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THE CHARACTERISTIC SPECTRUM OF VESSELS IN DIFFERENT EUROPEAN BASINS

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ABSTRACT

In this work, some of the results obtained during the European project JPI Oceans - DeuteroNoise are presented.
Measurement campaigns, including the recording of raw noise data, have been carried out in the Venice Lagoon, in the North Adriatic, on Barcelona shore and in the Black Sea. The results obtained from processing these measurements will be presented, revealing surprising differences between the basins, more significant than initially anticipated. The analysis of the recorded data specifically involves developing a taxonomy of vessel noise. The collected data were labelled according to vessel type, describing their primary acoustic characteristics (e.g., spectral distribution, temporal evolution) to enable clear characterization and facilitate future blind source identification. Throughout the measurement period, ships and routes data were acquired using AIS (Automatic Identification System) in the measurement sites. This analysis and labeling, together with the vessel data, allowed to obtain a vessel frequency spectrum typical of each basin and through a statistical analysis a single spectrum typical of all basins. The artificial reproduction in a tank of this typical spectrum allows for homogeneous noise exposure experiments to be carried out among the laboratories involved in the project [1][2][3][4][5].

Keywords: *vessel, spectrum, european, basin, sound.*

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1. INTRODUCTION

The following paper illustrates the procedure, from field measurements to statistical analysis, used to identify a typical frequency spectrum characterizing the noise produced by vessels in the Mediterranean and Black Sea basins. From this procedure it was possible to match this spectrum to a real measurement obtained in the field. This spectrum will be subsequently used in experiments, foreseen in the project, in laboratory tanks for several marine biology laboratories. [6]

Figure 1. Localization of measurement campaigns.

2. MEASUREMENT CAMPAIGNS

Both the research group of the University of Milano-Bicocca and the research group of La Salle-URL conducted measurement campaigns of the noise caused by the transit of vessels in the chosen sea basins. Among these, data from three measurement campaigns were chosen: Barcelona (EspaiVela, Spain), Chioggia (Venice lagoon, Italy) and Constanta (Black Sea, Romania), as shown in Figure 1.

The campaign data consists of multiple audio recordings lasting approximately 10 minutes each, covering the span of several days (from a minimum of two days to a week).
In Figure 2, the measurement layout that was used in the Northern Adriatic Sea is represented.

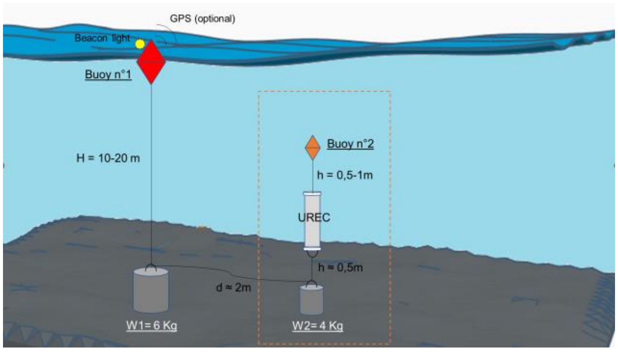

Figure 2. Outdoor measurement experimental layout.

Each recording has therefore undergone a process of careful analysis to identify in their temporal durations the moments corresponding to the transit of a vessel. This was possible by temporally comparing the data of the AIS (Automatic Identification System) signals sent by the vessels present in each basin during the measurement period with the moments of the audio recordings in which the transit of a vessel is perceptible. And in each of these moments of correspondence between the passage of a vessel and the detection of an audio signal, a frequency spectrum was obtained. This procedure was carried out manually for the measurement campaign carried out in Chioggia thanks to listening to all the audio recordings and the extraction of the frequency spectra with a dedicated software (SpectraPLUS) in the research group of Milano-Bicocca [7][8]. Instead, data collected by La Salle-URL was initially processed automatically and subsequently reviewed manually by actively listening to the audio recordings from the measurement campaigns in Barcelona and Constanta. This process was supported by custom Python code developed specifically by the research group [9][10]. Therefore, only data collected at these three sites were considered, as they provided frequency spectra for different vessel types passing within the same 250 m distance range. This distance was chosen because it represents the closest and most frequently observed proximity of vessels to the hydrophone across all three locations. Figure 3 shows a sample of the noise tracks recorded in these basins.

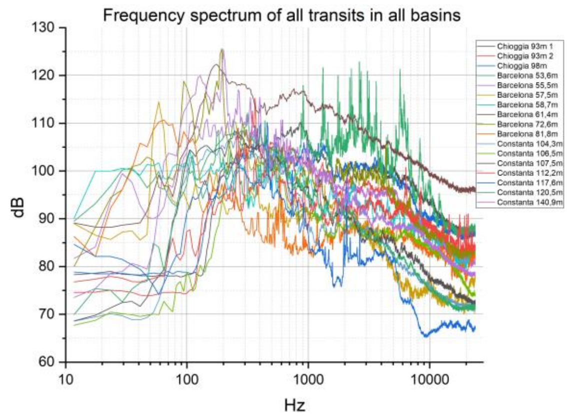

Figure 3. Frequency spectra of several characteristic vessel transits considered in the three selected basins.

3. STATISTICAL ANALYSIS TO IDENTIFY THE TYPICAL FREQUENCY SPECTRA IN THE STUDY AREA

The goal of this analysis is to better understand the spectral characteristics and distribution of recorded noise events across different basins and identify potential sound candidates for use in laboratory.
To establish a robust framework for spectral analysis, the energy distribution was analysed across two frequency bands: 100–1000 Hz and 1000–10000 Hz. This helped to visualize how acoustic energy is distributed across different frequency ranges and to identify the most relevant spectral domain.

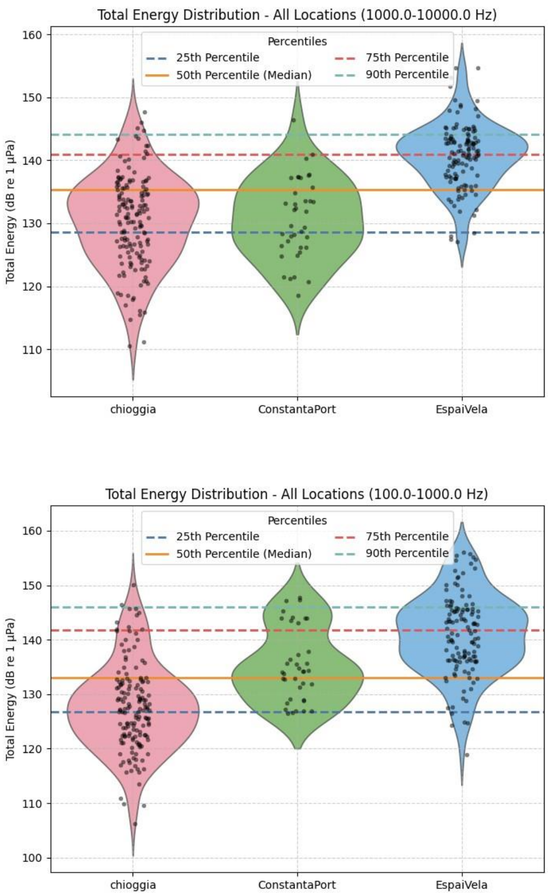

Figure 4. Violin plot of the total energy distribution

The violin plots reveal that energy distribution in the 1000–10000 Hz range exhibits greater dispersion, indicating a higher degree of spectral variability across locations. This variability might suggest that high-frequency components are influenced by localized environmental factors or transient noise sources. In contrast, the 100–1000 Hz range presents a more compact distribution (more significant in Constanta and Chioggia), implying a more consistent spectral structure across different sites, this relative uniformity makes it a more suitable range for focused analysis. The corresponding plots are shown in Figure 4. With the 100–1000 Hz frequency range identified as the primary focus; the next step was to ensure a balanced representation of events across different locations. Given that some sites, such as Chioggia, had significantly more recorded events than others, the dataset was imbalanced in terms of event representation, potentially leading to biases in subsequent analyses. To mitigate this, a systematic balancing approach was implemented to equalize event counts while preserving the integrity of the dataset. Rather than applying random down sampling, which could introduce artificial biases or remove critical patterns, events from the most overrepresented days have been removed. This approach ensures that the temporal distribution of events remains as consistent as possible, preventing any single location from disproportionately influencing the results. By aligning Chioggia's event count with that of the second most populated site, the dataset becomes more statistically comparable, reducing the risk of overfitting to location-specific characteristics.

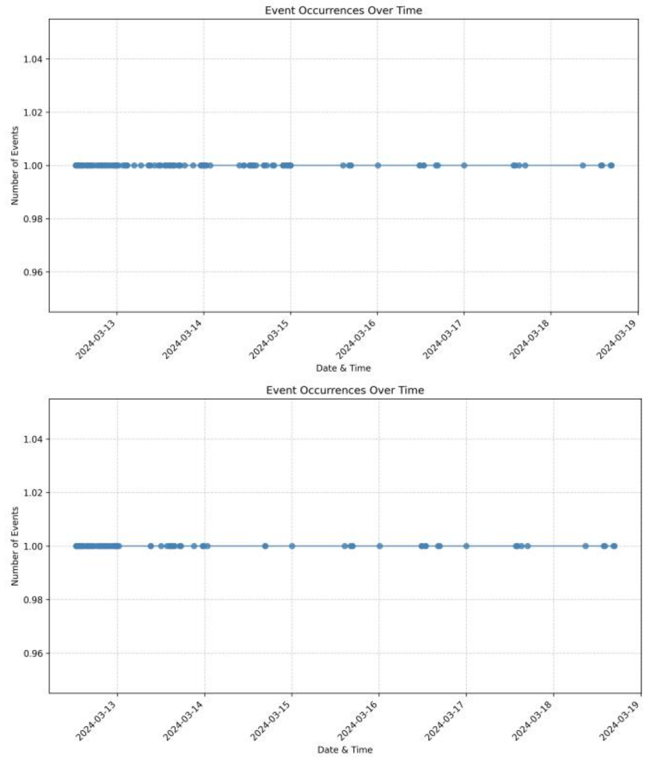

Figure 5. Event timestamps plot before and after balancing

To assess the effectiveness of this balancing process, temporal distribution plots were generated before and after adjustment. By visualizing event timestamps, how frequently events occurred and whether they were evenly distributed over time could be evaluated (Figure 5). The updated plots confirm that the dataset exhibits a more homogeneous distribution across locations, enhancing its suitability for comparative analysis

To ensure consistency and comparability across measurement sites, the analysis focused exclusively on vessel events recorded within a 0–250 m range. This specific distance range was selected because it captures events occurring close enough to the hydrophone to minimize environmental attenuation effects and represents the most frequent proximity at which vessels passed by the measurement stations, providing the most robust and representative acoustic data. Taking all these considerations into account (distances, balancing, and frequency ranges) events around the 50th to 55th percentile range were analysed. We believe that, for these analyses, this is the most representative value among all the measures considered (including, for example, the mean and the median). By narrowing down the dataset to this percentile range, noise events that are characteristic of the overall distribution were identified while avoiding potential biases introduced by exceptionally high (or low) energy cases in that specific frequency range. In Figure 6, the potential candidate events that fall within this percentile range are highlighted. These candidates will serve as the basis for the next stage of the analysis: exploring their spectral similarities. In this case, 14 potential candidates can be observed.

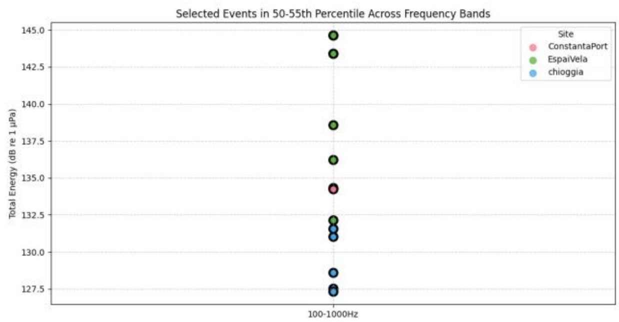

Figure 6. Selected events in the 50-55 percentile.

4. DEFINITION OF THE REPRESENTATIVE SOUND PROFILE

Then, the spectral similarity of events within the specified percentiles have been analysed through heatmaps and similarity matrices. In this case, the metrics Euclidean distance, Mean Squared Error (MSE), and Cross-Correlation were used. These similarity analyses help determine which events are most representative within the dataset. The results are shown in Figure 7.

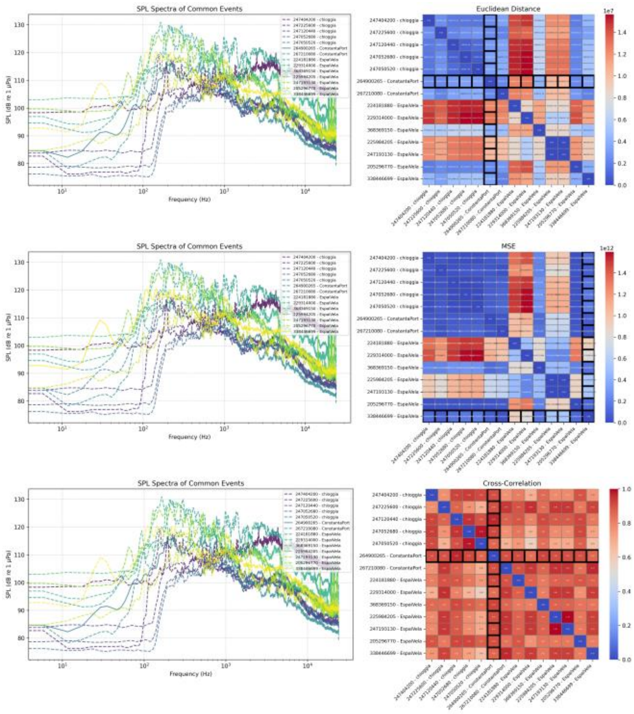

Figure 7. Euclidean, MSE and Cross-Correlation heatmap and related spectra.

Each figure contains the corresponding heatmap, and in the left spectrum plot, the highlighted proposed candidates can be found. Top-3 candidates based on the different metrics are:

Euclidean:

- **264900265-164.7.npy (From: ConstantaPort)**
- 267210080-112.2.npy (From: ConstantaPort)

247225600-185.0.npy (From: Chioggia)

MSE:

- 338446699-55.5.npy (From: EspaiVela)
- 267210080-112.2.npy (From: ConstantaPort)
- **264900265-164.7.npy (From: ConstantaPort)**

Cross-Correlation:

- 264900265-164.7.npy (From: ConstantaPort)
- 247120440-116.0.npy (From: Chioggia)

- 247193130-41.0.npy (From: EspaiVela)

In the end, since for the experiments in the laboratory a single trace is needed, the most suitable is the one related to the only one highlighted in all three metrics: **264900265-164.7 from the port of Constanta.**

5. CONCLUSIONS

This paper describes the procedure that led from measurements carried out at sea in different basins of the Mediterranean and the Black Sea to the definition of a sound that could be used in Deuteronoise laboratories tank experiments. This sound track reflected as closely as possible the typical frequency spectrum of the noise generated by a vessel in such basins in transit at a distance of between 0m and 250m. The frequency spectrum of the selected recording is shown in Figure 8.

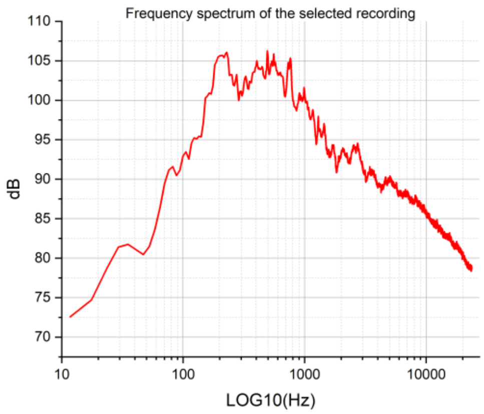

Figure 8. Frequency spectrum of the selected recording

6. ACKNOWLEDGMENTS

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