# Soundscaping using a smart cable prototype off the coast of Portugal

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***Abstract*—Ocean soundscaping is an important tool to monitor ocean noise and to understand how it may impact marine life. A promising approach is the exploration of the SMART cable concept that relies on the use of a telecommunication cable equipped with environmental sensors, allowing for ocean real-time monitoring. The K2D project[1] developed a set of cable nodes with extended SMART capabilities. These nodes were tested on a short telecommunication cable deployed off the coast of Sesimbra, Portugal. In this sea trial, several ocean variables were gathered, including underwater sound that was used to characterize the region's soundscape. Three types of analysis were conducted: a) the evaluation of the usual noise level baseline for all nodes, b) an attempt of sound source identification through frequency band analysis, and c) the evaluation of the noise level in different periods of the day. The results show that node 1 (the closest to shore) has higher noise levels and no significant difference between day and night periods in the frequency bands between 100 Hz and 1 kHz. No biological signatures were identified in the recorded data. Comparing the three nodes' locations, the results suggest that the area where node 1 was deployed is the most affected by (coastal) ship traffic.**

***Index Terms*—SMART-cable, soundscape analysis, shipping noise, underwater noise, Portugal.**

## INTRODUCTION

The ocean plays an indisputable role in the balance of Earth's climate. The disruption of this balance will have unpredictable consequences for humanity. It is, therefore, of paramount importance to accurately and thoroughly monitor ocean parameters in order to detect any signs of deviation from equilibrium. While the ocean surface can be scanned by satellites and thus obtain a synoptic view of large areas, the ocean interior remains for the most part inaccessible.

In 2010, a note posted in *Nature* by Yuzhu You, suggested that submarine telecommunication cables crisscrossing the oceans, provided a unique possibility to obtain the much needed environmental information of ocean interior, if they could be equipped with the appropriate sensors [1]. This idea was pursued and expanded under the the Joint Task Force (JTF) formed in 2012, and supported by ITU, WMO, UNESCO IOC and later also by NASA with the purpose of evaluating the potential of telecommunication cables for improving/complementing satellite ocean observations, namely its contribution to the calibration of altimetry and gravity. This initiative, under the leadership of principal investigator Bruce Howe, was named Scientific Monitoring and Reliable Telecommunications (SMART) and known as SMART-cables [2]–[4]. Focus was made on acquiring data for precise estimation of sea-level, heat content and ocean circulation, as well as its climate impact. Other fields of application of SMART-cable data is reliable earthquake detection and tsunami early warning (see network S-net details in [5]). The SMART-cable concept is that of equipping standard telecommunication repeaters with additional sensors, with a minimum impact for cable deployment and reliability.

Building on the SMART-cable concept, project K2D[1] aims at designing, developing and testing at sea extended sensing capacity for permanent ocean observation based on newly installed submarine telecommunications cables, taking advantage of the cable junctions (repeaters) to install cable-connected Environmental Observation Nodes (EONs). These EON have sensors for environmental sensing and for acoustic communication/interaction with nearby unmanned submarine platforms, such as gliders, AUV's, drifters, and others. Since the EON are connected via the data cable, each module may be viewed as a node of a large cable-connected distributed ocean observatory. K2D is specifically aimed at applying this extended SMART-cable concept to the design of the telecommunications cable connecting continental Portugal-Azores-Madeira-ring (CAM-ring) that is up for replacement in the next few years. Acoustic sensors will be used for transmitting and receiving information to/from the unmanned platforms and also for passively listening to ocean ambient sound for characterization and soundscaping. Even if the final design of the new CAM-ring is not known at this stage, it is of paramount importance to determine its overall expected performance for acoustic monitoring.

The K2D concept was tested on a 2 km long cable prototype with three sensing nodes recording for approximately three weeks off the coast near the town of Sesimbra, Portugal [6]. This work aimed at evaluating the underwater soundscape in the deployment area and acoustically characterize the surrounding noise levels and its daily variations.

[1]Knowledge and Data from the Deep Space, FCT-MIT Portugal, contract no. 045941.

## Materials and methods

### A. Definition of the area

The cable prototype was deployed on the southwestern coast of Portugal, near the town of Sesimbra (see Figure 1 and a detailed chart in Fig. 2). This region was chosen because it is situated within the boundaries of a Technological Free Zone (Zona Livre Tecnológica-ZLT) which is, in principle, subject to a close monitoring and oversight by the Portuguese Navy (PN), regarding fishing and boating activities. This allowed for the deployment of sensitive equipment in an, as much as possible, "controlled" environment.

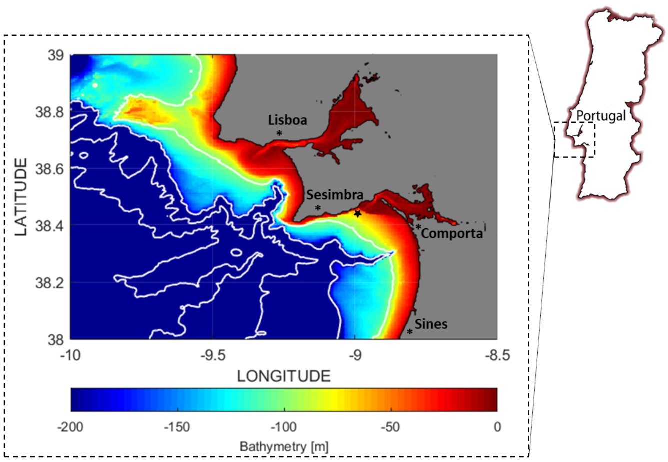



Fig. 1: *Bathymetry of the extended target area showing Sesimbra's region.*

### B. Detailed bathymetry

The bathymetry near Sesimbra is characterized by a diverse and dynamic underwater landscape. Its seabed features are a combination of sandy stretches and rocky outcrops. One prominent bathymetric feature near Sesimbra is the steep drop-off known as the Sesimbra Abyssal Plain. This underwater topographical element descends rapidly into deeper waters, offering a unique habitat for a variety of marine species. The Sesimbra Abyssal Plain is a crucial part of the local ecosystem, providing a transition zone for numerous marine organisms and contributing to the region's rich biodiversity and has gained attention for its potential in marine conservation efforts.

Figure 2 shows a detailed bathymetric view of the target area. It presents a very light slope, which varies between 15 m and 90 m water depth. Another important feature of the target area is the several underwater cables departing from Sesimbra to various destinations, which emphasizes the characteristics of this area for underwater cables' testing.

### C. Environmental characteristics and usual anthropogenic sources of noise

During the period of observation there were good weather conditions with air temperature 20 - 26º C, and a wind speed of 5 kn from northwest. The sea surface water temperature was at approximately 19.5º C. Fig. 3 shows the mean sound speed profile at the deployment location. Even if the target region is a protected area, its surroundings are one of the busiest regions of the Portuguese coast, usually frequented by fishing boats on their way to the port of Sesimbra. Also, the target area is an entering/exiting route to/from the busy industrial port of Setúbal, as shown in the shipping density map of Fig. 4, and is usually crossed by different ship types, such as cargo, container ships, and large fishing boats.

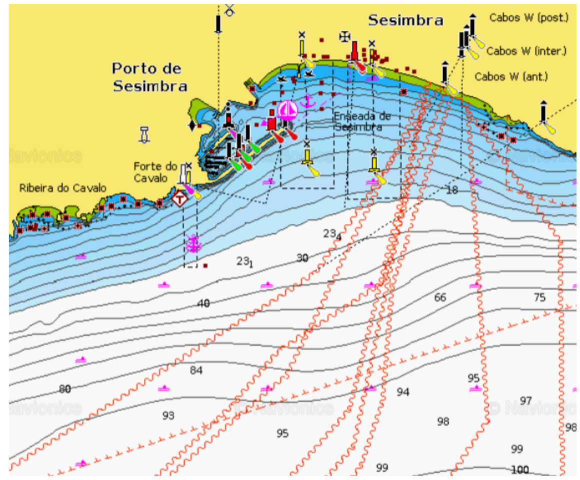



Fig. 2: *Bathymetry of the cable deployment area. Source: www.navionics.com*

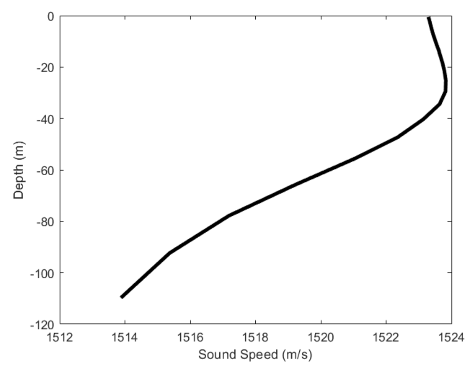



Fig. 3: *Mean sound speed profile at the cable nodes location.*

### D. Deployment and equipment used - Hydrophones

A land connected 2 km long telecommunication cable, equipped with three EON including their respective acoustic sensors, was deployed by the K2D project team with the naval means and support of the PN, as shown in Fig. 5. The EON where at approximately 500, 1000 and 2000 m from shore in 18, 36 and 87 m water depth, respectively. The three hydrophones have a sensitivity of -200 dB re 1$\mu$Pa, and a fixed gain of 40x followed by a programmable gain of 16x. All hydrophones were programmed with a 156250 Hz sampling

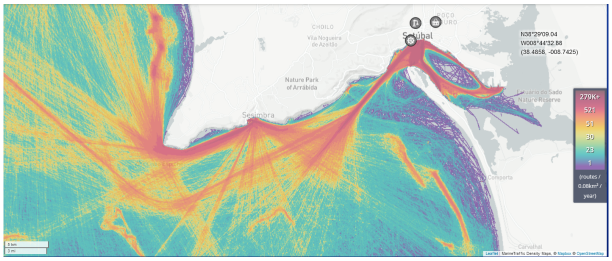


Fig. 4: *Shipping density in the target area, during the year of 2022. Source: www.marinetraffic.com*

rate for the recordings between September 6 and 10, that was then reduced to 78106 Hz in the remaining days, until September 23, 2023. In both cases, a 24 bits per sample and a file duration of 180 seconds were used (see details in [6]).


Fig. 5: *Experimental node deployment along the coast of Sesimbra, Portugal, from 6th to 23rd September, 2023.*

### *E. Acoustic data recording periods*

EON hydrophones started recording on the 6th of September 2023 at 22:00 and ended on the 23rd of September 2023 at 23:57. Fig. 6 shows a mapping of the hourly mean sound pressure level (SPL) for each time of the day for the whole recording period for nodes 1, 2 and 3 in plots (a) to (c), respectively. Blank areas denote periods with no data.

In general, node 1 presents the higher SPL along the recording period, followed by nodes 3 and 2 in decreasing order. This may be related to the fact that node 1 is located in a shallower area than the others and, therefore, might be impacted by noise generated by coastal traffic and boats reaching the port of Sesimbra. Fig. 6 shows that the sound level at the beginning of the recording period is the lowest of all nodes. Our belief is this is due to a higher surveillance of the PN during cable lay down operations and following cable checks, which might have compelled fishing and touristic boats to surround the area, with a consequent decrease of SPL received at the nodes. In all nodes, the period between 5 am and 17 pm showed the highest noise levels during the recording period. This can also be related to the fishing activity boat traffic that starts early in the morning and to the larger vessels

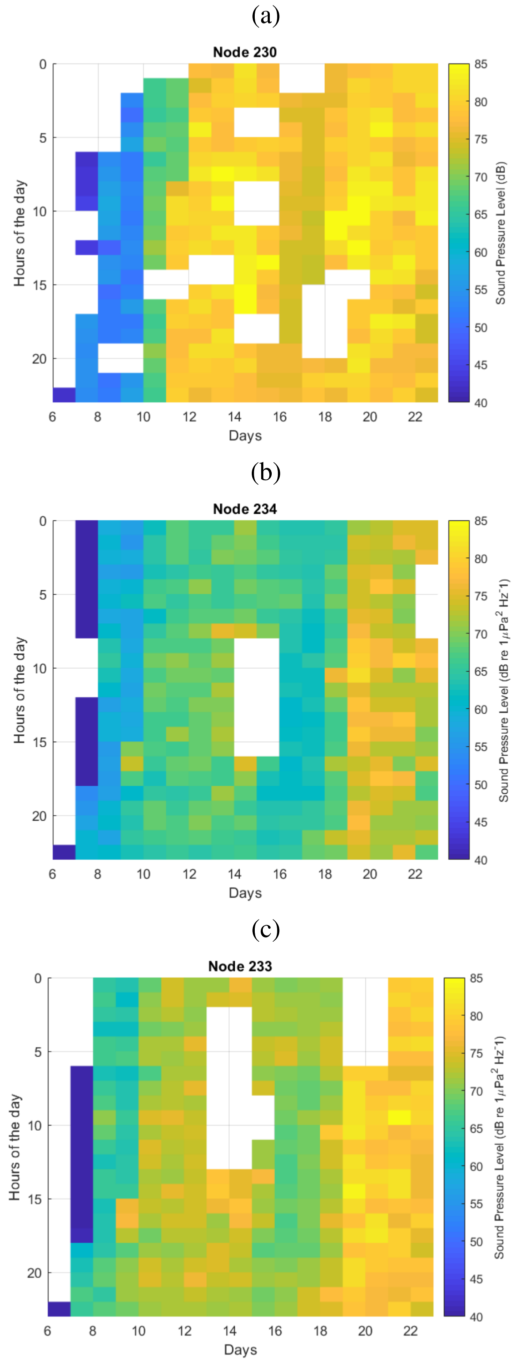



Fig. 6: *Hourly mean sound pressure level during the recording period in node 1 (a), node 2 (b) and node 3 (c).*

reaching the port early in the morning for loading/unloading. The recording period comprises two and a half weekends, and through the plots of Fig. 6, one can see a trend to have larger noise levels during the weekdays than during the weekend. This evidence lets us speculate that the activity of the port of Sesimbra is mostly work related rather than touristic activity-dominated. The exception is the last weekend of the recording period (23rd and 24th of September) during which, even if SPL

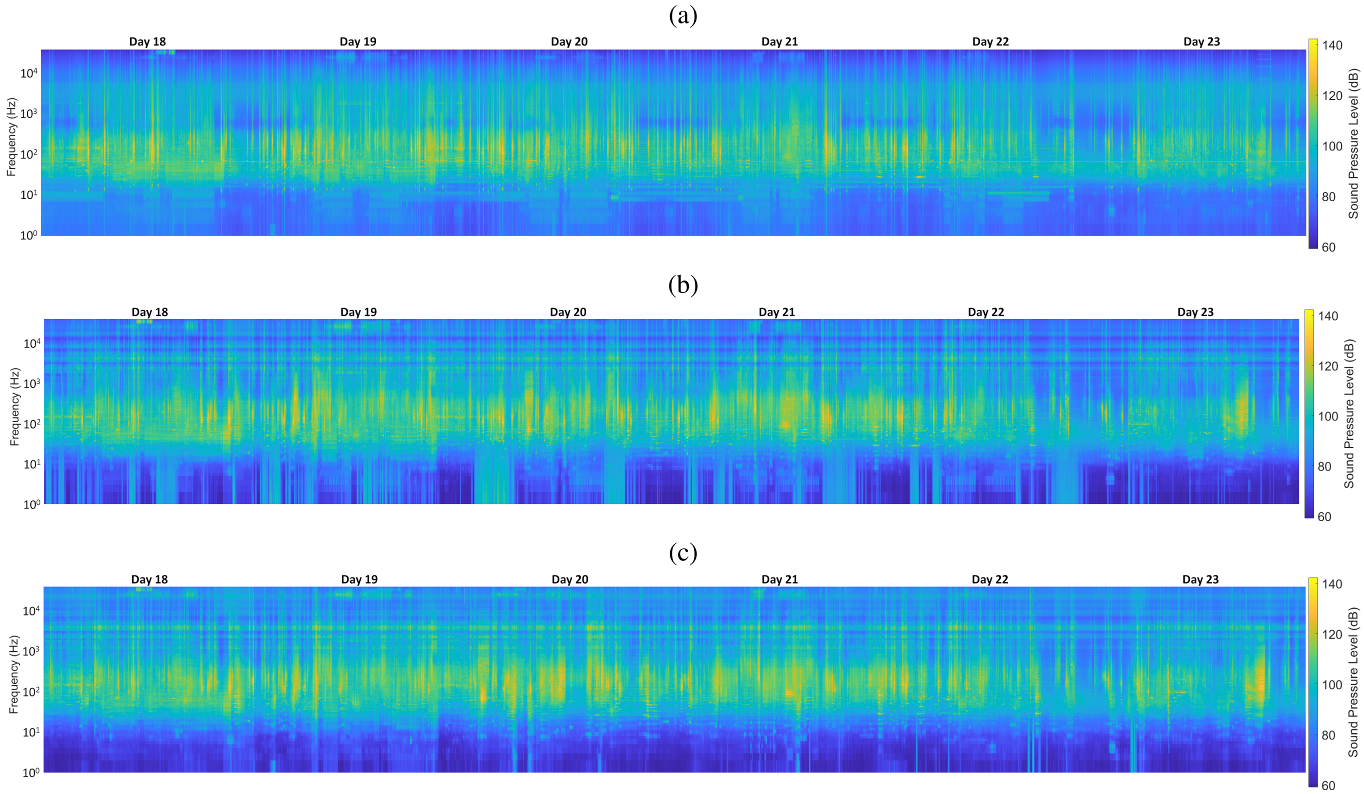



Fig. 7: *Spectrograms of node 1 (a), node 2 (b) and node 3 (c) between the 18th and 22nd of September 2023.*

decreases in node 2 and node 3, node 1 still shows a significant level comparable to that during the week days, indicating a high activity in the area. At the end of day 24, this activity may have been related to the breaking of the cable between node 1 and the land station.

## Results and Discussion

This analysis is divided into three different aspects. The first aspect gives a general overview of the acoustic data on each node; the second analyzes the data through two specific bands of interest; and the third divides and compares the analysis on diurnal/nocturnal periods. The frequency band and diurnal/nocturnal analyses are based on statistical indicators such as percentiles. This analysis uses the PAMGuide tool fully detailed in Merchant et.al [7] and adapted for the present work.

Figure 7 shows the spectrograms of the three nodes in the period of September 18 - 23, as an example. This period was chosen based on the non-recording interruptions observed. The spectrograms show higher sound pressure levels closer to shore (node 1) along the selected period, followed by node 3 and node 2. In all cases, the 65 Hz to 1 kHz is the most noise affected band. One of the particularities observed in the spectrograms is the identification of the periods where the vessels passed closer to the nodes, which were confirmed by the analysis of the correspondent raw data files. The other particularity is the fact that no biological signature is observed, although this region is known for abundant cetacean communities (pilot whales, among others). This may be due to the high ship traffic intensity registered, making it an unsuitable area for these species during that time period.

### *F. Baseline analysis*

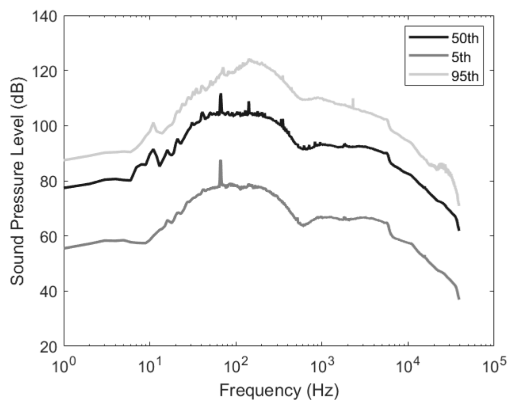
This section presents the baseline assessment for each node. The results in Fig. 8 show considerable differences in the baseline level among the nodes. For this study the baseline is defined as the median level or the level corresponding to the 50th percentile. As already mentioned, node 1 shows higher SPL levels along the analyzed frequency band, reaching a maximum of 105 dB. In decreasing order of SPL intensity, nodes 3 and 2 have the levels of 88 and 85 dB, respectively.

Figure 8 shows an attenuation slope below 80 Hz which is related to a high pass filter in the recording system and may preclude accurate analysis in that frequency band. The other important aspect of concern are the strong oscillations observed for frequencies above 1 kHz in nodes 2 and 3. It is also observed a number of isolated high intensity peaks in the frequency band 60 - 800 Hz in node 1, with smaller amplitudes in node 2, and even smaller in node 3, which are again possibly associated to constant coastal boat traffic.

### *G. Specific band analysis*

Anthropogenic noise sources, such as ships, usually produce noise emissions in the frequency band between 30 and 500 Hz

(a)

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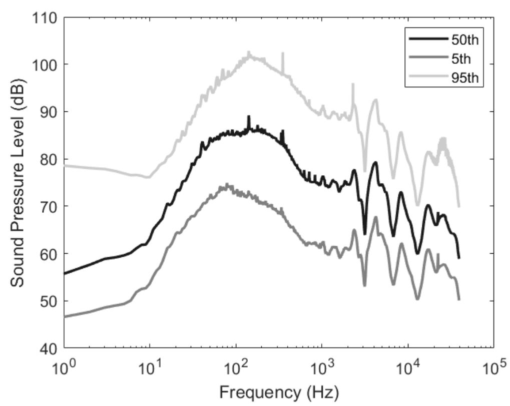



(c)

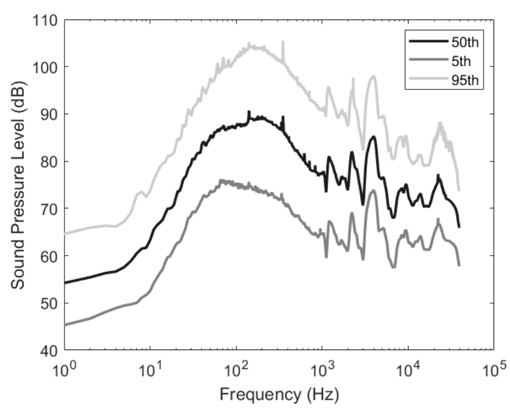



Fig. 8: *Baseline level and percentiles 5 and 95 for nodes: 1 (a), 2 (b) and 3 (c).*

reaching 1 kHz in some cases. Environmental related sound, such as that generated at the sea surface by the action of wind and waves, generally overlaps with shipping noise in the low end at 500 Hz and extends well beyond 1 kHz. Biological related sound covers a very wide band starting as low as 10 Hz and extending above 100 kHz for a few species. In our area the ocean sound spectrum will be dominated by shipping or boat related noise between say 100-800 Hz and then environmental and biological dominated above 800 Hz up to the band limit of 38 kHz.

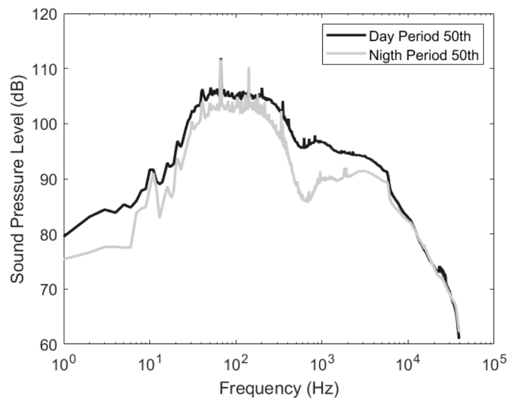
Considering the frequency band between 100-800 Hz one can notice that SPL is significantly higher in node 1 than in the other two nodes. In the first case, the noise level is centered between 95 to 105 dB. In the other two, the noise level is centered between 78 and 85 dB for node 2 and between 88 and 98 dB for node 3. Also, in this analysis, it is possible to see a number of peaks at isolated frequencies, denoting tonal components associated with single ships with significant presence in the area. There is a clear inflection point at approximately 800 Hz, that is clearer on node 1 than in the other two nodes. There is a clear change of regime (or noise generation mechanism) below and above 800 Hz.

In the higher frequency band, above 800 Hz, SPL measured in node 1 shows a slight increase followed by a plateau until approximately 5 kHz. The reason for this behavior is unknown but, excluding wind noise because of the low wind conditions, we speculate that it might be due to a mix of speed boats near the coast and biological sound generated in the coastal rocks. Above 5 kHz the SPL curves show a progressive normal decrease up the frequency limit. Nodes 2 and 3 show strong SPL oscillations above 2 kHz for node 2 and above 1 kHz for node 3, with an almost constant mean value up to the band limit. It is possible that this behavior is due to a recorder malfunction. No clear marine mammal associated vocalization was found during the recording period.

### *H. Diurnal/Nocturnal data analysis*

This section presents a diurnal/nocturnal analysis performed along the three nodes. The diurnal period was considered between 07:00 and 19:00 of each day. The remaining time was considered nocturnal. Fig. 9 shows each node's diurnal/nocturnal SPL comparison. The comparison between day and night periods shows a small SPL difference with the diurnal period showing higher levels than the nocturnal ($\approx$ 10-15 dB difference). This difference is approximately the same for all nodes. The difference observed could be related to the higher coastal speed boat or fishing-associated traffic during the day than during the night, which is also justified by the fact that the largest difference is observed in the frequency band between 800 to 1400 Hz in node 1 (a). Usually, small boats, as the ones used for coastal fishing, may emit at higher frequencies than larger boats or ships, which may justify this difference. In node 2 (b), this difference in this frequency interval is also observed, even though it is less accentuated. In node 3 (c), the difference between day and night periods is more or less constant along the whole frequency band. There are several SPL peaks with variable intensity at various frequencies, specially in node 1 and 2, during the night period. Again, although forbidden in this area, a trawler operating at low speed in the area during the night might generate these tonal components.

(a)

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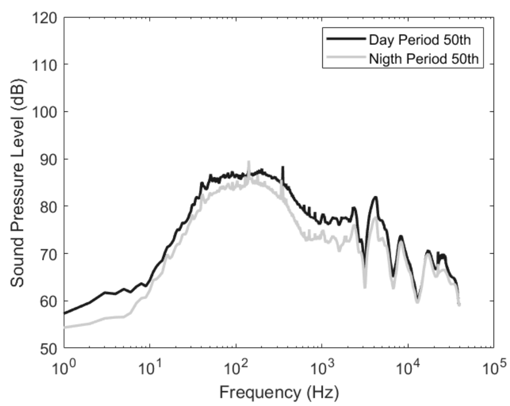


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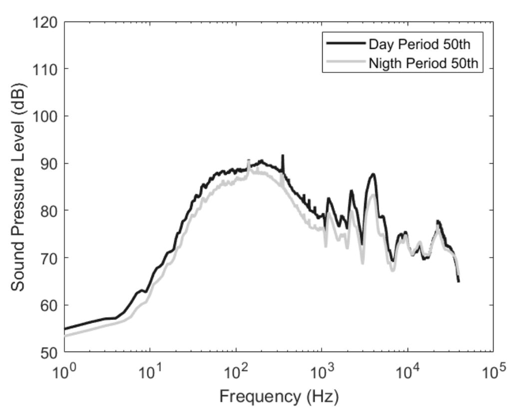


Fig. 9: *Day and night baseline comparison for nodes: 1 (a), 2 (b) and 3 (c).*

## CONCLUSIONS AND FUTURE WORK

Soundscape analysis is an important step into understanding and characterizing human and biological activities at sea and is of major importance to protect marine species. The sea experiment that took place during the K2D project in Sesimbra, Portugal, intended to evaluate the potential of an extended SMART-cable concept for, among others, estimate the ocean soundscape. The experiment took place in a limited coastal area during a three week period in September 2023.

The results showed that node 1 - the closest to shore - presents the higher sound levels; on the contrary, node 3 - the most further away from the coast - has the lower levels. It can be speculated that this is mainly related to fishing and coastal boating activities taking place close to shore, which is also corroborated by the fact that recorded sound levels are in agreement with the frequency bands normally associated with these boat types and that significant level differences were measured between day and night periods. Usually, anthropogenic noise sources are centered in lower frequency bands, say, between 30 and 1000 Hz, which is also a frequency band that encompasses shipping noise. On the other hand, biological sources of noise, as for example, marine mammals, may produce sounds that reach 10 kHz and above. During the recordings, no biological signature could be found, which may be a consequence of absence of animals due to the heavy ship's presence in the area during the experiment. Another possibility is that those signatures could not be observed due to a suspected malfunction of nodes 2 and 3 in the frequency band above 1 kHz.

High fidelity recording of underwater acoustic signals over a large band (e.g. 5 Hz to 50 kHz) is a relatively complicated task due to sound level and signal dynamics. A solution often adopted to circumvent this issue, encompasses the usage of separate hydrophones for different frequency bands with the appropriate filters and gains. Alternatively, the same hydrophone may be used with two frequency bands recording at alternate times with different gain and sampling frequencies.

## ACKNOWLEDGEMENTS

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