DOI: 10.61782/fa.2025.0222

FORUM ACUSTICUM EURONOISE 2025

COMPARATIVE ANALYSIS OF THREE UNDERWATER SOUNDSCAPES

Ramis-Soriano, Jaime[1*] **Poveda, Pedro**[1] **Carbajo, Jesús**[1]
Forcada, Aitor[2] **Valle, Carlos**[2] **Ullah, Naeem**[1]

[1] Department of Physics, Engineering of Systems and Signal Theory. University of Alicante (Spain)
[2] Department of Marine Sciences and Applied Biology, University of Alicante (Spain)

ABSTRACT

Although there are currently no standard metrics to characterize underwater soundscapes, their evaluation with ecoacoustic indices has been widely used in recent years. The aim of this work is to compare three underwater environments. One of them is artificial: the soundscape in a fish farm tank: the other two correspond to near-shore environments on Mediterranean beaches. The coastal area analysed shows anthropogenic noise sources due to the navigation of fishing boats near the study area. The work aims to contribute to the search for a representative set of parameters to describe and qualify the underwater soundscape and, in this way, to be able to predict the improvement or degradation of an action in a specific environment.

Keywords: *Ecoacoustic indices, underwater soundscape, antropogenic noise.*

1. INTRODUCTION

Acoustic landscapes are generally defined as "soundscapes" formed by the different sound sources that manage to reach the location of a sound receptor, which can be an animal or, as in the case study, a sound acquisition system [1]. The concept of soundscape was first introduced in the «World Soundscape Project», led by R. Murray Schafer [2]. The project was developed as a way of describing how humans perceive sounds in a particular area at a particular time. The concept is important for understanding how sound affects the health and quality of life of those who live there, among other factors.

However, this differs in water, as underwater acoustics does not include elements of perception due to uncertainty in the knowledge of how marine animals process and understand sounds.

The underwater soundscape has different spectral, temporal, and spatial characteristics which can be described from the purest orthodoxy, by the same parameters that are used in environmental acoustics in the aerial environment, such as the sound pressure level, the exposure level, the percentiles, etc. The important question is whether these or other parameters, whatever they are, are related to the feeling of well-being, in its different facets. This question is very difficult for humans to answer and is the subject of rigorous studies always subject to statistical variables with an associated uncertainty. In the case of animals (fish in this case), the problem is even more complicated. Perhaps the first option (perhaps the only possible one) is to establish reference levels in controlled environments and, from these, establish a proportional scale of values to a set of parameters selected in the first instance.

[*] ***Corresponding author***: *jramis@ua.es*

We know that there is currently no standard metric to characterise underwater soundscapes, although their assessment with ecoacoustic indices has been widely used in recent years, such as (Acoustic Complexity Index, ACI [3]; Normalised Difference Soundscape Index, NDSI [4]; Acoustic Entropy Index, H [5]; Temporal Entropy, Ht [5]; Spectral Entropy, Hf [5]; Acoustic Richness, AR [6]; Median of amplitude envelope M [6]; Acoustic Diversity Index, ADI [7]; Acoustic Dissimilarity Index, D [5]).

This paper describes the process carried out to compare three scenarios. Two of them natural and a third artificial that should serve as a reference to scale the dynamic range of the selected parameters. It is the beginning of a long journey to find a set of parameters that define an underwater soundscape.

2. MATERIAL AND METHODS

2.1 Selected environments

To compare the underwater soundscape in different environments, three locations were selected. The first corresponded to a beach in the *Serra Gelada* Natural Park, in the towns of Benidorm, Alfaz del Pi and Altea, Alicante, Spain (figure 1). It represents an area of approximately 5.653 ha, 4908 of them maritime. The location is characterized by its cliffs, of more than 300 m, and by the great number of coves. Among its coves, one of the best known is Cala Mina, so-called because of its mining history, which is part of the route to the lighthouse of "El Albir". The location is close to the harbour of Altea and is provided with anchor buoys. Its underwater environment is defined by sandy bottoms in the anchoring area with an approximate depth of 14-15 meters. The presence of very good quality Posidonia oceanica stands out, as well as rocky areas with great spatial heterogeneity. These characteristics make the cove an ideal area for the fish population, something that is reflected in the great diversity of species. Some of them, such as groupers, are good indicators of the effect of the Park's management. On the other hand, Cala Mina is located in a region with a large number of tourists, and it is also very close to aquaculture facilities.

The second location selected was the wreck Bou_Ferrer, found in 1999 on the coast of La Vila, Alicante [8] (figure 2). The wreck, dated to the late 1st century - early 2nd century AD, is located 1.2 km from a fish farm [9] and at a depth of 25 m. It is an area with a high level of maritime traffic due to its proximity to the mouth of the port of La Vila and the tourist influx.

Finally, an artificial environment was selected. It consisted of tanks for the maintenance and breeding of Bluefin Tuna (*Infraestructura Científico-Técnica Singular para el Cultivo del Atún rojo*, ICTS-ICAR), a scientific facility located in Mazarrón and belonging to the Spanish Institute of Oceanography, IEO (figure 3). In particular, measurements were carried out in a tank with concrete walls with a diameter of 22 m and 10 metres deep.

Figure 1. Location Cala Mina and surroundings.

Figure 2. Surroundings of the monitored soundscape in La Vila.

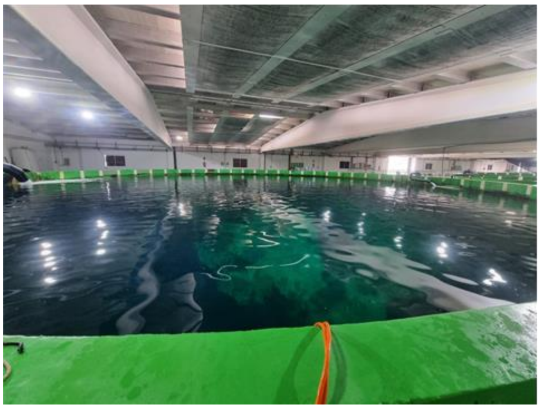

Figure 3. Bluefin tuna breeding tank at the IEO facilities in Mazarrón.

2.2 Measurement setup

Measurements were carried out using a Nauta uRec384k Underwater Recorder (figure 4). The device, with an autonomy of approximately 7 days, was configured for continuous sound acquisition during the entire monitoring campaign. To facilitate further processing and analysis of the data, the signals were stored in wav files every 5 minutes at a sampling rate of 48 kHz. After the device had reached the end of its autonomy, it was replaced by a new one or its batteries were replaced to ensure long term monitoring. The data shown in the present work represent 15 days of continuous measurements for the Bou Ferrer and Cala Mina locations, and one day for the Mazarrón tanks.

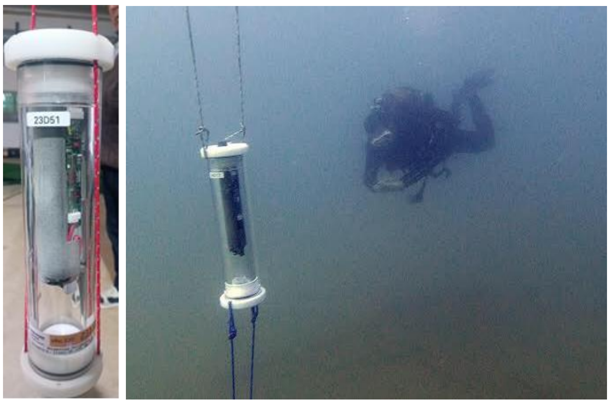

Figure 4. Nauta uRec384k stand-alone acquisition system.

2.3 Soundscape analysis

The analysis of the signals recorded during the measurement campaign was based, on the one hand, on the parameters included in the PAMGuide software [10]. First, according to a set window size (9600 samples, Hanning window), the single-sided spectral power of the signals (*Pss*) was calculated using the Discrete Fourier transform. From this data, both the power spectral density, *PSD* (eq. 1) and the sound pressure level, *SPL* (eq. 2) were obtained for different frequency bands.

$$PSD(f_i, m) = 10 \cdot \log\left(\frac{1}{B \cdot \Delta f}\frac{P_{SS}^{m}(f_i)}{p_{ref}^2}\right) - S(dB) \quad [1]$$

$$SPL = 10 \cdot \log\left(\frac{1}{p_{ref}^2}\sum_{i=f_{low}}^{f_{high}}\frac{P_{SS}(i)}{B}\right) - S(dB) \quad [2]$$

where p_{ref} is the reference pressure (1 µPa); Δf is the ratio between the sampling frequency and the number of samples of each signal block; *B*, is the noise power bandwidth of the window; *S* is the sensitivity of the measurement device (dB); f_{low} and f_{high} are the limiting frequencies of the frequency band to be calculated.

In order to reduce the number of processed data and to facilitate the visualisation of the figures, a temporal averaging of the results was carried out every 60 min. Similarly, the power level was established for different percentiles, finally calculating the difference between L_{90} and L_{10}, a result that accounts for the dynamic range of the noise in each environment. On the other hand, the noise exposure level, *SEL* (eq. 3) was established with an average of 120 min, distinguishing in this case between two daily periods: day (9:00h to 21:00h) and night (22:00h to 08:00).

$$SEL = 10 \cdot \log\left(\sum_{m=1}^{M}\sum_{i=f_{low}}^{f_{high}}\frac{P_{SS}^{(m)}(i)/B}{p_{ref}^2 \cdot s}\right) - S(dB) \quad [3]$$

Secondly, the eco-acoustic parameter Acoustic Complex Index, *ACI*, was calculated using the R Soundecology library [11]. This parameter, developed by Farina and Morri [12], makes it possible to monitor the dynamics of the soundscape and, therefore, to quantify to a greater or lesser extent the variations in sound intensity in a given area. This parameter, initially designed to quantify the singing activity of birds, has been used in various studies to assess the underwater soundscape in different regions [13-17]. This work compares the evolution of the ACI over a day in the different locations, with an average time of 5 min.

3. RESULTS

3.1 SPL and SEL analysis

The analysis of the SPL carried out shows a common pattern for the soundscapes of Bou-Ferrer and Cala Mina (figures 5 and 6). In both cases, there is an increase in noise during the day, coinciding with the hours of heaviest maritime traffic or recreational nautical activities. During the afternoon, evening and night, there is a significant decrease in noise, especially at high frequencies. Similarly, a decrease in noise is observed at weekends, showing the influence of anthropogenic noise on the soundscape. These weekend changes are more pronounced in the vicinity of Bou-Ferrer, an area more exposed to fishing traffic. For Cala Mina, however, the difference is less noticeable, since it is an enclave with a great tourist attraction.

Focusing on the SEL, there is a slight difference between day and night at both Bou-Ferrer and Cala Mina (figures 7 and 8). However, the graphs show a notable difference in the spectral composition of the noise exposure. While in Cala Mina the energy increases as a function of frequency, in Bou-Ferrer an almost constant SEL is obtained from 125 Hz onwards. There are two main reasons for this difference. The first, the size of the ships that pass through both locations. While Bou-Ferrer is exposed to large boats, Cala Mina is dominated by small boats and jet skis. On the other hand, the location of the hydrophone in Cala Mina is closer to the coast, a pebble beach whose sound can affect the measurements.

On the other hand, looking at the SEL obtained in the tank, there is a large difference between day and night (figure 9). This is mainly due to the operation of the installations during the day (vehicles, movement of loads, fish feeding). However, a frequency peak at around 140 Hz is observed in both the day and night results. This noise is due to the water filtration system, which remains always connected.

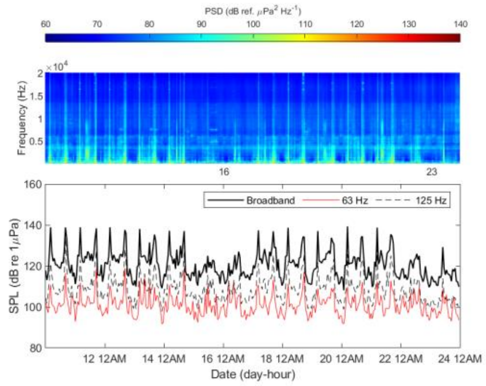

Figure 5. SPL evolution for Bou-Ferrer location.

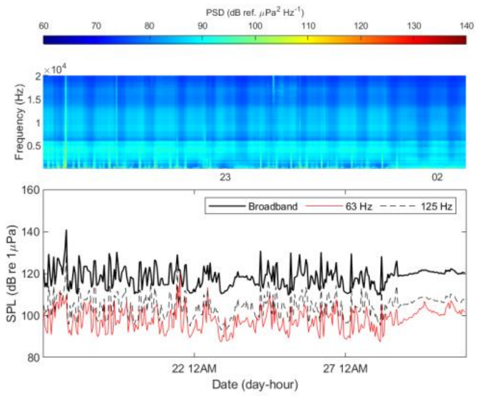

Figure 6. SPL evolution for Cala Mina location.

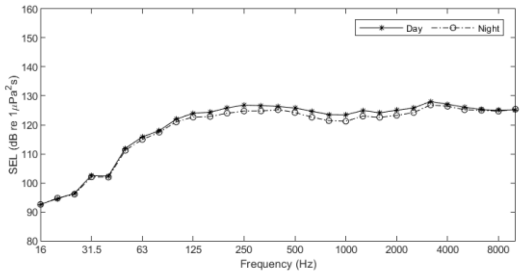

Figure 7. SEL for Bou-Ferrer location.

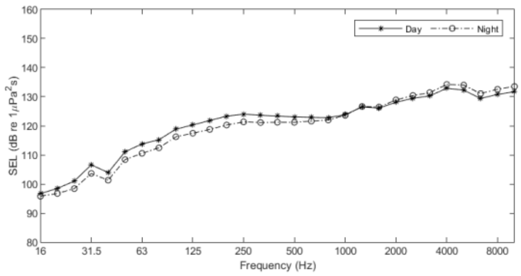

Figure 8. SEL for Cala Mina location.

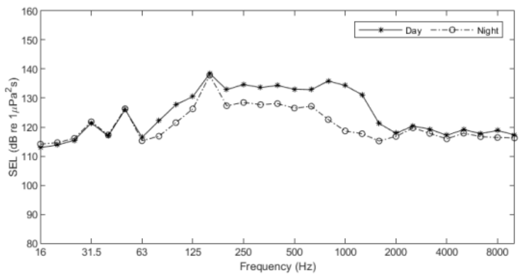

Figure 9. SEL for the tank.

In terms of PSD, the dynamics vary depending on the location, especially for the tank. In natural environments, noise is most likely to occur at low (below 100 Hz) and high (above 1 kHz) frequencies (figures 10 and 11). Inside the tank, however, the spectral probability density is evenly distributed across all frequencies (figure 12). The noise dynamics, obtained from the difference between the 90th percentile and the 10th percentile of the power spectral density, shows a significant difference between the locations (figure 13). In Bou-Ferrer, the dynamics peak at around 1000 Hz, while in Cala Mina it is high but constant in the band between 30 and 600 Hz, decreasing significantly at higher frequencies. The soundscape in the tank has a more constant and much lower dynamic, especially at low frequencies. These differences reflect the complexity of the soundscape in natural environments.

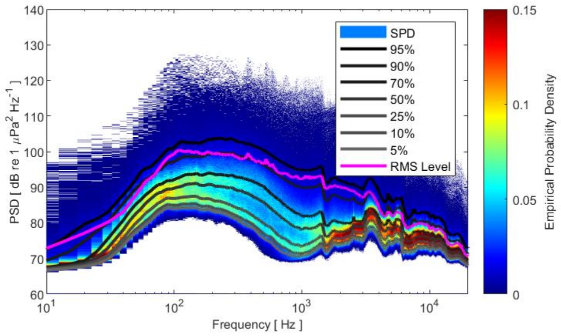

Figure 10. PSD an SPD for Bou-Ferrer.

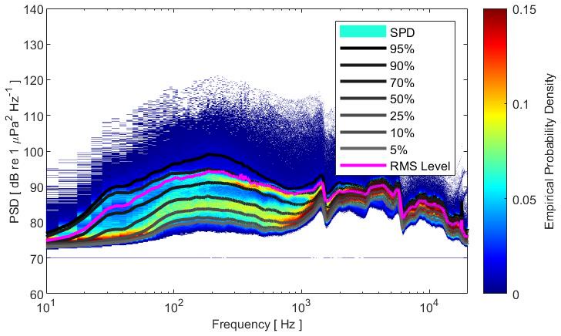

Figure 11. PSD an SPD for Cala Mina.

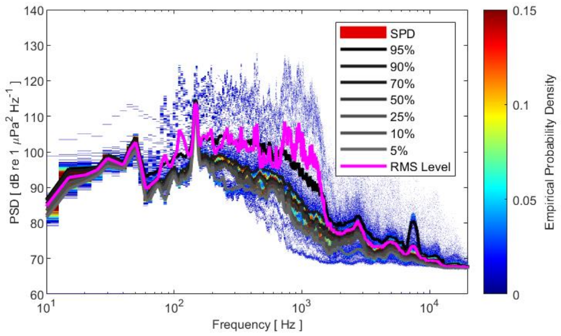

Figure 12. PSD an SPD for the fish tank.

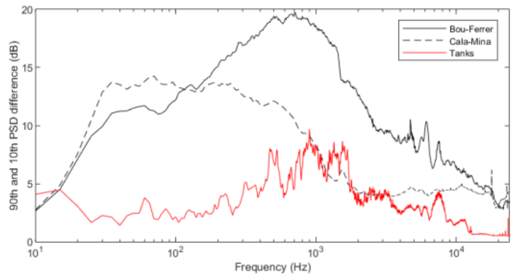

Figure 13. PSD 90th and 10th percentile difference.

Finally, the analysis of the daily evolution of the ACI shows a constant behaviour in the soundscape of the tank, which is evident considering the low variability of the soundscape (figure 14). In contrast, for Bou-Ferrer and Cala Mina, the index shows low values during the night period (similar to those of the tank), increasing during the day, possibly due to the fishing activity in the area.

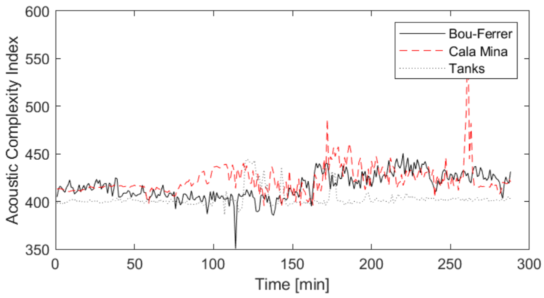

Figure 14. Comparison of ACI.

4. CONCLUSIONS

At first glance you can see clear differences in the acoustic environment of the artificial stage and the other two natural ones. As expected, the dynamic margin is much smaller in the first than in the other two. We dare assert the difference between (L90-L10) or such a time (L95-L5) being significant in differentiating an artificial acoustic environment (tank) and a natural one. This can be explained in part by the little reflection on the walls of the tanks that causes the existence of a reverberant field in practically the entire volume.

Differences can also be seen in the day-night environment but, possibly, the explanation lies in the absence of traffic during the night in the vicinity of the ICAR.

The other parameters obtained need a more detailed study to have reliable conclusions. Measurements have been carried out during the four stations that are currently being processed.

5. ACKNOWLEDGMENTS

This publication is part of the project PCI22022-135081-2, funded by MCIN/AEI/10.13039/501100011033 and by the European Union "Next Generation EU"/PRTR", where MCIN stands for the Ministry of Science and Innovation; AEI for the State Research Agency; 10.13039/501100011033 for the DOI (Digital Object Identifier) of the Agency; and PRTR for the acronym of the Plan for Recovery, Transformation and Resilience).

6. REFERENCES

[1] B. C. Pijanowski, A. Farina, S. H. Gage, S. L. Dumyahn, and B. L. Krause, “What is soundscape ecology? An introduction and overview of an emerging new science”, Landscape Ecology, vol. 26, no. 9, pp. 1213-1232, 2011.

[2] R. M. Schafer, *The New Soundscape: A Handbook for the Modern Music Teacher*, BMI Canada, Canada, 1969.

[3] N. Pieretti, A. Farina, and D. Morri, “A new methodology to infer the singing activity of an avian community: The Acoustic Complexity Index (ACI),” *Ecological Indicators*, vol. 11, no. 3, pp. 868-873, 2011.

[4] E. P. Kasten, S. H. Gage, J. Fox, and W. Joo, “The remote environmental assessment laboratory's acoustic library: An archive for studying soundscape ecology,” *Ecological Informatics*, vol. 12, pp. 50-67, 2012.

[5] J. Sueur, S. Pavoine, O. Hamerlynck, and S. Duvail, “Rapid Acoustic Survey for Biodiversity Appraisal,” *PLOS ONE*, vol. 3, no. 12, pp. 1-9, 2008.

[6] M. Depraetere, S. Pavoine, F. Jiguet, A. Gasc, S. Duvail, and J. Sueur, “Monitoring animal diversity using acoustic indices: Implementation in a temperate woodland,” *Ecological Indicators*, vol. 13, no. 1, pp. 46-54, 2012.

[7] L. J. Villanueva-Rivera, B. C. Pijanowski, J. Doucette, and B. Pekin, "A primer of acoustic analysis for landscape ecologists," *Landscape Ecology*, vol. 26, no. 9, pp. 1233-1246, 2011.

[8] De Juan, C., Cibecchini, F., Matamoros, C., Moya, J. A., y Molina, J. Jornada «El pecio Bou Ferrer de Villajoyosa: un yacimiento romano extraordinario». Boletín del Museo Arqueológico Nacional 34/2016 | ISSN: 2341 - 3409 | Págs. 457-474).

[9] Soler, E., Bras, M., Martínez, B. (2020). Estudio de impacto ambiental del proyecto de "Ampliación de producción de la granja marina nº12 de engorde de dorada, lubina, corvina y seriola en jaulas flotantes en aguas del mediterráneo, Villajoyosa (Alicante)" 2010.

[10] Merchant, N. D.; Fristrup, K. M.; Johnson, M. P.; et al. (2014). Measuring acoustic habitats. Methods in Ecology and Evolution. 13(4) (PAMGUIDE)

[11] Villanueva-Rivera LJ, Pijanowski BC (2016). soundecology: Soundscape Ecology. R package versión 1.3.2. (github.com/ljvillanueva/soundecology)

[12] Farina, A., Morri, D., 2008. Source-sink e eco-field: ipotesi ed evidenze sperimentali. Atti del X congresso nazionale della SIEP-IALE. Ecologia e governance del paesaggio: esperienze e prospettive. Bari, 365–372.

[13] Murilo Minello, Leandro Calado, Fabio C Xavier, Ecoacoustic indices in marine ecosystems: a review on recent developments, challenges, and future directions, ICES Journal of Marine Science, Volume 78, Issue 9, November 2021, Pages 3066–3074, https://doi.org/10.1093/icesjms/fsab193vila.

[14] Bertucci, F., Guerra, A.S., Sturny, V. et al. A preliminary acoustic evaluation of three sites in the lagoon of Bora Bora, French Polynesia. Environ Biol Fish 103, 891–902 (2020). https://doi.org/10.1007/s10641-020-01000-8.

[15] E. Lattanzi, V. Freschi, M. Dromedari and A. Bogliolo, "An Acoustic Complexity Index Sensor for Underwater Applications," in IEEE Sensors Journal, vol. 16, no. 11, pp. 4043-4050, June1, 2016, doi: 10.1109/JSEN.2015.2459383.

[16] Bittencourt L, Barbosa M, Bisi TL, Lailson-Brito J Jr, Azevedo AF. Anthropogenic noise influences on marine soundscape variability across coastal areas. Mar Pollut Bull. 2020 Nov;160:111648. doi: 10.1016/j.marpolbul.2020.111648.

[17] Sánchez-Gendriz I, Padovese LR. Underwater soundscape of marine protected areas in the south Brazilian coast. Mar Pollut Bull. 2016 Apr 15;105(1):65-72. doi: 10.1016/j.marpolbul.2016.02.055.