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# ANALYSIS OF THE UNDERWATER SOUNDSCAPE USING ECOACOUSTIC INDICES: ACOUSTIC STUDY OF UNDERWATER AREAS IN THE MEDITERRANEAN SEA

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## ABSTRACT

Ecoacoustics investigates sound to understand its properties, its evolution, and its function in the environment. Ecoacoustic analysis is becoming an important tool of quantifying the ecological aspects of the landscape (terrestrial or underwater), where living beings need to establish an acoustic communication between them. This soundscape is complex and requires procedures to transform the collected data into information that is useful for understanding the environment. In this case, these are the ecoacoustic indices. The purpose of this work is to study the acoustic behaviour of two underwater environments (using the second only for comparison) by means of the ecoacoustic indices analysed in the first part of the work. Different results are obtained in which common patterns and differences can be identified, with the final objective of discussing the viability, or lack thereof, of these indices in underwater environments.

***Keywords***— ecoacoustic indices, anthropophony, biophony, soundscape, underwater acoustics.

## 1. INTRODUCTION

Ecoacoustics, known as the study of environmental sound, is becoming an important way of quantifying the ecological aspects of the landscape, as mentioned in the first part of this work.

In this second part, after learning how ecosystems are generally studied using ecoacoustic indices, a change of approach to these reference studies is sought by applying these indices to an environment that differs from terrestrial ones, an underwater soundscape.

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. There is currently no standard metric to characterise underwater soundscapes, although their assessment with ecoacoustic indices has been widely used in recent years.

The intention of this work is to show the results of the ecoacoustic indices shown in the first part of the work (Acoustic Complexity Index, ACI [3]; Normalised Difference Soundscape Index, NDSI [4]; Acoustic Entropy Index, H [5]; Temporal Entropy, $H_t$ [5]; Spectral Entropy, $H_f$ [5]; Acoustic Richness, AR [6]; Median of amplitude envelope M [6]; Acoustic Diversity Index, ADI [7]; Acoustic Dissimilarity Index, D [5]). These results differ, to a greater or lesser extent depending on the case, from the reference studied in the theoretical part. Therefore, this study serves primarily to investigate the viability of these indices and to understand what is happening in an underwater soundscape.

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## 2. MATERIALS AND METHODS

### 2.1. Study area

The main area chosen for the study is the bay of El Gorguel (37°33’55.3” N, 0°52’26.9” W), located in El Gorguel, Murcia (Spain). The recorded files and information regarding location and sample collection were provided by the research team of the Gandía Campus of the *Universitat Politècnica de València* (UPV) and the *Instituto de Investigación para la Gestión Integrada de Zonas Costeras*. The coastal area analysed shows sources of anthropogenic noise due to maritime navigation on the coast of Cartagena, close to the study area.

Throughout the study and given the high presence of anthropogenic noise in the recordings collected in El Gorguel, it was decided to compare the results of the various indices obtained by incorporating other types of recordings that did show marine biodiversity. These secondary recordings were taken in a marine reserve near Tabarca island, close to the coast of the province of Alicante (Spain). Unfortunately, the coordinates or position of the device on the seabed used were not known.

### 2.2. Materials and sound recording

For the recording of the audio files a mooring system was used with the following elements: anchor weight, acoustic releaser , passive acoustic recorder (known as SAMARUC) and depth buoys. All of these are joined together by two high strength connecting ropes. One of them connects the parts that will be recovered at the end, while the other is used to connect the acoustic release and the anchor weight, which are lost after the recovery of the rest of the system. This separation is made by the acoustic release, which has two units (depth and surface) that communicate between them.

The most important element is the SAMARUC unit. It contains the sound recorder, the Cetacean Research® C57 hydrophone. All electronics and batteries are protected inside a sealed metal cylinder, while the hydrophone is kept on the outside of the cylinder surrounded by a protective cage.

In total, three mooring campaigns were analysed in El Gorguel for the collection of the acoustic recordings used in this analysis. Including the day of anchoring and collection, the campaigns have a duration of 24 (15th May 2018 to 07th June 2018), 48 (07th June 2018 to 24th July 2018) and 48 (25th October 2018 to 11th December 2018) days, respectively.

In the secondary zone of the marine reserve in Tabarca, only 5 recordings were selected out of many more, collected using the Ocean Instruments SoundTrap 300 STD hydrophone from Ocean Instruments®. The reduced choice is because they are only used to calculate the D index [5]. Its calibration sensitivity is -184.1 dB.

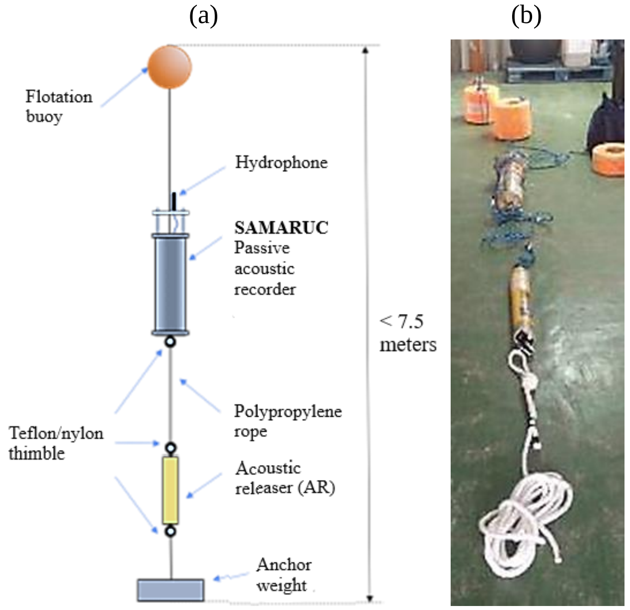

**Figure 1.** (a) Basic drawing of the mooring system. (b) Picture of the real mooring system, except for the anchor weight.

### 2.3. Data processing

The sampling frequency ($f_s$) used in El Gorguel was 9.6 kHz in the first two campaigns, while the last one was recorded at 48 kHz. To avoid this difference and to facilitate the comparison, the sampling frequency was limited to the minimum, so that all recordings would have an $f_s$ of 9.6 kHz. However, the results were also studied with the original frequencies.

The duty cycle used was 5 minutes of recording and 10 minutes of rest. Some recordings were eliminated, as the hydrophone picked up its entry and exit from the water, as well as the sound of human voices of the staff who worked on the positioning. These recordings are not suitable for the study and, although worth mentioning, will not be included. This would leave a total of 9753 recordings in this area. In the underwater environment of Tabarca, the files had 1 minute of non-stop recording.

The reference sound pressure underwater is 1 µPa (as opposed to 20 µPa in air) and the sensitivity for the complete measuring equipment used is -167 dB re 1V/µPa.

For the analysis of acoustic files, most of the literature reviewed relies on the use of two libraries or packages called *seewave* [8] and *soundecology* [9]. Both provide functions to perform the calculation of different indices. Calculations of other acoustic parameters have been made with *PAMGuide* [10] which shows in a more organised and accurate way the environmental sounds collected in different soundscapes. It can be used in *MATLAB* as well as in *R*.

## 3. RESULTS

### 3.1. Differentiated events in the recordings

Events have been differentiated using the spectral representation of the files. Given the massive amount of data collected, it is useful both in the analysis and in the understanding of the results obtained. The events differentiated in El Gorguel are:

1. Ship engine sounds (Fig. 2a): shows the engine sound of the different ships in the area. In some cases, the energy level represents the acceleration and deceleration of the ships, or movements of approach and distance from the hydrophone.
2. Mechanical punctual sounds (Fig. 2b): slightly impulsive noises are displayed, lasting at most a few seconds. They sound like the sounds of dragging, or a motorised tool being activated and then stopped after a short time. There are also very impulsive sounds, lasting milliseconds, which belong to the triggering of a tool called *lupara*, a type of sawed-off shotgun used in nearby fish farms.
3. Continuous tonal noise over time (Fig. 2c): displays noise that has components of a certain frequency. Mostly there is a continuous noise that seems to come from some engine or machine. In some cases, they are clearly generated by a ship. In other cases, the sound source is hardly recognizable.
4. Discontinuous noise caused by metallic collisions (Fig. 2d): similar to no. 2, it is different in that the spectrum shows shorter and lower energy sounds that could be the collision of fish cages in the fish farm or some other metallic element.
5. Apparent silence (Fig. 2e): recordings occur in which “nothing is heard” apart from a low-frequency noise comparable to the sound of running water or falling water hitting a surface. It can also be seen in spectral representations of previous events, although it is sometimes overlapped or completely cancelled. The event is spectrally similar to no. 3 with a lower energy level. It could be the case that some of the sounds collected are from biological sources, such as the gilt-head seabream or sea bass that inhabit the fish farm or other living things on the seabed. Some of these sounds are produced at a frequency of approximately 400-500 Hz, while others reach the 3 kHz band.

In general, in 2018, there are no major differences in noise levels in the area due to the change of season. In all of them the marine traffic is reflected in the hours of sunshine, while at night the activity relaxes.

Different marine species coexist on the island of Tabarca, such as groupers, gilthead bream and other types of fish, molluscs, turtles, etc.

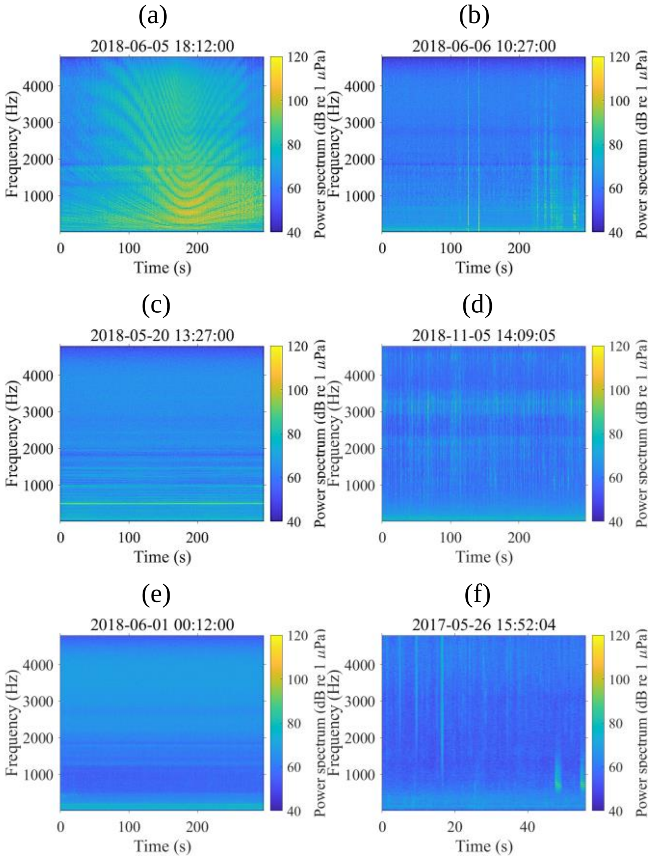

**Figure 2.** Examples of sounds collected by the SAMARUC unit divided by events: sounds emitted by passing ships (a), mechanical punctual sounds (b), continuous tonal noise over time (c), discontinuous noise caused by metallic collisions (d), apparent silence (e). The last figure shows a recording collected by another unit in Tabarca (f).

The audio files show some grouper vocalisations (known as booms) and some gilt-head seabream croaks. These booms are located below 500 Hz, while the croaks are concentrated between 0.5 kHz and 1 kHz. At higher frequencies, high-pitched clicks, belonging to crabs, can be heard (Fig. 2f).

### 3.2. Ecoacoustic indices

To show the results obtained, representations show the results of each index averaged for each event. This average was obtained from a selection of files from each of the campaigns that fulfil the conditions described in each event.

The ACI (Fig. 3a) results in maximum values generally higher than 160, never exceeding the value of 190. This value is not high if we consider that some studies have provided values higher than 3500 [11]. The moment where the ACI is somewhat higher is in event 4 (metallic collisions), although the variance is high. In this event, there is a greater number of intensity variations with numerous amplitude peaks.

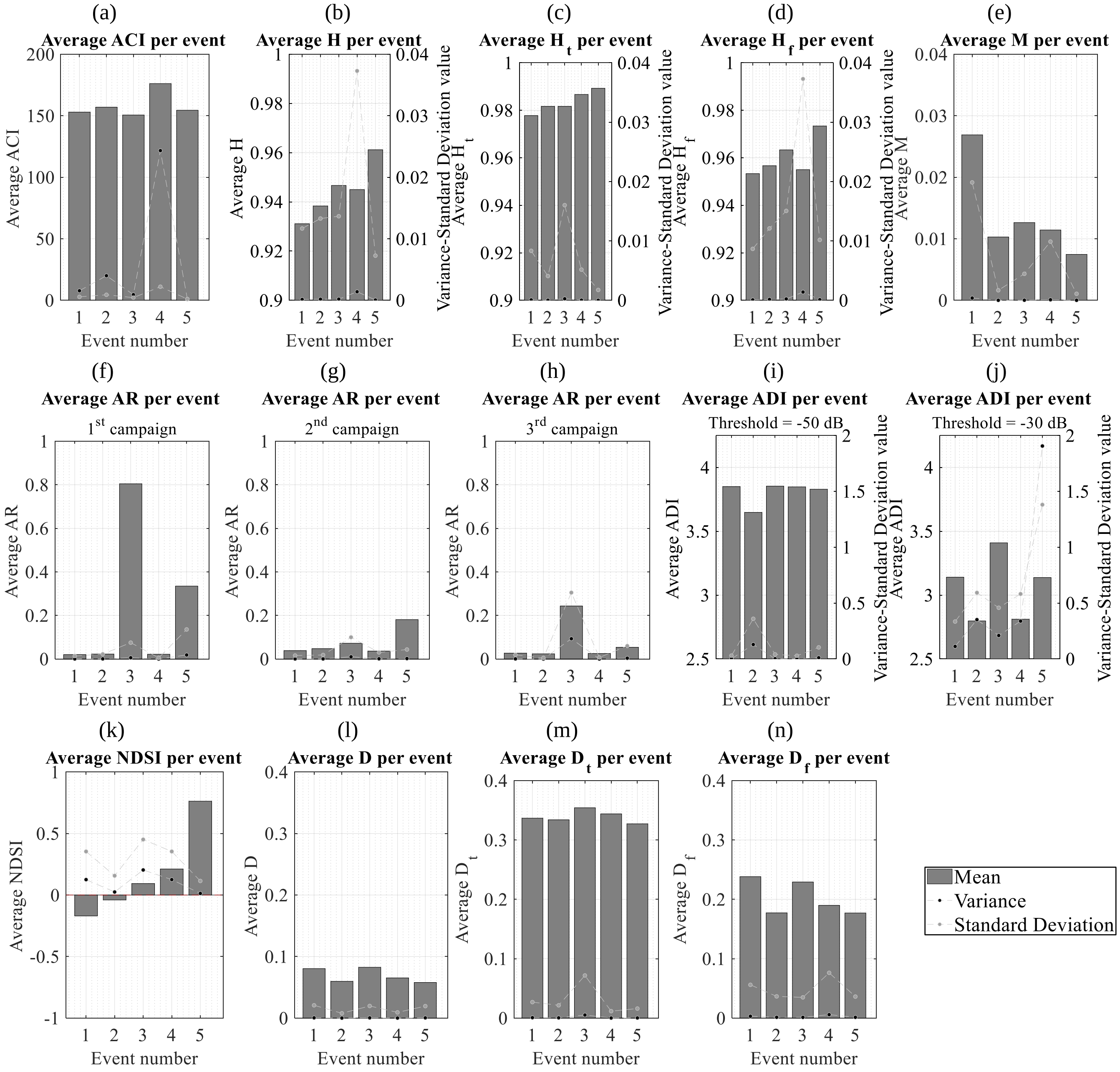

**Figure 3.** Bar chart of the different ecoacoustic indices averaged over the campaigns calculated for all events.

However, this amplitude is not very high, resulting in a higher ACI, but not very high compared to other soundscapes. Impulsive sounds do not stand out too much from the background noise and, generally, the presence or absence of ships does not seem to affect this index too much. The rest of the events have approximately the same ACI values, being perhaps somewhat lower in event 3 or 5, where the sound remains mostly continuous without abrupt differences in amplitude.

In the calculation of H (Fig. 3b), both $H_t$ (Fig. 3c) and $H_f$ (Fig. 3d) are considered. Analysing first $H_t$, it is generally high in all the campaigns, approaching the maximum value for this index. The minimum value is obtained in recordings that are part of event 1. However, not all ship traffic sounds produce minima. These are those that are very concentrated temporally in one part of the recording, covering practically the whole spectrum in a certain period. The sounds produced by the active machinery of ships result in a more uniform occupation of the frequency spectrum, resulting in lower temporal entropy. However, the value obtained is particularly high even in its minimums. Analysing the $H_f$, it has a greater differentiation between maxima and minima. The situation is similar to $H_t$, but on a different axis. In this case, recordings close to event 3 are lower, as there is a continuous sound in time at a certain frequency that could be produced by machinery or dragging procedure. The conclusions are the same as those given in the case of $H_t$, but on the frequency axis. On the other hand, the maximum values of this index are generally lower than for $H_t$. However, event 5 still gives higher values. Finally, H provides values similar to those of $H_f$, lower given the influence of $H_t$. This index increases from 0 to 1 in more heterogeneous signals, so that higher values of H would indicate richer and more diverse habitats, more random sounds, and a lower presence of strictly pure tones. In the reference, it is mentioned that noises caused by wind, water or human activities could reduce the reliability of H [5]. In this case, it would be expected that the most continuous sounds, temporally or spectrally (such as events 1 and 3), would give very different minimums from the rest and that events with a more “random” sound, such as 2 or 5, would maximise the values. This, in practice, is not entirely rigorous. There are recordings where this assumption holds true and, at the same time, there are very similar recordings that give different values. In short, the deep sea is a chaotic and very noisy environment that makes it difficult for the entropy indices to perform, so working with them underwater is not recommended.

The AR results (Fig. 3f, g, h) depend on the set of input files. Having campaigns that differ in their number of files, the comparison between them is not viable. The M index (Fig. 3e), that ranges from 0 to 1, provides small values. It is calculated using the median of amplitude envelope, so it will be higher where the envelope remains higher for a larger number of samples, such as in those events where there are sustained ship sounds (event 1 or 3) and even numerous high amplitude levels but presented discontinuously (event 4). An increase in the M index does not directly translate into an increase in AR due to the way the files are classified. M showed higher values in event 1, while AR remains minimal. This may be due to $H_t$ values dropping in the presence of highly concentrated ship noise. Those campaigns with fewer archives show higher values. Although these recordings do not explicitly show distinct animal species, the index is not rigorous, showing relatively high values in recordings that, in principle, have a very low overall activity.

The ADI has been obtained twice, assigning a size of 100 Hz to each frequency bin and a threshold of -50 dB (Fig. 3i) and -30 dB (Fig. 3j). The first one, taken from the reference [7] and lower, takes more background noise, resulting in very high results with little difference. The -30 dB threshold results in much more oscillations of values and minimum peaks where the trend at -50 dB was almost flat. It shows minima when the energy level is kept at low and almost constant levels except at one point, which differs from the rest by a noticeable number of decibels depending on the case. These recordings could be similar to those analysed in event 2, where punctual sounds were produced. This index is higher the more uniform the frequency bands are. Therefore, it is understandable that events 3 and 5 are the highest, as they show more constant values over time. Also, depending on the case and the continuity of the sound emitted by the ships, event 1 may provide high values. Meanwhile, those events with more punctual sounds (events 2 and 4) are lower. Event 5 (apparent silence) shows a large deviation due to an unexpected initial sound effect (a small backfire sound) at the beginning of the recordings in the 3rd campaign, which greatly decreases the ADI obtained.

For the calculation of the NDSI (Fig. 3k), in underwater environments it is often the case that the majority of biotic sounds occur at very low frequencies, so that biophony may occur below anthropophony. There may also be masking of biological sounds in the presence of mechanical signals. However, due to several problems, it was decided to follow the reference [4], adapting the function to the $f_s$ of 4.8 kHz. The NDSI oscillates between values of -1 and 1. In all the campaigns, in the time slots close to 00:00 (GMT/UTC + 1), the NDSI tends to be higher, with values above 0.5, while as ship traffic begins to occur, these values decrease below 0, showing periodicity. The maximum values for the NDSI correspond to event 5 (apparent silence). Although the choice of the frequency bands chosen did not seem to be a good determinant, the results made possible to detect vocalisations of living beings when the sound of ships disappears. The absence of the ship sound means that, especially at night, sounds with a higher power are heard between 2 and 3 kHz. The 1 kHz band, meanwhile, has lower levels. This is why the NDSI increases and, although sounds at 500 Hz are not considered biophony in the processing (which is the frequency at which vocalisations occur), it also manages to classify them. On the other hand, the event with the lowest rates is event 1, given the high radiation power of the ships in the 1 kHz band. Those recordings where the NDSI is minimal present very concentrated ship sound, below 2 kHz. The rest of the events have disparate behaviours. This index, in this type of recordings, does not seem to be the most appropriate. The spectral overlap of anthropogenic and biological sound is a major problem in reaching a band separation that provides good results. It would be more useful in environments where the presence of biological and non-biological sounds is more differentiated in the spectrum or where there is an absence of masking anthropogenic sound.

Finally, to calculate D (Fig. 3l), the number of samples of the longest recordings has been adjusted to the number of samples of the shortest ones, which last 1 minute in Tabarca. Therefore, the remaining 4 minutes of the El Gorguel recordings would be excluded. This limitation may mean that some of the recordings from this area are left without the event that characterised them. The result obtained in the comparison of the 5 files of the marine reserve with the rest is very similar, since both the variance and the deviation provide reduced values. The $D_t$ values (Fig. 3m) are the highest and remain practically constant in all the events analysed. Temporally, the recordings show more dissimilarity, which means a greater difference between the two areas analysed. However, considering that 1 is the maximum value, the dissimilarity obtained is low. $D_f$ (Fig. 3n) shows more differences, but smaller values. According to the results, those recordings that show a strong presence of ship traffic, such as event 1 or 3, have an increased dissimilarity, while the rest provides similar and lower values. The D index shows a very small value, which translates into a high similarity. In the theoretical part, talking about the $\beta$ indices, it was commented that they are still simple indexes and need to be developed. It is proven in practice. The files compared show differences that should be interpreted as dissimilarity. It may be that, as mentioned above, the limited duration of the audios in the first zone may have had a negative influence on the results. However, very noisy events are still reflected, such as the continuous sound of ship mechanics, as opposed to the occasional croaks and clicks that occur in the natural reserve.

## 4. CONCLUSIONS AND FUTURE LINES OF ACTION

Anthropophonic elements invade the underwater environment with noise, masking natural sounds. In this case, it has been possible to analyse recordings over relatively long periods of time in different seasons. The division of the large amounts of files into generic events has been key to the success of this work. Despite this, the results have not been as accurate as expected.

The indices that analyse the intensity or amplitude of the signal, such as the ACI, are not so far from what is expected, while those that determine heterogeneity, species richness, abundance, etc. generate more diffuse conclusions. Indices such as AR or H are not the most suitable in underwater environments with anthropogenic noise present. The role of indices dedicated to the analysis of the complete soundscape, such as the NDSI, should also be highlighted. It has been shown that marine individuals communicate at frequencies that interfere and overlap with anthropogenic sound, which makes the differentiation between geophony, biophony and anthropophony very complicated.

Moreover, the $\beta$ indices, although necessary, need to be optimised to complex sound environments. Therefore, apart from contributing new data by carrying out studies with these indices, it is crucial to adapt or develop new indices that consider the acoustic aspects of the water, overcoming the limitations of these initially terrestrial indices. The purpose of this study was to carry out an in-depth analysis of how the soundscape behaves. All the work carried out in a maritime traffic area shows that other types of environments, perhaps less relevant in biodiversity studies, can also serve as a reference for future work.

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