UNCOVERING THE SOUNDSCAPE OF THE IONIAN SEA: ACOUSTIC MONITORING DATA REANALYSIS, ACQUIRED DURING THE HELPE'S 2D/3D MARINE SEISMIC SURVEYS, 2016-2023

Elias Fakiris[a], George Papatheodorou[a], George Mikoniatis[b], Yannis Vavassis[b], Xenophon Dimas[a], Dimitris Christodoulou[a], Nikos Georgiou[a], Vasileios Giannakopoulos[a]

[a]Laboratory of Marine Geology and Physical Oceanography, Geology Dpt., University of Patras, Greece.
[b]HELPE Exploration & Production of Hydrocarbons (HELPE UPSTREAM S.A.), Athens, Greece.

Elias Fakiris, fakiris@upatras.gr

Abstract: *Hellenic Petroleum S.A. has undertaken five Marine Seismic Surveys in the Greek territorial waters of the Ionian Sea between 2016 and 2023. Those were coupled with intensive marine noise monitoring programs, applied to 13 stations with a longitudinal span of about 300 km. Stations were mostly placed around Marine Protected Areas in coastal waters, collecting more than 350 hours of sound data. Two pre-calibrated compact embedded recorders were used, equipped with two hydrophones each. The research vessel swapped locations between the stations on a daily schedule, deploying the underwater recording units at 20 m water depth to acquire sound data for 3 to 6 hours. The vessel was left drifting, hardly stabilized by using a floating anchor, to minimize self and flow noises. Noise sound pressure levels (SPLs) have been estimated regarding the zero to peak, peak to peak, and root mean square, as well as the sound exposure level (SEL), all integrated for 1s durations. The above SPL metrics have also been examined as a function of sound frequency components via third-octave bands (from 16 Hz to 20 kHz centre bands) while also 30 s integrated power spectrum densities (PSD) have been estimated. The estimated SPLs gave insights into the footprints of the anthropogenic and biogenic factors on the soundscape of the Ionian Sea, including continuous ship traffic noises, impulsive noises, fauna and marine mammal sounds. Traffic noise SPL has been further assessed as a function of distance to any ship versus frequency components, using automatic identification system (AIS) data from the MarineTraffic service. As far as we know, this is the most extensive regional-scale assessment of ambient noise in the Greek seas.*

Keywords: *ambient noise, ship noise, acoustic monitoring, marine traffic, Greece*

1. INTRODUCTION

The underwater acoustic environment comprises a diverse array of complex sound sources, collectively known as the soundscape. Noise sources are commonly classified as either natural (geophonies and biophonies) or anthropogenic noise (anthrophonies) [1] Geophony includes sounds from earthquakes, wind-wave, and rain, biophony from marine mammals, crustaceans and fish while anthropophony from human activities including commercial shipping, oil and gas exploration, development and production which utilize ships, airguns, and oil drilling. Naval operations also contribute through military sonars, communications, and explosions. Fishing activities generate anthropogenic noise through commercial or civilian sonars, acoustic deterrents, and harassment devices. Ship traffic is the primary contributor to underwater acoustic pollution [2]. The acoustic emissions from large commercial vessels are generally characterized by loud, low-frequency sounds. These sounds typically exhibit broadband source levels ranging from 180 to 195 dB re 1μPa, with maximum levels occurring in the frequency range of 10 to 125 Hz. The frequency content of vessel noise significantly overlaps with the hearing ranges of many marine species, especially with marine mammals. This overlap masks their signals and disrupt the ability of species to communicate. The European Marine Strategy Framework Directive (MSFD) 2008/56/EC and the Commission Decision 2010/477/EU [3] require European Member States to develop strategies to achieve and maintain Good Environmental Status (GES) in European Seas. In particular, the MSFD Descriptor 11 introduced human-induced marine acoustic noise as important indicator in defining GES. Continuous low-frequency and impulse sounds are of particular concern, and Indicator 11.2 requires year-round measurements of the temporal distribution of noise levels within the 1/3 octave bands centered at 63 Hz and 125 Hz [4]. Although the Greek fishing fleet is one of the largest in Europe and passenger and cargo ships exhibit high densities in the Greek territory waters, passive acoustic monitoring (PAM) is very limited in contrast to the other regions in Europe. The only published in-situ data assessment regards two passive aquatic listeners deployed on POSEIDON ocean observation system between 2008 and 2009 in Pylos (Ionian Sea) and Athos (N. Aegean Sea) [5, 6], while small scale experiments were conducted by [7] in Crete. Significant work has been done in modelling the ship noise levels in the whole Mediterranean by [8], but validation data are lacking.

Hellenic Petroleum S.A. has undertaken 5 Marine Seismic Surveys in the Ionian Sea between 2016 and 2023, coupled with sound noise monitoring in 13 stations with a longitudinal span of about 300 km, collecting more than 350 hours of sound data. This databank is for now the most spatially extensive source of underwater noise information regarding the Greek territory waters. In this work, data acquisition and processing methods used to build this databank, as well as elementary ambient noise assessment results are presented. Emphasis has been given to ship noise levels in regard to the line-of-sight distance between each sound monitoring station and the proximal ships.

2. DATA ACQUISITION AND PROCESSING

During the sound noise monitoring program as part of HELPE's Marine Seismic Surveys in the Ionian Sea between 2016 and 2023, 350 hours of sound data were recorded from 13 monitoring stations, mostly in coastal waters around Marine Protected Areas. The stations had a longitudinal span of about 300 km, from the Messinia regional unit (SW Peloponnese) to Corfu Island (NW Ionian) (Fig. 1a). Two calibrated EA-SDA14 (RTSYS) compact embedded recorders were used, attached to two hydrophones each, a high sensitivity (170 dB dynamic range, 215 dB sensitivity) and a low sensitivity one (215 dB dynamic range, 170 dB sensitivity). Both channels were recording at 24 bits, with a sampling frequency of 78,125 Hz, allowing a bandwidth of up to 30 kHz. The research vessel was equipped with a GPS to acquire positioning data for sound data georeferencing.

Realization of spot measurements has been decided to be the most efficient approach for the acoustic monitoring survey, offering flexibility and improved sound data quality [9]. The research vessel changed locations between the specified locations in a daily schedule, performing spot acoustic noise measurements in coastal (25-50 m depth) waters. For each station the research vessel turned off the engines and deployed the underwater recording unit at 20 m water depth, attached to a SPAR buoy to uninterruptedly acquire sound data for 3 to 6 hours. In each deployment the vessel was left drifting in the winds and the sea currents, hardly stabilized by using a floating anchor.

Noise sound pressure levels (SPLs) have been estimated regarding the zero to peak (SPLpeak), peak to peak (SPLp-p) and root mean square (SPLrms) definitions, as well as the sound exposure level (SEL), all integrated for 1s durations. All above SPL metrics have also been examined as a function of sound frequency components via third-octave bands (from 16 Hz to 20 kHz centre bands) while 30s integrated power spectrum densities (PSD) were also estimated. A suite of MATLAB codes has been implemented to perform georeferencing, impulse sounds detection, analysis, and reporting of the acoustic data.

Assessing the marine traffic noise in the soundscape of Ionian Sea was one of the main objectives of this work. Historic ship automatic identification system (AIS) data were purchased from the MarineTraffic network, a web-based ship tracking service (www.marinetraffic.com), for the periods that sound monitoring data existed. A separate suite of MATLAB codes was implemented to synchronize the processed sound recordings with the AIS data and estimate the line-of-sight distance between the stations and any registered ship. Apart from the ship coordinates, AIS data also include valuable information for source SPL, such as: (a) vessel type, (b) speed, (c) ship dimensions and (d) tonnage.

3. RESULTS / CONCLUSIONS

3.1. Ambient noise assessment

The average SPLrms of all stations was 110±6 dB re 1μPa. Fig.1a shows the spatial distribution of SPLpeak in the Ionian Sea while Fig.1b its statistical distribution per ecoregion (N. Ionian, Inner Ionian and S. Ionian) via bar-chart and violin plots. The Inner Ionian has the higher average SPLpeak (129.2 dB re 1μPa), followed by the S. Ionian (127.7) and N. Ionian (127.1). Although the average SPLpeak is not significantly different between ecoregions, their statistical distribution is. The Inner Ionian ranges between about 110 and 150 dB re 1μPa, in contrast to N. Ionian which has a very narrow distribution of values between 120 and 130 dB re 1μPa. Inspection on the sound data revealed that the anthropophony of the area is majorly dominated by ship noises. Comparison of the SPLs per station and the marine traffic density in the area revealed a direct relation between them (Fig.1c). Other sources of anthropophony included sea-farm coastal noises and some occurrences of military exercises from the wider Ionian-Adriatic area, including explosions and sonar sounds. Biophony was also a strong component of the soundscape in the area. Click sounds from crustaceans (snapping shrimps) were noticed in the shallowest stations while dolphin whistles and clicks have been recorded in a dozen of instances.

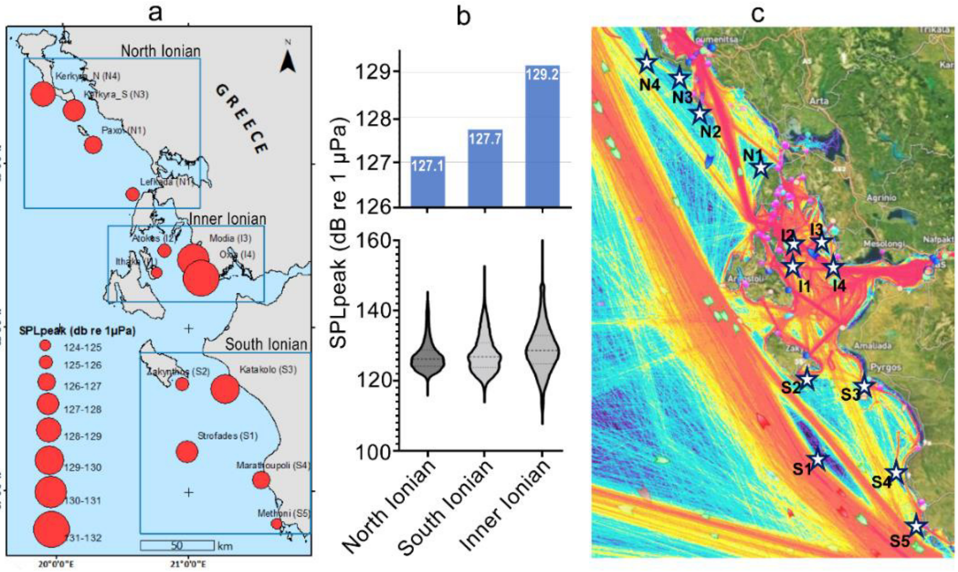

Fig.1: (a) Map showing the average SPLpeak for all recordings in each one of the 13 stations. (b) Bar-chart and violin plots comparing the SPLpeak value statistical distribution between the 3 ecoregions, i.e. N. Ionian, S. Ionian and Inner Ionian. (c) Marine traffic density heat map in the Ionian Sea with the stations displayed as stars.

3.2. Marine traffic noise assessment

Fig.2 shows the assessment results of SPLrms vs line-of-sight distance to any ship. It regards the full band sounds (Fig.2a), the recommended by the MSFD 63 Hz (Fig.2b) and 125 Hz (Fig.2c) third octave center bands, as well as the 1 kHz one. The 1 kHz center band has been chosen as the one with the highest SPL difference between natural and heavy traffic sounds (Fig.3b), with natural referring to sound recordings where the distance to any ship was > 60 km and heavy traffic to ones with distance < 5 km. Significant SPL differences are apparent in all center bands between 200 Hz and 5 kHz (Fig.3b). All full spectrum and third octave center bands exhibited a logarithmic SPLrms decrease with line-of-sight distance to any ship, especially the full spectrum and the 1 kHz center band (Fig.2a,d). Full spectrum sound demonstrated an increase of 15 dB between natural and traffic-dominated soundscapes, which potentially reach 25 dB in closer proximity to ships according to the logarithmic fit function. The corresponding increase is even steeper in the 1 kHz third octave center band, reaching > 20 dB levels and likely > 30 dB in even closer proximity to passing-by ships. A similar increase of 10 dB re 1μPa is evident in the SPLrms histograms of Fig.3a, corresponding to the full-spectrum sound.

In both full spectrum and 1 kHz third octave center band logarithmic fits (Fig.2a,d), a steep increase of SPLrms is evident only closer than 30 km to any ship. This distance from passenger and cargo ships can be considered a threshold distance where marine traffic starts dominating the soundscape of the monitoring stations. Another threshold that can be set is the 10 km distance, before which the logarithmic function has the steepest slope. According to these, more than 30% of the sound recordings were dominated by marine traffic noise, estimated as the percentage of time that ships were less than 30 km away from any recording station. In the same manner, 6% of the recording time, ships were closer than 10 km from the monitoring stations and 4% of time they were closer than 5 km (heavy traffic). Of all stations, Modia (Inner Ionian) was the most exposed to marine traffic noises, with 11% of recording time being in proximity to ships.

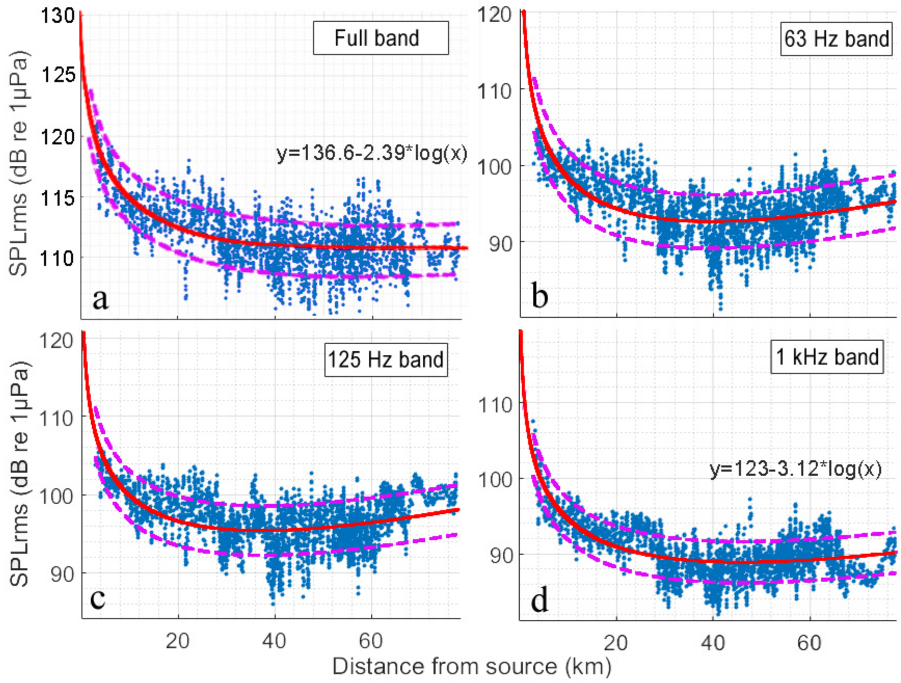

Fig.2: Comparison of SPLrms decrease with the distance to any ship regarding: (a) the full spectrum sound, (b) the 63 Hz, (c) the 125 Hz and the (d) 1 kHz 1/3 Octave centre bands. In all cases, a clear logarithmic SPL increase is noted closer than 30 km to ships.

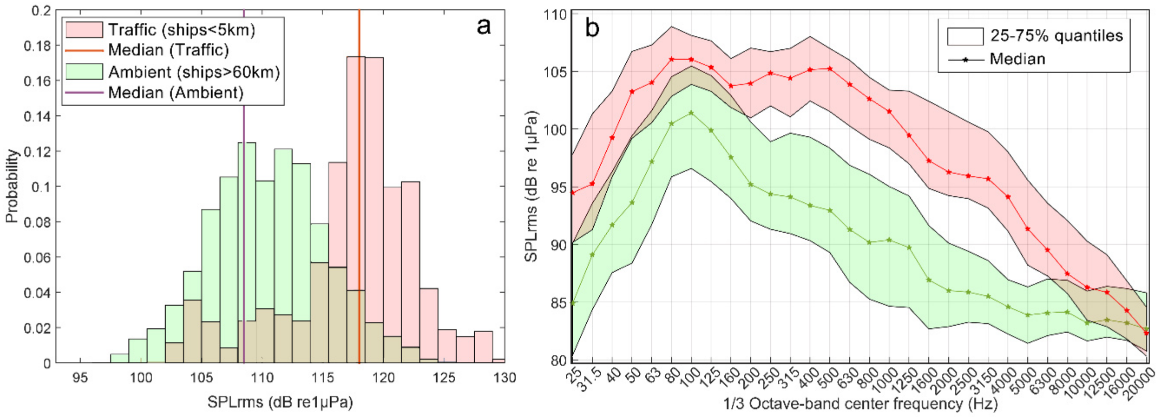

Fig.3: (a) SPLrms histograms and (b) 1/3 Octave bands, for sound recordings indicating natural (> 60 km from any ship) and heavy traffic (< 5 km from any ship) sounds, using all the recordings.

A stacked spectrogram of traffic sound events in Atokos (Inner Ionian) is provided in Fig.4a, where seven events of passenger ships are captured passing by < 5 km away the monitoring station. An interesting visualization of the spectral contribution of ships in relation to the line-of-sight distance to the soundscape of the same station is provided in Fig.4b. As in Fig.3b, the SPLrms of center bands between 500 Hz and 5 kHz appear to increase inversely to distance, with the range between 500 Hz and 1 kHz appearing more affected closer than 30 km away from ships.

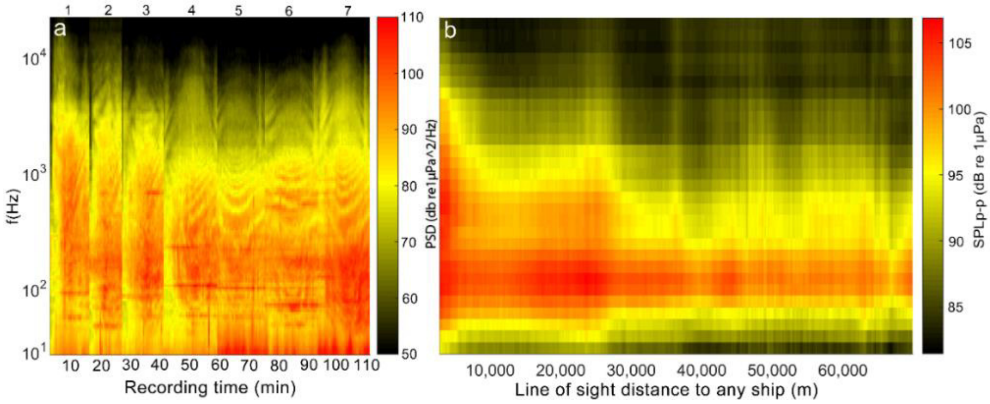

Fig.4: (a) Stacked spectrograms in Atokos station for recordings where the distance to any ship was < 5 km (heavy traffic) and (b) 1/3 octave bands vs distance to any vessel occurrence in Atokos station (a 100 m moving rms filter has been applied).

ACKNOWLEDGEMENTS

We would like to thank all diachronic members of Oceanus-Lab, Geology Dpt., University of Patras, Greece (https://oceanus-lab.upatras.gr), for supporting field works. We would also like to express our gratitude to Philippe Blondel for his kind feedback on a previous manuscript and engaging in valuable discussions regarding eco-acoustics.

REFERENCES

[1] **F.J. Rodrigo, J. Ramis, J. Carbajo, P. Poveda**, Underwater Anthropogenic Noise Pollution Assessment in Shallow Waters on the South-Eastern Coast of Spain, *J Mar Sci Eng*, 10 (9), 1311, 2022.

[2] **J.A. Hildebrand**, Anthropogenic and natural sources of ambient noise in the ocean, *Mar Ecol Prog Ser*, 395, 5–20, 2009.

[3] **E.U. Commission**, On criteria and methodological standards on good environmental status of marine waters, *Official Journal of the EU*, L, 232, 14–24, 2010.

[4] **S. Viola** et al., Continuous monitoring of noise levels in the Gulf of Catania (Ionian Sea). Study of correlation with ship traffic, *Mar Pollut Bull*, 121, 1–2, 97–103, 2017.

[5] **J. A. Nystuen, M. N. Anagnostou, E. N. Anagnostou, A. Papadopoulos**, Monitoring Greek Seas using passive underwater acoustics, *J Atmos Ocean Technol*, 32, 2, 334–349, 2015.

[6] **A. Prospathopoulos, D. Kassis, M. N. Anagnostou, K. Pagou, P. Panayotidis**, Monitoring underwater noise in Greek waters: Key issues in implementing the EU Marine Strategy Framework Directive, In *4th Underwater Acoustics Conference and Exhibition*, Skiathos Island, Greece, 881-888, 2017.

[7] **P. Papadakis, G. Piperakis, M. Taroudakis**, Pilot experiments for monitoring ambient noise in Northern Crete, In *Euronoise*, M. Taroudakis, 30, 2811-2815, 2018.

[8] **E.K. Skarsoulis, G. Piperakis, A. Prospathopoulos, D. Makropoulos**, Prediction of shipping noise in range-dependent environments. *J. Mar. Sci. Eng.*, 11, 2, 290, 2023.

[9] **A. Lillis, F. Caruso, T. A. Mooney, J. Llopiz, D. Bohnenstiehl, D. B. Eggleston**, Drifting hydrophones as an ecologically meaningful approach to underwater soundscape measurement in coastal benthic habitats, *J. Ecoacoustics*, 2(1):2, 2018