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LOW-FREQUENCY CONTINUOUS NOISE WITHIN THE *POSIDONIA OCEANICA* KEY COASTAL ECOSYSTEM: PRELIMINARY RESULTS FROM THE NORTH-WESTERN MEDITERRANEAN

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ABSTRACT

Coastal marine ecosystems are increasingly exposed to sensory pollutants such as anthropogenic noise and artificial light at night. Within the AquaPLAN project framework, in summer 2024 we characterized the noise pollution levels within shallow *Posidonia oceanica* seagrass meadows. Sampling occurred at an urbanized light-polluted site (port) as well as at three naturally dark sites at different level of protection within marine protected areas (MPAs), along the Tuscan coastline (Italy). Acoustic data were recorded up to 192 kHz sampling frequency applying a 16% duty cycle (5 mins recording every 30 mins) by passive acoustic monitoring. Here, we present some preliminary results of a subset of data (96 files) from recordings of 3 days, considering 2 recordings each per 4 parts of the day (nighttime; dawn; daytime; dusk), per day (N=3), per site (N=4). These were processed focusing on the low-frequency continuous noise. Noise was louder and more frequent within the meadow situated close to the port of Capraia, while meadows within MPAs exhibited variable noise pollution levels. These findings provide critical baselines for long-term initiatives assessing noise pollution exposure along with quantitatively measured light pollution levels and then developing mitigation strategies for key-habitats.

Keywords: *Mediterranean Sea, Posidonia oceanica, Noise pollution*

1. INTRODUCTION

Coastal zones are densely populated and largely exposed to human-induced global and local stressors [1]. With the fast pace at which coastal urbanization goes, some novel human-related stressors have become more common, including sensory pollutants like anthropogenic noise and artificial light at night [2,3,4].
The Horizon Europe project AquaPLAN (Aquatic Pollution from Light and Anthropogenic Noise: Management of Impacts on Biodiversity) aims to characterize, both spatially and temporally, anthropogenic noise and artificial light at night and their effects in aquatic habitats. The interest of the Italian project partners, University of Pisa and Stazione Zoologica Anton Dohrn, focus on the impacts of the before-mentioned pollutants on subtidal coastal ecosystems, such as those sustained by the seagrass *Posidonia oceanica*, forming extensive meadows which provide several ecosystem services. This species, endemic to the Mediterranean Sea, is protected together

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with its peculiar habitat type (Habitat 1120) [5] and, to date, only a few studies have directly investigated the anthropogenic noise levels to which this is exposed [6].
Here, we present preliminary data collected in summer 2024 at four sites, selected by an *a-priori* qualitative assessment of potential differences in noise pollution levels, as related to recreational boating and the proximity to a marina where light pollution also occurred.
Following the Marine Strategy Framework Directive (MSFD; 2008/56/EC), our goal was to describe the anthropogenic low-frequency continuous noise levels present in these sites and to assess the possible threatened status of the investigated meadows. The MSFD is one of the few legislations directly mentioning noise as the 11th descriptor for a good environmental status (GES) and it defines it as '*anthropogenic sound that has potential to cause negative impacts on the marine environment, including component biota but not necessarily the whole environment*' [7]. Anthropogenic noise sources in water can be distinguished into impulsive and non-impulsive (continuous), with the latter being mainly associated with noise pollution (NP) produced by shipping, sonar and recreational boats often continuously emitting at low frequencies <1-kHz [8]. Regarding this, the 11.2.1 indicator defined the average level centered at 63- and 125-Hz of the 1/3 octave frequency bands (TOLs) as representative of the non-impulsive low-frequency noise ('shipping bands' *sensu* [9]).

2. MATERIAL AND METHODS

2.1 Study area

Field monitoring activities were conducted between July and September 2024, where *Posidonia oceanica* is at its maximum growth [10]. Among the selected sites, three were located around Capraia Island (Capraia Port - CP, Cala del Moreto - CM, and Peraiola – PER - this latter being part of a no-take zone), and one offshore the Leghorn port, on a shallow bank called 'Secche della Meloria - MEL – within a Marine Protected Area (MPA) (Fig.1).

2.2 Data acquisition and processing

Acoustic recordings were collected via Passive Acoustic Monitoring technique (PAM) using an autonomous recorder (Hydromic384K, DODOTRONIC) with sensibility of -156.1 dB re. 1 V/µPa. Acoustic data were acquired up to a sampling frequency of 192 kHz and 16-bit dynamic range, with a 16% duty cycle (5 mins of recording every 30 mins). This was selected to balance battery time-consumption and data storage limitation. The recorders were mounted and tidily assured on a seabed station and deployed at around 10 m depth for 14 days at Capraia Port (672 files), 19 days at Peraiola (912 files), 20 days at Cala del Moreto (960 files) and 21 days at Secche della Meloria (5040 files). Sea state conditions were similar among sites (<3 Beaufort scale) and wave height field (2-3 Douglas scale). The temperature at the three sites at Capraia island was 26.67±1.30°C, while at the Secche della Meloria site was 23.88±1.89°C. Salinity was constant at around 37-38 ppm.

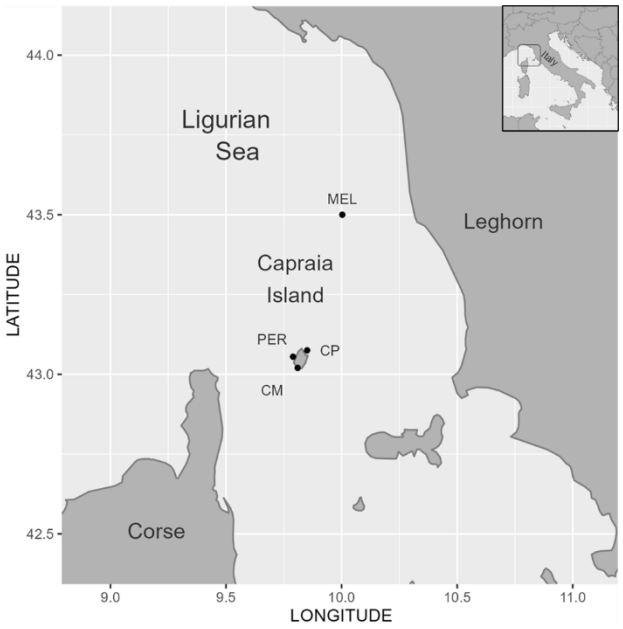

Figure 1. Map of the study area located in the Ligurian Sea (Italy), on the northwestern Mediterranean Sea: MEL - Secche della Meloria; CP – Capraia Port; CM – Cala del Moreto; PER – Peraiola. Map obtained in R Studio version 4.3.3 [11-14].

To this preliminary study, we extracted one subsampled dataset following a procedural scheme: two 5-min recordings per hour per four slots per day from three randomly chosen days per site. The three days included at least one weekend-day (N=6) and the whole subset consisted of 40 minutes a day for a total of 480 minutes. The four slots were the following: 'night'– from midnight to 1am; 'dawn' – from 6 to 7am; 'day' – from noon to 1pm;

'dusk' – from 6 to 7pm. Data were collected as .wav files and no pre-amplification or filtering was applied. Firstly, the audio files were aurally and visually inspected using the free software Raven Lite (from the Cornell Laboratory; www.birds.cornell.edu/home/). The Sound Pressure Level (SPL dB re: 1µPa-rms) was calculated for seventeen 1/3 octave bands (TOLs - frequency range 25 Hz – 1 kHz) using a toolbox in MATLAB [15], with Hann window type with 1 second window length, 50% window overlap and 300 second time-average data (one value for each single file). Special attention was given to the two 1/3 octave bands highlighted by the MSFD and centered at 63-Hz and 125-Hz. Statistical analyses and plots were run in RStudio v.4.3.3 [11,14]. Data was processed with generalized additive mixed effect models (GAMMs) through the 'mgcv' package [16] for the two bands separately. The additive mixed model was chosen to address the non-linear relationship between time of the day and SPL (rms) per site, with the former as the smooth part and days as the random intercept. Due to the limited set of data here processed, we set a flexibility of 4 knots to avoid overfitting.

3. RESULTS

The variations of the SPLs centered at the two shipping bands of the 1/3 octave bands per site are shown in Figure 2. Overall, the 125-Hz band was louder than the 63-Hz at all sites and time slots. Both shipping bands' values showed a similar diel trend, except for the Capraia Port site, where at noon and at dusk higher values were recorded at both bands (Fig. 2). The diel trend of the root-mean-square sound pressure levels at both 63- and 125-Hz bands showed non-linear patterns with variation over time at Capraia Port and Cala del Moreto, while at Peraiola the trend was linear and no temporal pattern was observed (GAMM, $p<0.05$). Meloria site showed a significantly different temporal trend at 63-Hz, but not at the 125-Hz band. The Capraia Port site was the loudest with peak values recorded at dusk for the 63-Hz and at noon in the 125-Hz band. Following the Capraia Port site, Cala del Moreto was the second loudest with the highest peak recorded at noon at both bands, being three- and two-fold lower than the Capraia Port value at 63-Hz and 125-Hz, respectively. The models explained 68.7% and 81.3% of the diel variance for the 63-Hz and 125-Hz bands. As for the random terms, days resulted significantly different at Capraia Port at both bands, and at Meloria when considering the 63-Hz band. For both TOLs, the difference in the medians of the loudest and quietest sites was around 18-22 dB and about 34 dB at 63- and 125-Hz, respectively.

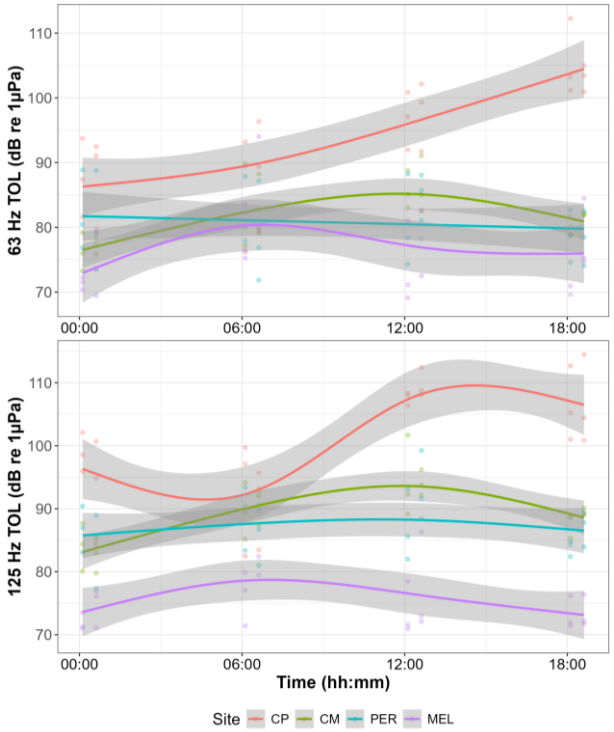

Figure 2. Temporal trend of the two shipping bands TOLs centered at 63- and 125-Hz (dB re: 1µPa). Coloured points and lines represent the SPL (rms) values per site, recorded at a six-hour interval per three days per site (N=2 per time slot). Shaded lines represent upper and lower 95% confidence intervals.

4. DISCUSSION

The preliminary data here shown are, to date, the first related to the anthropogenic noise exposure level of the *P. oceanica* meadows of the Tuscan coast (north-western Mediterranean Sea, Italy) and expressed in terms of TOLs sound pressure levels [17]. Here, our interest was addressed to the diel variation of the two shipping bands, the 63-Hz and 125-Hz, at four different sites, including two MPAs. Not surprisingly, the Capraia Port site was the loudest with the highest median values recorded at noon (92.73 dB re 1µPa and 105.89 dB 1µPa) and at dusk (92.02 dB 1µPa and 103.15 dB 1µPa) at 63- and 125-Hz bands, respectively, when most human activities happen. Moreover, our values were comparable to those obtained in other noisy coastal areas within the Mediterranean Sea (e.g., Gulf of Naples, Civitavecchia port, and the North Adriatic Sea) characterized by intensive human presence [18,19,20,21].

Cala del Moreto, the site on the western coast of Capraia island, was significantly different from Capraia Port and showed significant non-linear temporal trends, possibly due to its site location facing several naval routes as well as small vessels traffic [22]. The highest value at Cala del Moreto was recorded at noon for both bands with 81.03 and 88.40 dB 1µPa at 63- and 125-Hz, respectively. Interestingly, the two MPAs, Peraiola and Secche della Meloria, had two different temporal trends. The former was constant along the diel cycle spanning from 73.40 and 79.11dB 1µPa, and 82.81 and 87.63 dB 1µPa at 63- and 125-Hz, while the latter had a significantly different temporal behavior at 63-Hz, and no differences were recorded at 125-Hz. The lowest rms SPLs at the 125-Hz band were also recorded at Meloria, spanning from 71.34 dB 1µPa at dawn to 71.74 dB 1µPa at noon, respectively (median values). The overall louder 125-Hz band could be due to the combination of shallow sites, high number of recreational boats and less favorable propagation conditions for low frequencies, affecting the contribution from distant shipping as suggested by Garrett et al (2016) [23].

5. FUTURE REMARKS AND CONCLUSION

Drawing conclusions regarding the anthropogenic noise pollution of these sites require further investigation integrating PAM data with automatic identification system (AIS) data [17,19,20]. Follow-ups will consist in processing the remaining recordings, which span a period of ~2-3 weeks and expanding the analyses to natural biological sounds (biophony). This will contribute to widening soundscape information related to the Mediterranean Sea and, more in particular to *Posidonia oceanica* meadows. Furthermore, soundscape analysis, considering both anthropony and biophony, combined to naval traffic information may allow us to detect possible effects of noise pollution on species associated to the meadows. Urbanized sites such as the Capraia Port are also affected by several other threats such as artificial light at night, so that investigating the two factors in multiple stimuli research will provide further insights towards a more comprehensive characterization of sensory pollutants exposure levels [24]. Finally, because the amelioration of sensory polluted sites can be immediate by limiting the naval traffic in certain areas and switching off/to light emission at certain wavelengths, knowledge of their combined effects can help to quickly act and mitigate their impacts within the purpose of the here-presented AquaPLAN project.

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7. REFERENCES

[1] Q He and BR Silliman (2019) Climate Change, Human Impacts, and Coastal Ecosystems in the Anthropocene. *Current Biology* 29: R1021–R1035. 10.1016/j.cub.2019.08.042

[2] JA Hildebrand (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395:5-20. 10.3354/meps08353

[3] C Duarte, L Chapuis, SP Collin, DP Costa, RP Devass, et al (2021) The soundscape of the Anthropocene ocean. *Science* 371: eaba4658. 10.1126/science.aba4658

[4] TW Davies, JP Duffy, J Bennie and KJ Gaston (2014) The nature, extent, and ecological implications of marine light pollution. *Frontiers in Ecology and the Environment* 12:347-355. 10.1890/130281

[5] European Community (1992) Council Directive 92/43/EEC of the European Council of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official journal of EC, N°L206/7.

[6] M Ceraulo, E Papale, F Caruso, F Filiciotto, R Grammauta et al (2018) Acoustic comparison of a patchy Mediterranean shallow water seascape: *Posidonia oceanica* meadows and sandy bottom habitats. *Ecological Indicators* 85: 1030-1043. 10.1016/j.ecolind.2017.08.066

[7] European Marine Strategy Framework Directive Good Environmental Status (MSFD-GES) Report of the Technical Subgroup on Underwater Noise and other forms of energy, pp. 31.

[8] T Gotz, G Hastie, LT Hatch, O Raustein, BL Southall et al (2009) Overview of the impacts of anthropogenic

underwater sound in the marine environment. OSPAR Biodiversity Series, London 134.

[9] P Blondel, B Dell and C Suriyaprakasam (2020) Acoustic Signatures of Shipping, Weather and Marine Life: Comparison of NE Pacific and Arctic Soundscapes. *Proceedings of Meetings on Acoustics* 40(1): 070011. 10.1121/2.0001312

[10] A Peirano, S Cocito, V Banfi, R Cupido, V Damasso et al (2011) Phenology of the Mediterranean seagrass *Posidonia oceanica* (L.) Delile: Medium and long-term cycles and climate inferences. *Aquatic Botany* 94 (2): 77-92. 10.1016/j.aquabot.2010.11.007.

[11] [RStudio] R Core Team (2024) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

[12] A South (2011) rworldmap: A New R package for Mapping Global Data. The R Journal 3(1): 35-43. 10.32614/RJ-2011-006

[13] A South (2012) rworldxtra: Country boundaries at high resolution. https://CRAN.R-project.org/package=rworldxtra

[14] H Wickham (2016) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

[15] N Merchant, KM Fristrup, MP Johnson, PL Tyack, MJ Witt et al (2015) Measuring acoustic habitats. *Methods in Ecology and Evolution* 6(3): 257-265. 10.1111/2041-210X.12330

[16] SN Wood (2017) Generalized Additive Models: an introduction with R, 2nd edition. Chapman and Hall/CRC, Boca Raton, FL.10.1201/9781315370279

[17] G Buscaino, M Ceraulo, N Pieretti, V Corrias, F Filiciotto et al (2016) Temporal patterns in the soundscape of the shallow waters of a Mediterranean marine protected area. *Scientific Reports* 6:34230. 10.1038/srep34230

[18] N Pieretti, M Lo Martire, C Corinaldesi, L Musco, A Dell'Anno and R Danovaro (2020) Anthropogenic noise and biological sounds in a heavily industrialized coastal area (Gulf of Naples, Mediterranean Sea). *Marine Environmental Research* 159: 105002. 10.1016/j.marenvres.2020.105002

[19] V Cafaro, D Piazzolla, C Melchiorri, C Burgio, G Fersini et al (2018) Underwater noise assessment outside harbour areas: The case of Port of Civitavecchia, northern Tyrrhenian Sea, Italy. *Marine Pollution Bulletin* 133:865-871. 10.1016/j.marpolbul.2018.06.058

[20] A Codarin and M Picciulin (2015) Underwater noise assessment in the Gulf of Trieste (Northern Adriatic Sea, Italy) using a MSFD approach. *Marine Pollution Bulletin* 101(2):694-700. 10.1016/j.marpolbul.2015.10.028

[21] M Picciulin, A Petrizzo, F Madricardo, A Barbanti, M Bastianini et al (2023) First basin scale spatial-temporal characterization of underwater sound in the Mediterranean Sea. *Scientific Reports* 13: 22799. 10.1038/s41598-023-49567-3

[22] L Wilson, MK Pine and CA Radford (2022) Small recreational boats: A ubiquitous source of sound pollution in shallow coastal habitats. *Marine Pollution Bulletin* 174: 113295. 10. 1016/j. marpo lbul. 2021. 113295

[23] J Garrett, P Blondel, B Godley, S Pikesley, M Witt and L Johanning (2016) Long-term underwater sound measurements in the shipping noise indicator bands 63 Hz and 125 Hz from the port of Falmouth Bay, UK. *Marine Pollution Bulletin* 110(1):438-448. 10.1016/j.marpolbul.2016.06.021

[24] W Halfwerk and P Jerem (2021) A systematic review of research investigating the combined ecological impact of anthropogenic noise and artificial light at night. *Frontiers in Ecology and Evolution* 9:765950. 10.3389/fevo.2021.765950