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ON THE PROBLEM OF UNDERWATER SOUND MAPPING IN SHALLOW WATERS: A CASE STUDY

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ABSTRACT

Directive 2008/56/EC of the European Parliament identifies underwater acoustic energy, in Descriptor 11, as a source of pollution, making it necessary to monitor and control the acoustic levels in the maritime environment. Two methodologies are established to determine the level of underwater acoustic pollution: monitoring through the deployment of hydrophones and the elaboration of sound maps. The first method requires long-term equipment deployment, which implies high costs, while the elaboration of sound maps based on statistics data and simulations is a more affordable and feasible alternative to establish noise levels in a given maritime area. This paper discusses the methodology and difficulties encountered in completing a sound map in a specific area of shallow waters in the Mediterranean Sea.

Keywords: *Noise Maps***,** *Sound Maps, Ray Tracing, Underwater Acoustics.*

1. INTRODUCTION

Global economic growth has intensified human activities in the underwater environment. In response, Europe adopted Directive 2008/56/EC, known as the Marine Strategy Framework Directive (MSFD), which addresses underwater noise pollution in its Descriptor 11 [1]. Additionally, Decision 2010/477/EU [2] established criteria to assess the good environmental status of marine waters, specifically focusing on strong impulsive sounds, such as explosions and drilling, and continuous and continuous low-frequency sounds, typical of ship engines and other industrial sources. The Technical Subgroup on Underwater Noise (TG Noise) [3] has supported the implementation of Descriptor 11 by recommending the creation of underwater noise maps to monitor acoustic pollution and mitigate its impact on the marine ecosystem.

As with any communication system, underwater acoustics depend on the noise source, its propagation in water, and the characteristics of the receiver. To create soundscapes, various noise sources, both natural and anthropogenic, their propagation peculiarities, and relevant acoustic parameters must be considered.

This work aims to detail the methodology followed to create acoustic maps of the noise generated by maritime traffic in a specific area, presenting practical cases with applications developed by SAES.

The article is organized into 6 sections: Introduction, characterization of underwater noise sources, underwater noise sources, underwater acoustic propagation, creation of underwater noise maps and conclusions.

2. UNDERWATER SOUND SOURCES

An acoustic noise map is a visual representation that shows noise levels in a specific geographic area, providing information about the ambient noise present in that zone. Ambient noise refers to the constant background noise originating from various sources, such as marine traffic, industrial activities, and natural elements like wind and wildlife.

2.1 Ambient Noise

The definition of ambient noise has evolved with the development of new underwater acoustic applications and the increase of anthropogenic sources. Urick [4] defined ambient noise as sound that does not come from the hydrophone or its deployment, nor from identifiable sources, encompassing both natural and anthropogenic sounds [5].

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Nowadays, the noise sources that contribute to the ambient noise are classified as natural (e.g. waves and marine wildlife) and anthropogenic (e.g. drilling and shipping traffic) [6] to study their acoustic impact on the marine environment.

2.2 Anthropogenic Noise

Anthropogenic noise arises from human activities and has been increasing with the expansion of industrial and commercial operations in marine settings. Examples of anthropogenic noise sources include dredging, constructions, gas and oil extraction, maritime and air traffic [7], geodetic surveys, SONAR systems, underwater explosions, and oceanographic studies. Among these, maritime traffic stands out as the primary source of acoustic pollution. It produces a combination of tonal and broadband sounds from 2 Hz to 100 kHz, mainly due to propeller cavitation and onboard machinery [8] [9]. Maritime traffic noise is the main focus of attention in noise mapping, as it is a significant contributor to noise pollution in marine environments.

To create noise maps, it is assumed that ambient noise from natural sources is homogeneous, while anthropogenic noise sources need to be identified. These sources are generally static, except for maritime traffic, which can be tracked using the Automatic Identification System (AIS). This system provides information about vessels, including identification, type, position, course, and speed. Figure 2 shows an example of AIS data along the Spanish coast.

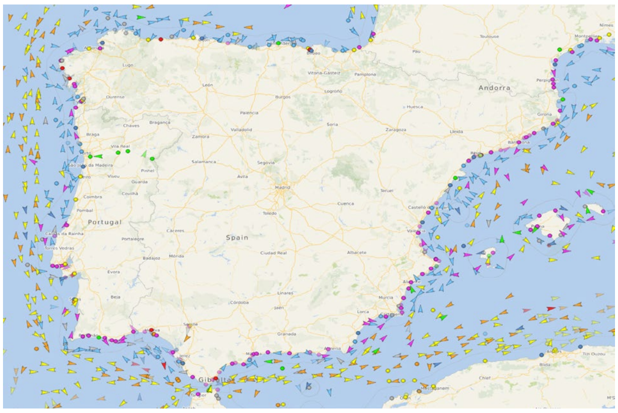

Figure 1 An example of maritime traffic from www.vesselfinder.com

3. UNDERWATER ACOUSTIC PROPAGATION

Understanding the basic phenomena of acoustic propagation in the underwater environment, and specifically within the study area, is essential for creating an underwater soundscape. This section introduces the propagation models used for this purpose

3.1 General Concepts

Acoustic noise propagation from a submarine source depends on factors such as seawater temperature and salinity (varying with depth), seabed depth and type, and the source's depth. The speed of sound in the sea typically ranges between 1450 and 1540 m/s and can be calculated using empirical formulas based on temperature, salinity, and pressure (related to depth), following algorithms from Mackenzie [10], Medwin [11] and Leroy [12].

Seawater generally shows a density stratification, where vertical density gradients are thousands of times greater than horizontal ones, due to variations in salinity and temperature. As a result, sound velocity is usually stratified vertically, changing significantly with depth.

The representation of how sound speed or temperature changes with depth is known as the Sound Velocity Profile (SVP) and the thermal profile, respectively. These profiles are typically divided into four distinct zones: the surface layer, where conditions are influenced by atmospheric interactions; the seasonal thermocline, which undergoes variations based on seasonal heating and cooling; the permanent thermocline, characterized by a rapid decrease in temperature with depth; and the deep isotherm, where temperatures are nearly constant.

The received level (RL) of sound pressure at a given point is determined by the source level (SL) of the acoustic signal, minus the transmission loss (TL). These transmission losses consider the attenuation of the signal as it travels through the medium, caused by factors such as geometric dispersion (divergence), absorption by water molecules and suspended particles, and reflection and scattering of sound waves at the sea surface and bottom.

3.2 Propagation Models

Propagation models are used to calculate the transmission losses that sound experiences as it travels through the marine environment. Typically, these models solve the wave equation or Helmholtz equation for specific frequencies, applying inverse transforms when modeling broadband signals. The choice of models varies based on frequency characteristics, environmental conditions, and water depth. Distance-dependent models are preferable when bathymetry or water column conditions vary along the propagation path.

Propagation models are categorized by calculation method, including ray tracing, normal mode (wave theory), parabolic equation, wave number integration, energy flow, finite difference and element models, image method, and multi-path models. [13] [14] [15] [16]

SAES uses ray tracing models integrated into SEAPROF for underwater soundscapes, verified by the Centre for Maritime Research and Experimentation (CMRE), ensuring estimation accuracy. Figure 3 shows ray tracing from the SAES propagation model for a specific SVP, covering direct paths, and surface/bottom reflections. SAES's model is distance-dependent, accounting for reverberation effects.

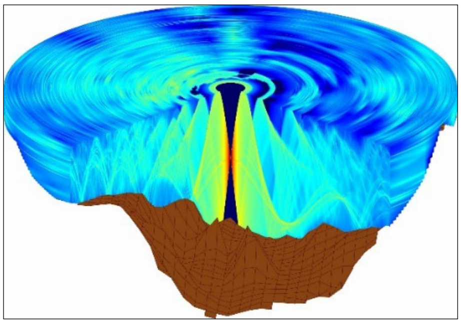

Figure 2 3D ray tracing for a specific scenario with a known bathymetry

4. CREATION OF UNDERWATER NOISE MAPS

4.1 System Description

Figure 4 shows the block diagram used in generating noise maps. Which includes two independent databases: one for characterizing the noise level radiated by ships, and another for the environmental parameters and bathymetry of the area.

The noise characterization database was constructed from data collected over a period of one year from actual measurements of various ship types under typical operating conditions. From these data, an extrapolation was made to assign noise levels or source levels (SL) per third octave to the different ships present in the area, based on the ship information provided by the AIS

The other databases include the background parameters and velocity profiles present in SeaProf, which are needed to calculate transmission losses, as well as the bathymetry information that the software uses for its ray-tracing model.

Additionally, SAES contracted the positioning and course data from VesselFinder to obtain AIS data for ships navigating along the Valencian coast for approximately one month. These data had a resolution of one hour, meaning that only one data point was provided per ship every hour.

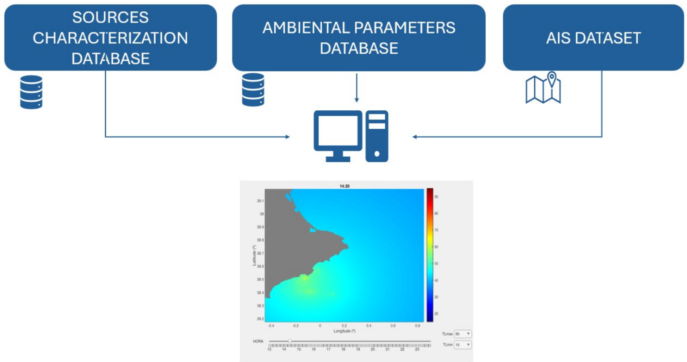

Figure 3 Noise map generation scheme

4.2 Maps Generation

Underwater noise generated by ships varies significantly depending on the type of vessel and the activity being conducted. Small fishing and recreational boats tend to follow routes close to the coast that are relatively undefined. In contrast, large cargo ships and cruise liners navigate further from the shore on fixed routes, creating what could be compared to maritime "highways."

The noise maps created as part of the SONORA project incorporate AIS data from a quadrant large enough to cover both the coastal waters and segments of major shipping lanes for cargo and large vessels. In this context, the area of Villajoyosa (Costa de Alicante, Spain) was chosen for generating specific noise maps, with the following considerations taken into account:

- The noise maps were calculated for the period from May 1, 2024, to May 31, 2024.
- Due to the low resolution of the AIS data, ship positions were estimated based on course and speed for 30 minutes after receipt of the initial sample. If no new AIS data were received from

the ship after that time, the ship was removed from the map calculation.

- Maps were generated at 5-minute intervals.
- Maps were averaged for the morning peak period (5am-5pm) and another for the afternoon period.
- Two frequencies were evaluated 62.5Hz and 125Hz.
- The maps were calculated both with SEAPROF and a simplified analytical model (assuming TL=15log10(r))
- A constant ship depth of 5 meters was assumed.

4.3 Initial Maps Results

Figure 5 and 6 display as example tow of the noise maps obtained for the same geographic area. The first map shows the noise levels during the daytime, specifically from 5 AM to 5 PM, while the second one illustrates noise levels during the nighttime, from 5 PM to 5 AM. These simulations were conducted assuming a constant depth of 5 meters and analyzing a frequency of 62.5 Hz. In both maps, the average noise contributions from all the vessels present in the area during these specific hours have been calculated. The comparison between the two maps reveals a notable difference in noise levels; during the day, there is a significantly higher number of ships, resulting in increased noise levels compared to the nighttime, where fewer vessels contribute to a quieter noise map.

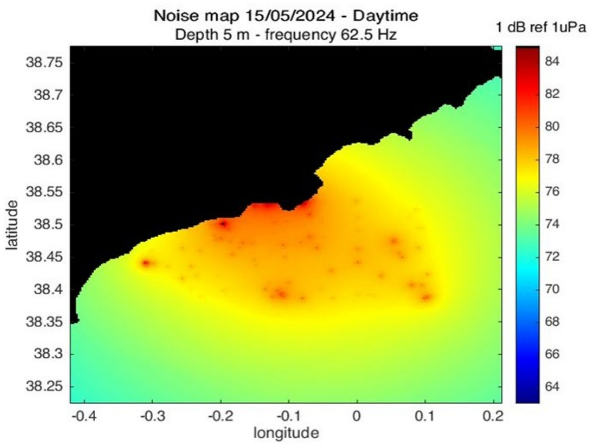

Figure 4 Day noise maps

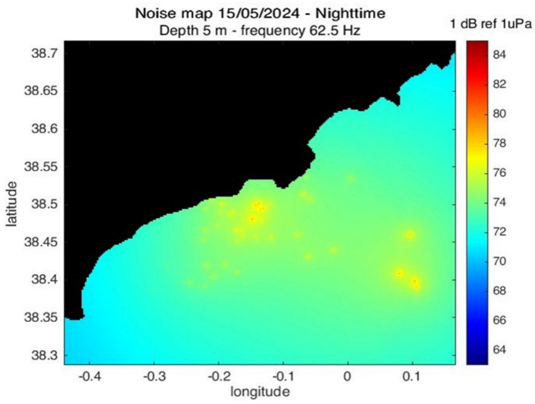

Figure 6 Night noise maps

The obtained results offer a solid overview of the marine traffic activity in the selected area. However, to ensure the validity of this data or enhance its completeness, it is essential to both validate the results with real measurements and improve the resolution of AIS data by replacing estimated ship positions with actual ones.

5. CONCLUSIONS

Although noise maps are extremely valuable tools for quantifying underwater noise, certain measures could significantly enhance their accuracy. First, improving the resolution of the AIS data is essential. During the creation of these maps, AIS data were collected at one-hour intervals, meaning that ships entering the quadrant report their position, course, and speed only once per hour. If a ship changes course or speed within that hour, such changes are not reflected in the simulation, potentially affecting the noise map's accuracy. Additionally, AIS reporting is not a mandatory technology, particularly for smaller vessels, which do not always use it. As a result, the acoustic contributions of these smaller vessels, which can sometimes be quite noisy due to the type of engines they use, are not represented in the maps. Another measure could involve conducting direct measurements with hydrophones placed in areas near the monitored zone, allowing for a more accurate quantification of the acoustic contributions of these vessels and a better calibration of the map simulations. However, this approach would require extensive data processing, undoubtedly representing an intriguing avenue for future research.

6. ACKNOWLEDGMENTS

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