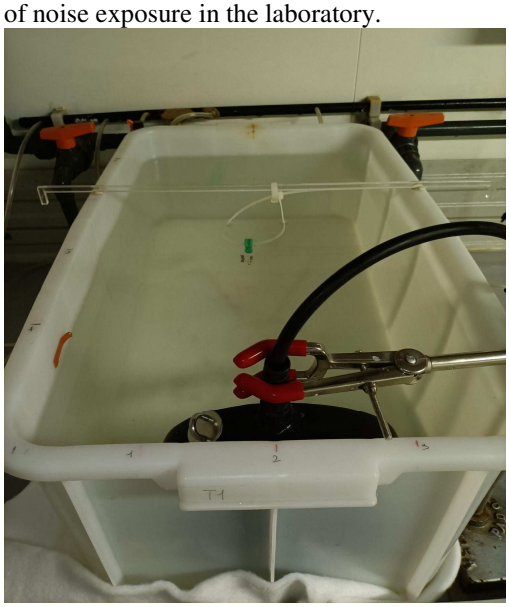

Figure 9. Noise exposure experimental layout, University of Padua laboratory

When the effects of noise on the organisms studied in the tanks will be analysed, all the precautions and approximations of the case will be considered before extending the results to the natural environment since the confined environment of the tanks is very different from what can normally be found in the open sea.

5. ACKNOWLEDGMENTS

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