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A FIELD-TO-LABORATORY PIPELINE FOR UNDERWATER VESSEL NOISE MONITORING IN THE DEUTERONOISE PROJECT

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Abstract

Anthropogenic underwater noise from maritime traffic is an increasing concern for marine ecosystems, particularly in coastal and semi-enclosed areas exposed to intense commercial, industrial and recreational vessel traffic. Within the JPI Oceans DeuteroNoise project, La Salle – Universitat Ramon Llull has developed and operated the acoustic monitoring infrastructure supporting this effort across five European sites spanning the Catalan coast, the Black Sea and the North Sea. This paper summarises that framework and its outcomes: a real-time, AIS-based vessel-tracking station synchronised with hydrophone recordings; a standardised deployment protocol recently extended with particle-motion accelerometers; and field campaigns pairing noisy and quiet sites at each basin. From these campaigns, a characteristic vessel-noise spectrum was derived and applied to a laboratory bio-exposure setup for marine deuterostome invertebrates, motivating new field-based approaches to calibrate it. A direct comparison between Espai Vela and Pont del Petroli illustrates the resulting contrast in underwater noise levels. Finally, the open, calibrated DeuteroNoise dataset and its access tools are presented, together with a hybrid framework, combining propagation modelling and data-driven synthesis, for generating realistic synthetic vessel noise. Together, these tools support a more comprehensive, reproducible assessment of underwater noise pollution and its ecological impact.

Keywords: *underwater vessel noise, AIS vessel tracking, multi-basin soundscape characterization, bioacoustic exposure experiments, open dataset, synthetic noise generation*

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1. Introduction

Underwater noise from maritime traffic is recognised as an anthropogenic stressor on marine ecosystems, particularly in coastal areas or basins where commercial, industrial and recreational vessel activity overlaps [1]. Monitoring and mitigating this pressure is recomended for EU member states under Descriptor 11 of the Marine Strategy Framework Directive [2]. Within the JPI Oceans DeuteroNoise project, La Salle – Universitat Ramon Llull has led, together with University of Milano-Bicocca, the acoustic-related effort across several European basins, aiming to characterise vessel-radiated noise and support laboratory studies on its impact on marine deuterostome invertebrates [3].

This paper summarises the methodological and technical work carried out over the course of the project by the La Salle team. The real-time AIS-based vessel-tracking infrastructure and the hydrophone deployment protocol used across campaigns are described first, followed by field deployments in the Catalan coast (Pont del Petroli, Espai Vela), the Black Sea (Mamaia, Constanţa) and the North Sea (Rong, Norway). The characteristic vessel noise spectrum derived across these basins is then presented, along with its application to the laboratory exposure setup, and a direct comparison between a noisy and a quiet site. Finally, the open DeuteroNoise dataset and its interactive access tools are outlined, together with a hybrid framework for generating synthetic underwater vessel noise.

2. Real-Time Vessel Tracking via AIS

To contextualise every acoustic recording with independent vessel-traffic information, a Very High Frequency (VHF) receiving station was installed at the La Salle Campus Barcelona — Universitat Ramon Llull, driven by a Raspberry Pi equipped with a dAISy HAT and running the AISdispatcher utility. This station decodes Automatic Identification System (AIS) messages transmitted by vessels, validating and deduplicating them in real time, and has been operating continuously for the last three years with only brief interruptions [4]. The decoded stream is shared with AISHub, a community network that in exchange grants free API access to the global feed. A Python script queries AISHub every 60 seconds – the shortest interval allowed under the free tier – for all positional reports falling inside a bounding box centred on each hydrophone position, retrieving Maritime Mobile Service Identity (MMSI), timestamp, GPS position and speed-over-ground for every vessel in range. On average the deployed Barcelona station alone detects around 140 transiting vessels and up to 100 unique MMSIs per day [4].

Each AIS record is enriched with static vessel metadata (type, length, beam, gross tonnage, flag and an image) scraped from VesselFinder, and time-aligned with the acoustic recordings through coordinated timestamps. This AIS-acoustic synchronisation is the basis of an automated event-detection workflow that determines the start and end of every vessel passage, locates the peak noise level closest to the hydrophone, and is manually validated by active listening [5].

3. Hydrophone Deployment Setup

All campaigns share a common acquisition chain to keep sound pressure levels comparable across basins. Recordings are obtained with an autonomous uRec-384k recorder (Nauta-RCS) coupled to a calibrated AS-1 omni-directional hydrophone (Aquarian Audio; −209.7 dB re 1 V/μPa nominal sensitivity, 10 Hz–190 kHz frequency response), with the pre-amplifier fixed at +50 dB re 1 μPa. Each unit records continuously at 48 kHz, 24-bit PCM, segmented into 10–15 min WAV files, and is powered by alkaline D-cells providing 24 to over 70 h of autonomy depending on the deployment [4], [6].

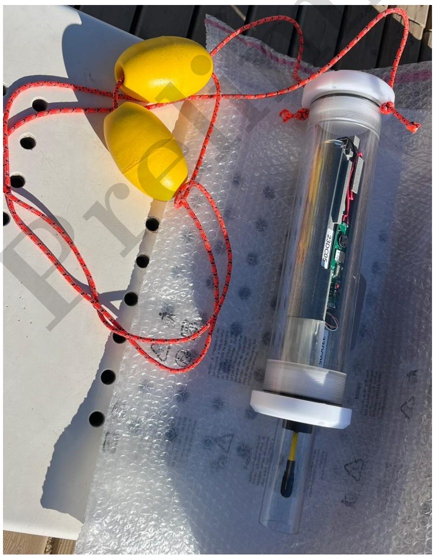


Figure 1: uRec-384k hydrophone recorder with its float buoys, prepared for deployment.

The hydrophone is suspended on a vertical mooring line: a bottom anchor (∼6 kg) and a secondary anchor (∼4 kg, 2 m apart) damp surface-induced motion, while the hydrophone itself is held 0.5–1.5 m above the second anchor with its capsule facing downwards to minimise flow noise. Two small float buoys keep the line vertical, and a surface recovery buoy is added only where required by local port authorities. Total line length is adapted to local bathymetry (typically 15–20 m depth) [4], as illustrated in Fig. 2.

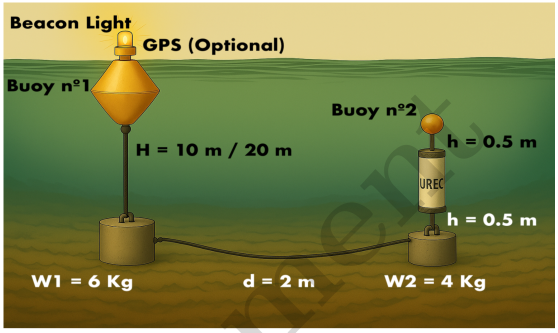


Figure 2: Mooring configuration: primary buoy with optional GPS and beacon light, secondary buoy holding the hydrophone 0.5–1.5 m above the seabed anchor.

Since 2025, this acoustic chain has been complemented at several sites (Espai Vela, Constanţa Port, Bergen) with GeoSpectrum M20-040 particle-motion sensors, recorded on independent Zoom H5 units and deployed alongside the hydrophone at a fixed position (e.g. raft corner or quay).

4. Field Campaigns Across Basins

LaSalle has carried out hydrophone deployments in five European sites, each selected to contrast a noisy, traffic-exposed location against a comparatively quiet one [4]. Along the Catalan coast, **Espai Vela** (Port of Barcelona, UPC facilities) captures dense commercial, cruise and recreational traffic, while **Pont del Petroli** (Badalona), a 250 m pier 20 km northeast of the port, provides a less-polluted reference site. In the Black Sea, **Constanţa Port** is regularly transited by tugboats, cargo ships and dredgers, whereas the nearby **Mamaia** pier is comparatively quiet in winter, though seasonal recreational boating increases its noise floor in summer. Most recently, a fifth site was added in **Rong, Norway**, in collaboration with the University of Bergen, one of the DeuteroNoise consortium partners [3]. Fig. 3 maps three of the four basins monitored – Catalan coast, Venice Lagoon, and Black Sea.

5. Characteristic Vessel Spectrum Across Basins

Building on the AIS-labelled vessel passages described above, each event is assigned a vessel type and its acoustic signature is characterised through spectrograms and frequency spectra computed at the closest point of approach [5]. Aggregating these signatures

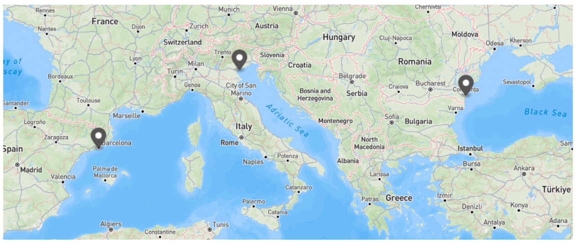


Figure 3: Geographic locations of the coastal sites studied in the Catalan coast, Venice Lagoon, and Black Sea basins. Adapted from [4].

across the Catalan coast, the Lagoon of Venice and the Black Sea revealed a clear taxonomy of vessel noise, describing spectral distribution and temporal evolution per vessel class, and exposed cross-basin differences in soundscapes that were larger than initially expected [7].
From this per-basin characterisation, a statistical analysis was performed to derive a single spectrum representative of vessel noise across all studied basins, rather than one specific to a single site or vessel class [7]. This unified spectrum was validated against real field measurements and is designed to be reproduced in a laboratory tank, enabling homogeneous noise-exposure conditions to be replicated consistently across the different marine biology laboratories participating in the project, independently of where their reference recordings were originally collected. This characteristic spectrum is the direct link between the field campaigns of Sections 3–4 and the bio-exposure setup discussed next.

6. Bio-Exposure Setup

The characteristic spectrum derived in Section 5 is reproduced in laboratory tanks using a custom underwater speaker and amplifier, with an identical control tank exposing animals only to background noise. This setup has been applied to eight deuterostome invertebrate species across multiple life stages, with containment adapted to each species (grid racks, glass slides, falcon tubes, or beakers) to keep exposure conditions consistent. Because sound pressure levels are spatially heterogeneous within a tank, a fixed reference position was previously selected from a 3×4 measurement grid and used as the standard exposure point for all species and trials.

7. Outcomes so far

7.1. Espai Vela vs. Pont del Petroli

As a direct output of the paired noisy/quiet deployment design, sound pressure level (SPL) was computed for 20-second windows and averaged per frequency band at matched times of day, allowing a controlled comparison between Espai Vela (Port of Barcelona) and Pont del Petroli (Badalona) [6]. At the 63 Hz third-octave band, recorded at the same hour (18:00) on different winter days, Espai Vela reached 106.83 dB re 1 μPa against only 76.97 dB re 1 μPa at Pont del Petroli – a difference of about 30 dB attributable to sustained port activity (Fig. 4). A clear day–night contrast was also observed at Espai Vela itself, with the 63 Hz SPL dropping from 106.83 dB at 18:00 to 80.76 dB at 01:00, confirming that nocturnal quieting only partially closes the gap with the naturally quieter site.

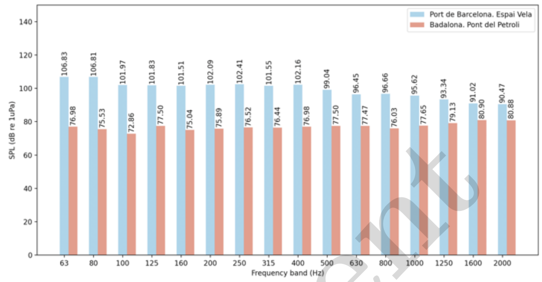


Figure 4: Comparative SPL values across frequency bands at the same hour (18:00) for Espai Vela (Port of Barcelona) and Pont del Petroli (Badalona). Adapted from [6].

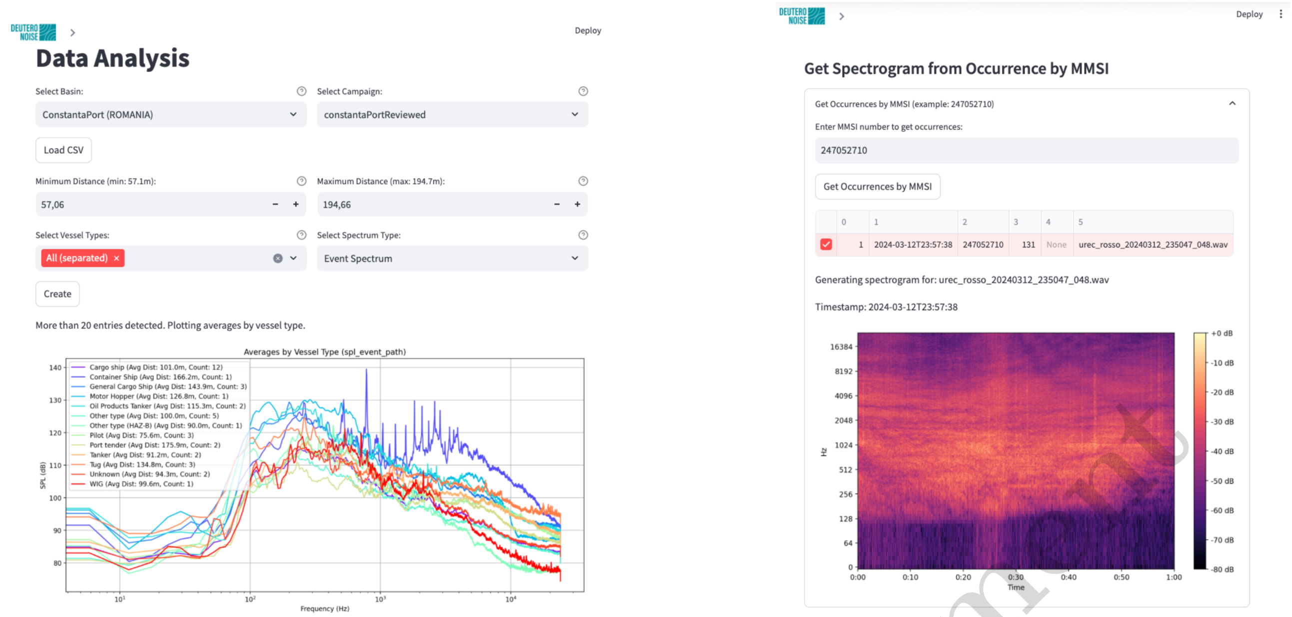
These results confirm that vessel traffic, rather than time of day alone, is the dominant driver of underwater noise pollution along the Catalan coast, and motivate the noisy/quiet pairing adopted at every basin studied.

7.2. The Open DeuteroNoise Dataset

All recordings, AIS-derived metadata and processed acoustic descriptors are consolidated into the open, calibrated DeuteroNoise dataset, comprising nearly 700 h of continuous hydrophone audio paired with time-synchronised vessel metadata across the studied basins [4], [8]. The dataset is built on PostgreSQL, storing static vessel information (type, dimensions, tonnage, flag, image) and dynamic per-passage records (timestamp, distance, speed-over-ground, audio reference), while the raw audio itself is kept on external storage and referenced by path.
A RESTful API, developed with FastAPI, exposes this information for retrieval by MMSI, vessel type, distance or time range, as well as precomputed statistics and spectral descriptors (e.g. PSD values). A complementary Streamlit web dashboard allows researchers and non-specialists alike to explore campaigns by basin and vessel category, inspect spectrograms interactively, and retrieve vessel-level summaries without writing any code [8]. Fig. 5 illustrates two of these interactive views: averaged SPL spectra by vessel type for a selected campaign, and the spectrogram retrieved for a single vessel occurrence identified by its MMSI.

8. Hybrid Synthetic Underwater Noise Generation

The DeuteroNoise dataset (Section 7.2) provides real vessel recordings across basins, but their diversity is inherently limited by which vessels transited during each campaign. To overcome this, a hybrid framework



(a) Averaged SPL spectra by vessel type, Constanţa Port campaign.

(b) Spectrogram retrieved for a single vessel occurrence by MMSI.

Figure 5: DeuteroNoise interactive dashboard: (a) vessel-type SPL comparison; (b) per-occurrence spectrogram view.

is under development that combines physics-based acoustic propagation modelling with data-driven audio synthesis. Starting from a recorded vessel event, a representative one-third-octave sound pressure level (SPL) profile is extracted and propagated under realistic environmental conditions using dBSea **dbsea**, yielding a propagation-informed SPL profile for arbitrary distances and bathymetries rather than only the conditions actually observed in the field.

This profile is then used to condition three synthesis strategies of increasing complexity: an example-based granular synthesis, a statistical texture synthesis operating at the band level, and conditional generative adversarial networks (GANs) operating on spectrograms, with neural outputs converted back to the time domain. This propagation-informed, hybrid approach is intended to support controllable dataset augmentation and benchmarking for passive acoustic monitoring, complementing the field campaigns described throughout this paper.

9. Conclusions

This paper has summarised the acoustic monitoring infrastructure developed by La Salle within the DeuteroNoise project: a real-time AIS-based vessel-tracking station, a standardised hydrophone deployment protocol extended since 2025 with particle-motion accelerometers, and field campaigns across five European basins. These campaigns have yielded a characteristic vessel-noise spectrum applied to laboratory bio-exposure experiments, a quantified contrast between a noisy and a quiet site on the Catalan coast, and an open, calibrated dataset with interactive access tools. Ongoing work focuses on closing the gap between laboratory and field acoustic conditions through improved tank calibration, and on a hybrid propagation-informed framework for generating synthetic vessel noise. Together, these efforts support a more comprehensive, reproducible assessment of underwater noise pollution across European coastal waters, and its ecological impact on marine invertebrates.

10. Acknowledgements

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