



JUMP

***Joint Action: a stepping-stone for underwater noise
monitoring in Portuguese water***

***Deliverable 3.2- Background noise levels of
Portuguese waters***

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1 EXECUTIVE SUMMARY

In this study, the background marine noise levels of the Portuguese coast were measured and determined at two different sites of economic, marine biodiversity and conservation importance: the coastal area around Aveiro and the outer zone near the Ria Formosa. The measurements of noise levels were carried out with a monitoring program based on acoustic snapshots and during different seasons, winter/autumn, and spring/summer. Two different underwater noise measurement systems were employed: a bottom mounted system (consisting of 3 PAM stations) and a surface-based system.

A total of 199 acoustic recordings of background noise were collected during the snapshots. The ambient noise levels of the acoustic recordings were obtained through the broadband sound pressure levels (SPL), the power spectral density (PSD) and the sound levels in the two third-octave bands (TOL) recommended by the Marine Strategy Framework Directive (MSFD) for underwater noise monitoring: 63 Hz and 125 Hz.

The background noise levels varied among the two sampling sites, seasons, PAM stations and acoustic measurement systems. Although different types of noise sources, both of natural (physical and biological) and of anthropogenic origin, characterized the acoustic soundscape of the two sampling sites, the dominant sounds were from human-generated sources.

SUMÁRIO EXECUTIVO

Neste estudo foram medidos e determinados os níveis de ruído ambiente na costa portuguesa em dois locais diferentes de importância a nível económico, da biodiversidade marinha e da conservação: na zona costeira de Aveiro e ao redor da Ria Formosa. As medições dos níveis de ruído foram efetuadas através de um programa de monitorização baseado em *snapshots* acústicos e durante diferentes estações do ano, no Inverno/Outono e na Primavera/Verão. Foram utilizados dois sistemas diferentes de medição do ruído subaquático: um sistema fixado ao fundo (constituído por 3 estações PAM) e um sistema com base na superfície.

Um total de 199 gravações acústicas de ruído ambiente foram recolhidas durante os *snapshots*. Os níveis de ruído das gravações acústicas foram obtidos através dos níveis de pressão sonora (SPL), da densidade espectral de potência (PSD) e dos níveis sonoros nas duas bandas de terceira oitava (TOL) recomendadas pela Diretiva-Quadro Estratégia Marinha (DQEM) para a monitorização do ruído submarino: 63 Hz e 125 Hz.

Os níveis de ruído ambiente variaram entre os dois locais de amostragem, de acordo com as estações do ano, entre as estações PAM e entre os dois sistemas de medição acústica. Embora diferentes tipos de fontes de ruído, tanto de origem natural (física e biológica) como antropogénica, tenham caracterizado a paisagem acústica dos dois locais, os sons dominantes provieram de fontes de origem humana.



2 INTRODUCTION

Underwater noise has increasingly become a concern for environmental and scientific organizations due to the growing pressure from anthropogenic activities in the ocean, including resource exploration, extraction operations, commercial and military use of sonar, maritime traffic, and leisure boating (Brooker & Humphrey, 2016; Soares et al., 2019). Different studies have shown that underwater noise pollution can have a significant impact on marine organisms across taxa (Halliday et al., 2017; Soares et al., 2019; Duarte et al., 2021). Although distinct sources contribute to background noise levels in the ocean, shipping is considered the most globally significant noise contributor, since the dominant noise source of lower frequencies (between 20 to 200 Hz) is usually from engines and propellers of merchant ships which propagates very efficiently in the marine environment (Hildebrand, 2009). In fact, recent studies indicate an increase in noise levels from shipping (McDonald et al., 2006; Hatch et al., 2008; McDonald et al., 2008; McKenna et al., 2012). In addition, several other sources can potentially intensify loud sounds in the marine environment, namely, seismic air guns used in seismic exploration, sonars, pile driving, and power-generating wind turbines in shallow waters (Popper et al., 2003; Soares et al., 2019).

Underwater sound is a major habitat feature for sea organisms, especially for those that depend on sound for navigation, communication, and detection of prey, predators, and conspecifics (Halliday et al., 2017). Short- or long-term anthropogenic noise exposure can cause different effects in these animals, for example, physiological stress, auditory masking, behavioral changes, and temporary or permanent hearing loss in marine mammals and fish (McCauley, Fewtrell & Popper, 2003; Popper et al., 2003; Nowacek et al., 2007; Jensen et al., 2009; Rolland et al., 2012). Anthropogenic noise sources can drive animals out of critical habitat areas or even lead to changes in the efficiency of their hearing response or the emissions of their vocalizations (McDonald et al., 2008; Soares et al., 2019). Monitoring underwater noise in different ocean environments can provide information about changes in noise levels over time, as well as a baseline for changes in the future. Therefore, it is important to document shifts in ocean noise to understand the current status of the sea environment and to help with the conservation of marine species (McDonald et al., 2008).

In Portugal there are increasingly more human activities at sea, such as industry, shipping, fishing, tourism and recreation activities (Soares et al., 2019). However, there is no systematic monitoring of underwater noise in Portuguese waters. Thus, the jUMP project, aimed to represent a stepping-stone for monitoring underwater noise in Portugal. The main goals of this project include developing catalogues with background information, the systematic assessment of underwater noise levels, implementing sound propagation models and promoting the discussion of underwater noise monitoring in Portugal.



In order to contribute to the sustainable management of background noise, a monitoring program based on acoustic snapshots was carried out along the Portuguese coast at two different sites and seasons: the coastal area of Aveiro and the outer zone of Ria Formosa during winter/autumn and spring/summer. The selection of these sites was based on their proximity to relevant ports, geographical remoteness and importance for marine biodiversity and conservation. Both areas support several anthropogenic activities such as shipping, aquaculture, fishing activities, salt production, sediment mining and shellfish harvesting (Dias, Lopes & Dekeyser, 1999; Soares et al., 2019). Therefore, they are of great economic value at a regional and national level. Additionally, these two sites support a great diversity and density of marine organisms such as different species of invertebrates, fish, seabirds, and cetaceans (Gomes, 2015; Soares et al., 2019).

The majority of these human activities are sustained through local boat traffic, which consists of passenger, fishing and recreational vessels, sailboats running on motors, as well as smaller boats with on-board or outboard engines (Soares et al., 2019). Hence, boat traffic can be quite intense in these two areas throughout some seasons of the year, raising concerns on the impacts of underwater noise on marine fauna. Small vessels with on-board or outboard engines radiate most acoustical energy in the frequency range of 0.1 to 5 kHz and can reach source levels near 200 dB re 1 μ Pa (Hildebrand, 2009; Halliday et al., 2017). These levels can mask significant acoustic signals and disturb the behaviour of several fish and cetacean species (Halliday et al., 2017; Soares et al., 2019).



3 MATERIALS AND METHODS

3.1 STUDY AREA

Measurements of background noise levels were conducted on the Atlantic northwest and south coast of Portugal around the Nature Reserve of Dunas de São Jacinto, located in Aveiro, and near the Armona Island, situated in Algarve, Ria Formosa (Figure 1). The Natural Reserve of Dunas de São Jacinto is an area inserted in Ria de Aveiro, a coastal lagoon intended for the protection of biodiversity as well as natural habitats (Dias, Lopes & Dekeyser, 1999). Ria Formosa is a coastal mesotidal lagoon that supports a great variety and abundance of fish species, particularly juvenile populations of commercially important species. This lagoon has an extension of 18,400 hectares and covers 60 km with six islands, including Armona Island (Soares et al., 2019). Besides the Ria Formosa being one of the two multiple inlet systems of European coasts, it was also considered in 1987 as a natural park.

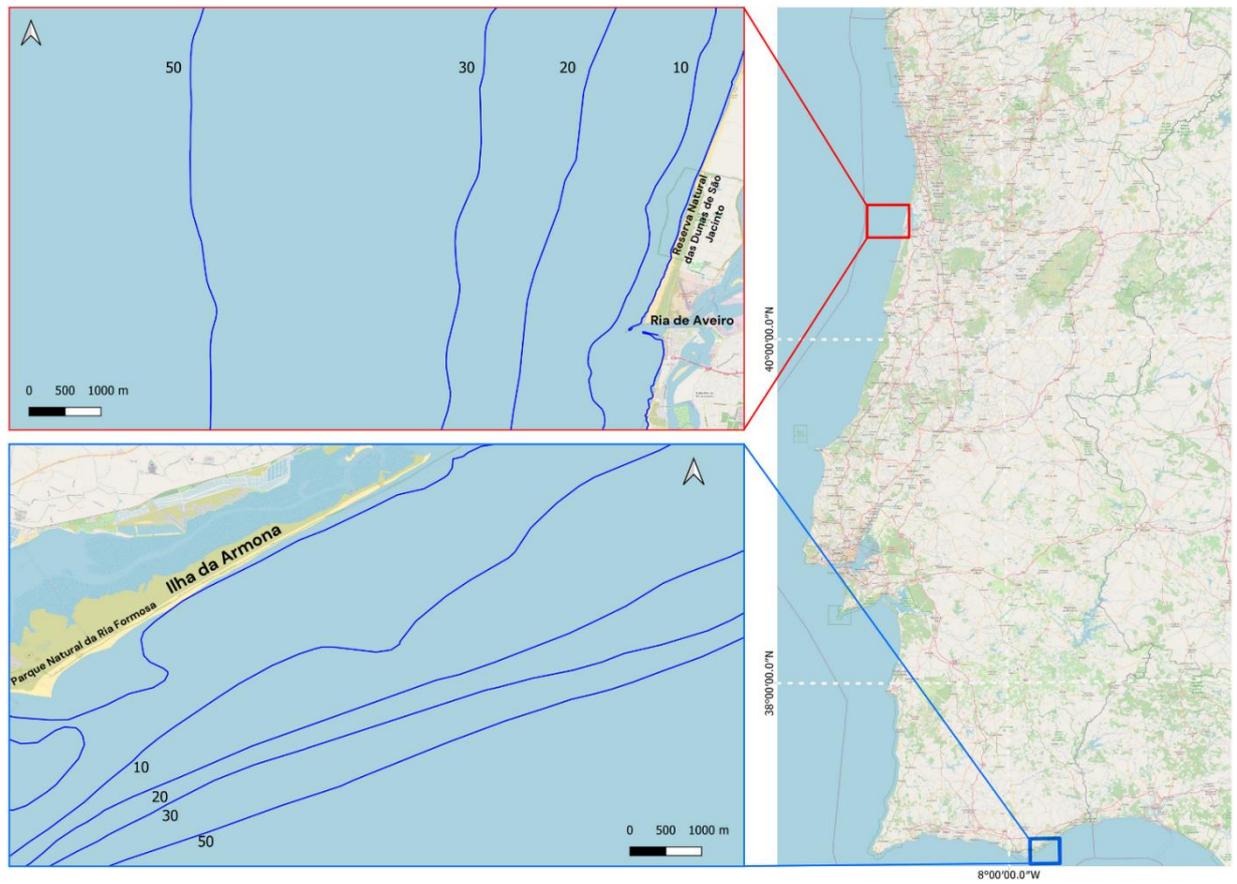


Figure 1. - Study area with the respective bathymetric lines (between 10 and 50 m). Top panel - Aveiro, Bottom panel – Algarve.



3.2 DATA COLLECTION

To monitor underwater noise, a total of 4 snapshots (two in Aveiro and another two in Algarve) were carried out between March 16th and September 29th, 2021. Two different noise measurement methods were employed: a bottom mounted system consisting of three Passive Acoustic Monitoring (PAM) stations and a surface-based system. In addition, underwater signal emissions at different distances from the PAM stations, as well as salinity and temperature profiles were performed.

For all measurements, GPS positions were registered using a portable GPS (Garmin Foretrex 301). Positions were taken at the deployment and retrieval of PAM stations; at the salinity and temperature profile sites; and at the signal emissions and in acoustic measurements made with the surface-based system. An anemometer device (HoldPeak® HP-866B-APP) was used to measure wind speed.

3.2.1 EQUIPMENT

Each PAM station consisted of a single acoustic ST-300 HF SoundTrap (Ocean Instruments, Auckland, New Zealand) autonomous recorder attached to the seabed by ballasts and a sub-surface buoy connected to an anchored surface buoy (Figure 2). The ST300-HF are self-contained digital sound recorders with a sensitivity of -203 ± 3 dB re V/ μ Pa, a frequency range of 20 Hz-150 kHz and low self-noise level (30 dB re 1 μ Pa/Hz).

Data were sampled at 192 kHz and 16-bit recording continuously in 5min segments every hour for the experimental snapshot and every 10 min for the following snapshots. Underwater noise data was recorded by the system during the deployment period, and after its recovery, data was downloaded in wav format for storage and processing.

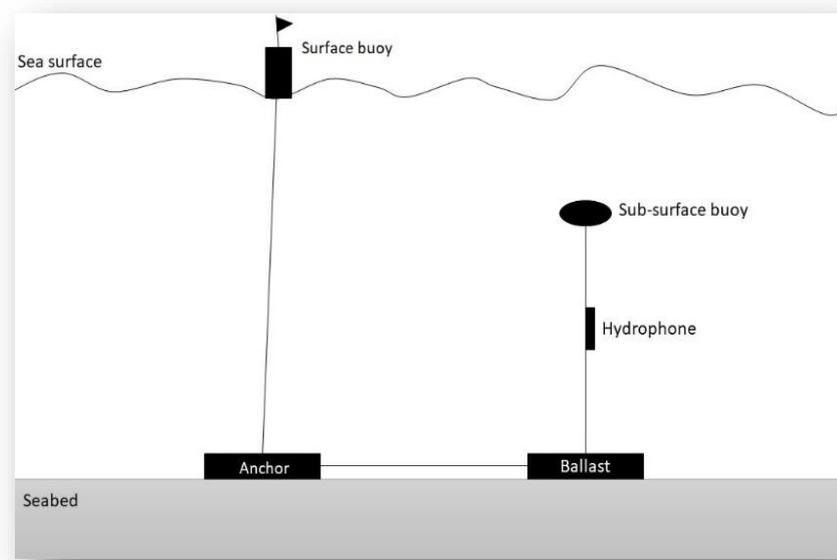


Figure 2. - Configuration of each PAM station.

Ambient noise measurements were also carried out using a surface-based system deployed from a drifting platform (a vessel). A factory-calibrated Cetacean Research Technology hydrophone (model C55) recording system was used, with effective sensitivity of -165 dB re 1 V/ μ Pa, frequency response of $\pm 3/20$ dB in the 0.006-203 Hz band and in the 0.009–100 kHz band. This acoustic sensor was connected by a 10 m cable to a digital recorder (Fostex FR-2).

Recordings with the surface-based system were made with 90s duration and with a sampling rate of 192 kHz and 24-bit resolution. All digital recordings were stored on Compact Flash memory cards as time-stamped wav files for subsequent signal analysis.

The underwater signal emissions were played back with an underwater speaker (LL-1424HP, Lubell Labs, Columbus, US) from a laptop. This device has a frequency response of 200 Hz-21 kHz, and a nominal impedance of 8 ohms. Playback sound file consisted in 30 seconds pulses of different frequency signals (63 Hz, 125 Hz, 250 Hz, 500 Hz, 2000 Hz and 10000 Hz), with a total duration of approximately 6 minutes. All sound samples were created in the software Audacity.

Salinity and water temperature profiles were measured throughout the day in several moments with a multiparameter probe: CTD 48 (Conductivity, Temperature and Depth) that reaches up to 2000 m depth and has Standard sensors (Sea & Sun Technology GmbH, Germany).



3.2.2 EXPERIMENTAL SNAPSHOT

The three PAM stations were deployed at different depths (20, 30 and 50 m) in the coastal area off Aveiro during winter, on March 16th (Figure 3). Each system was attached to the seabed by anchors and ballasts, according to the water column depth: the systems deployed at 20- and 30-m depth, had 15/16 kg ballasts while the system at 50 m depth had a 20 kg ballast. In addition, 3 kg anchors were used in all systems.

Underwater signal emissions were conducted at different sites according to the distance from the hydrophone located at 50 m depth (1, 3, and 5 km, Figure 3). Additionally, another playback broadcast was made at approximately the same distance from all PAM stations (± 7 km, Figure 3). Acoustic measurements of background noise with the surface-based system were made at the same locations as underwater signal emissions (Figure 3).

The CTD profiles were carried out at several locations: at the deployment of each PAM station; before the signals' emissions; and at the end of the day, before hydrophone recovery.

Since the field conditions at the selected sites for the emissions did not allow for good visibility in the hydrophones area, the planned monitoring every 5 minutes did not occur.

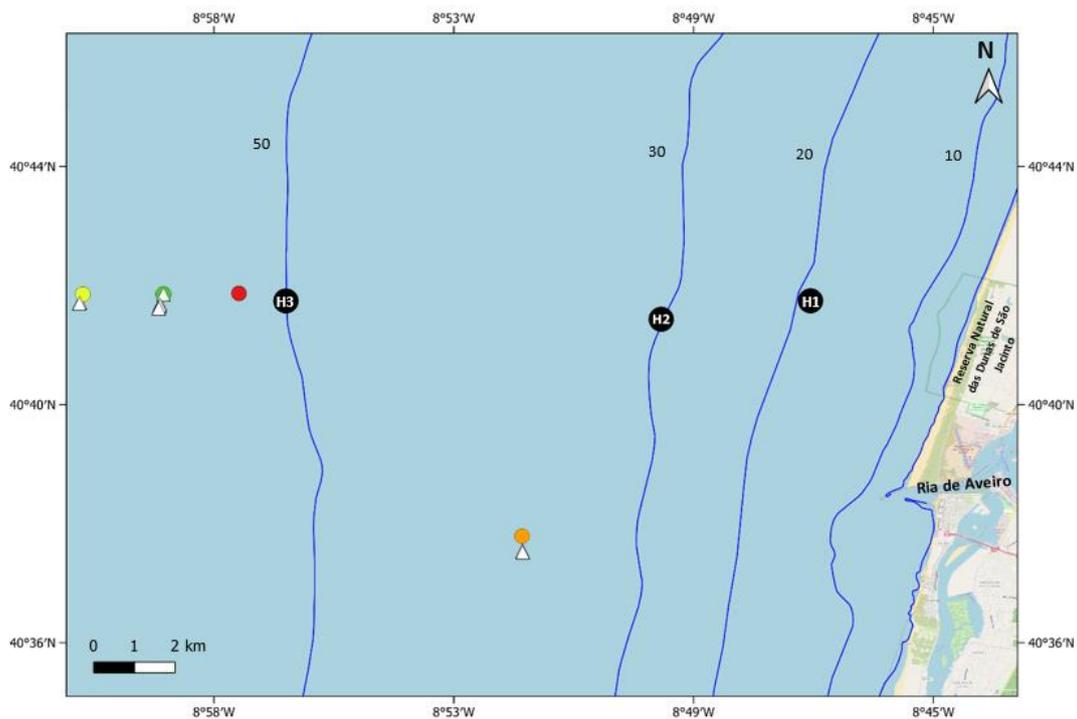


Figure 3. - Deployment of the three PAM stations (H1, H2 and H3) and the respective underwater signal emissions at different sites (circles: Red - 1 km; Green - 3 km; Yellow - 5 km and Orange - ± 7 km). Positions of the acoustic measurements obtained with the surface-based system (white triangles) (SNIG, 2010).



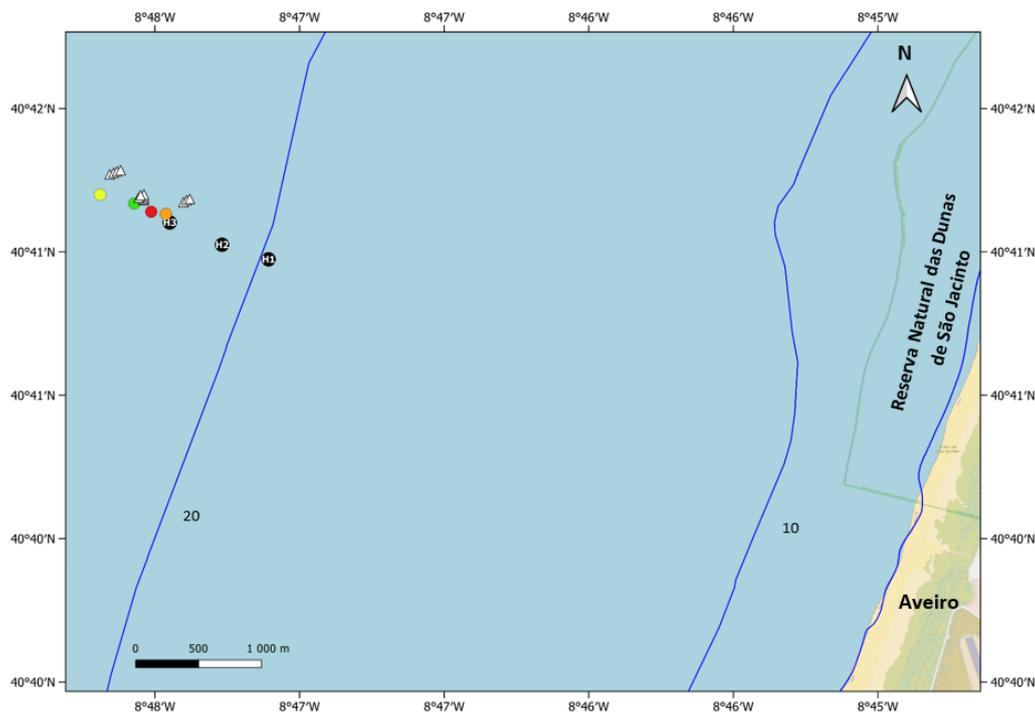
3.2.3 SNAPSHOTS

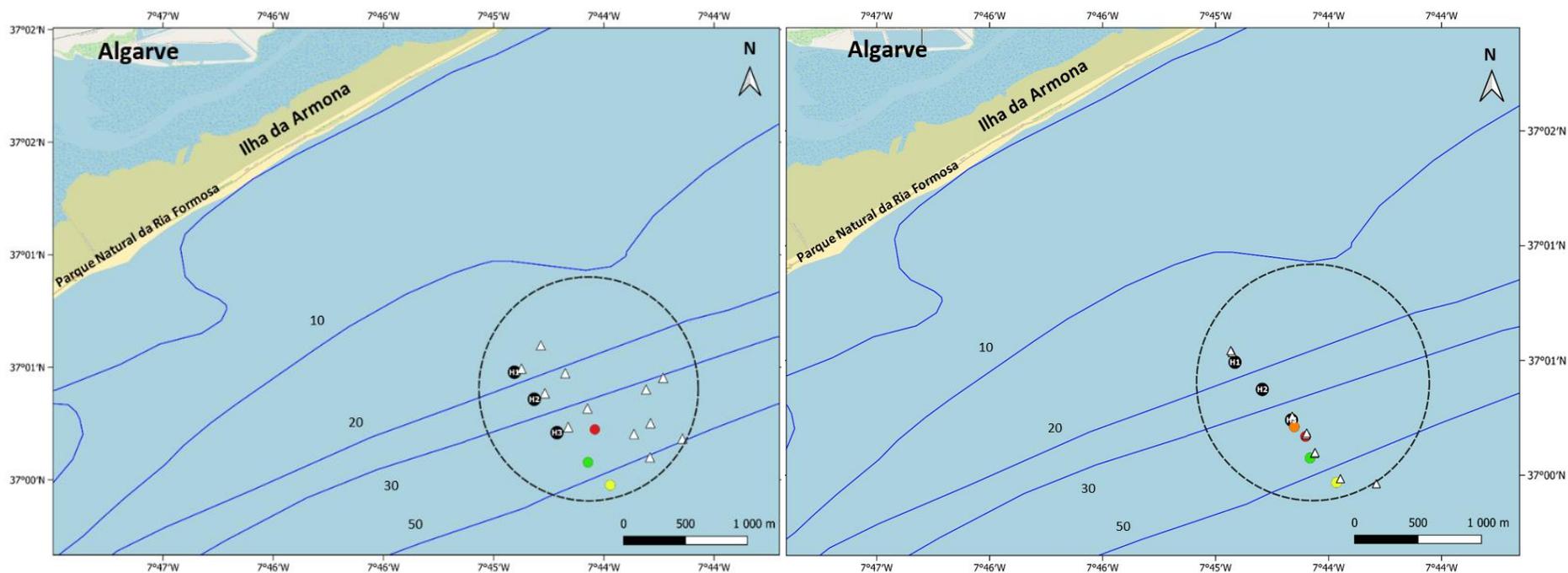
Following the experimental snapshot, further data collection was carried out in Aveiro in summer (Figure 4), on July 2nd, and at the Algarve coast in spring (Figure 5) and autumn (Figure 6), on May 14th and September 29th, 2021. For these snapshots the distance between the hydrophones and the underwater signal emissions was reduced to minimize the travel time and allow the observation of the PAM stations area.

Therefore, the PAM stations were deployed at a depth of ± 20 meters (H1) and at 250 m from this point (H2 and H3). The hydrophones H2 and H3 were deployed at ± 30 m and 40 m depths in Algarve (Figure 5 and 6), while in Aveiro they were installed at ± 23 m and 25 m depths (Figure 4). The systems were attached to the seabed by anchors and ballasts, according to the depth of the water column. The hydrophones position in relation to the seabed also varied according to the sampling sites: all hydrophones were positioned at 8 m from the seafloor in Aveiro, while in Algarve, only the H1 was deployed at the same depth; H2 and H3 were positioned at 10 and 15 m from the sea bottom.

Regarding underwater signal emissions, these were conducted at different sites (at ± 50 , 100, 250, and 500 meters) in relation to the hydrophone deployed at a greater depth (Figures 4, 5 and 6). The acoustic measurements using the surface-based system and the CTD profiles were carried out at the same locations as mentioned previously.

The areas surrounding PAM stations and the sites where signal emissions took place were monitored frequently. Several anthropogenic noise sources and different marine species were recorded in these areas.





Figures 4, 5 and 6. - Deployment of the three PAM stations (H1, H2 and H3) in Aveiro (top) and in Algarve during spring (left) and autumn (right). Positions of the underwater signal emissions (circles: Orange - ± 50 m; Red - ± 100 m; Green - ± 250 m and Yellow - ± 500 m) and the acoustic measurements obtained with the surface-based system (triangles) (SNIG, 2010). The dotted line corresponds to a Fisheries Restricted Area.



3.3 ACOUSTIC DATA ANALYSIS

The background noise levels of the acoustic recordings collected were obtained through the broadband sound pressure levels (SPL), the power spectral density (PSD) and the sound levels in the third-octave bands (TOL). The values of these metrics were processed and calculated in RStudio software (R Core Team, 2018) by adjusting the code (Hamming window, 8192 points of recording length and 50 % overlap, 1 second time window) that was available in a previous study (Merchant et al., 2015). The Welch method, which estimates the signal power at different frequencies, was applied to process these metrics as in previous studies (Merchant et al., 2012 and 2015). For the metrics computation of the recordings obtained by the PAM stations, the recordings conducted at deployment and recovery of the systems were discarded (usually the first and last recordings). In the case of acoustic measurements carried out with the surface-based system, the recordings where the hydrophone was not calibrated were excluded.

The average values of SPL were calculated to determine the variation of the sound level along the acoustic recording duration. Regarding TOL sound levels, the average values were also estimated for the two third-octave bands recommended by the Marine Strategy Framework Directive (MSFD) for underwater noise monitoring: 63 Hz and 125 Hz (Van der Graaf et al., 2012). As for the PSD values, they were plotted on Spectral Probability Density (SPD) graphs and calculated for frequencies ranging from 10 Hz to 100 kHz. This frequency range covers not only the MSFD frequencies (63 Hz and 125 Hz) but also the vocalizations of different marine species such as fish and cetaceans (May-Collado & Wartzok, 2008; Romagosa et al., 2017; Soares et al., 2019; Vieira et al., 2021).

The acoustic recordings were also analysed in Raven Pro 64 1.4 program (Cornell Lab of Ornithology, Ithaca, NY) to assess whether sounds identified in the recordings were of anthropogenic or natural origin. To proceed with this analysis, the recordings were down-sampled from 192 kHz to 8 kHz.

4 RESULTS

A total of 199 acoustic recordings of ambient noise were collected during the snapshots (144 with the bottom mounted systems and 55 with the surface-based system; Table 1). In the experimental snapshot, recordings were only obtained for one hydrophone (H1). These acoustic measurements were collected every hour, while the second snapshot obtained recordings in 10-minute samplings.



Table 1: Recordings collected with the two different underwater noise measurement methods during all snapshots and at different sites

Snapshots	Date	Number of PAM station recordings (H1, H2, H3)	Number of recordings with the surface-based system
Experimental - Aveiro	16/03	7	9
2nd - Algarve	14/05	20; 17; 16	14
3rd - Aveiro	02/07	16; 15; 13	17
4th - Algarve	29/09	16; 13; 11	15
Total	-	144	55

4.1 AUXILIARY DATA

During acoustic data collection, different marine species were observed in the PAM stations area, such as seagulls, northern gannets (*Morus bassanus*), and short-beaked common dolphins (*Delphinus delphis*). Additionally, several sources of anthropogenic noise were recorded near the hydrophone sites, including fishing boats (trawlers), commercial ships, tugboats, and recreational vessels (sailboats, vessels with outboard engines and motorboats). In Algarve, aquacultures of tuna, gilthead seabream and mussels were also sighted, as well as vessels supplying nourishment to these fish farms.

Wind speed data was obtained for all the snapshots, at different times of the day, (Table 2). The data collected showed that wind was more intense in the first snapshot conducted in Aveiro and during winter. On the other hand, the snapshot presenting the lowest wind speed values was the last one, carried out in Algarve during the autumn (Table 2).

Table 2: Average wind speed during the snapshots. The numbers in brackets represent minimum and maximum values.

Date	Wind Speed (m/s)
16/03	5.0 (1.3-7.4)
14/05	3.2 (1.8-4.0)
02/07	1.1 (0.4-1.8)
29/09	1.0 (0.4-1.7)



In addition to wind speed, data obtained from water temperature and salinity profiles showed that mean water temperature varied between 13.91°C and 15.74°C (Figure 7) and the average salinity ranged from 35.13 PSU to 36.01 PSU (Figure 8). Data from the CTD profiles obtained in the last snapshot, carried out in Algarve on September 29th, could not be downloaded.

Through the CTD profiles it was also possible to calculate the average sound speed values that varied between 1504.0 (m/s) and 1510.4 (m/s). The profiles conducted in Aveiro had the lowest mean values while those carried out in Algarve showed the highest average values of sound speed.

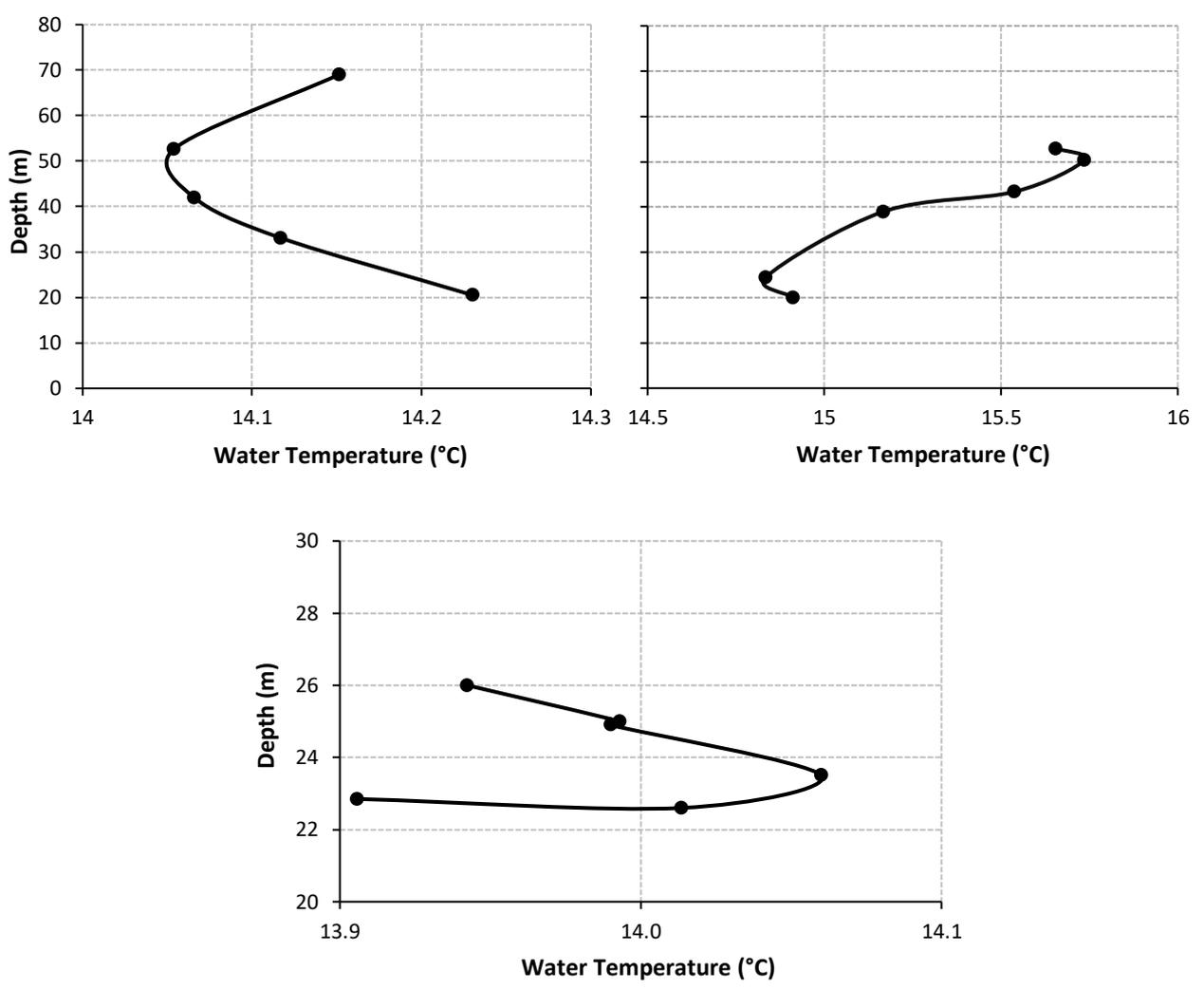
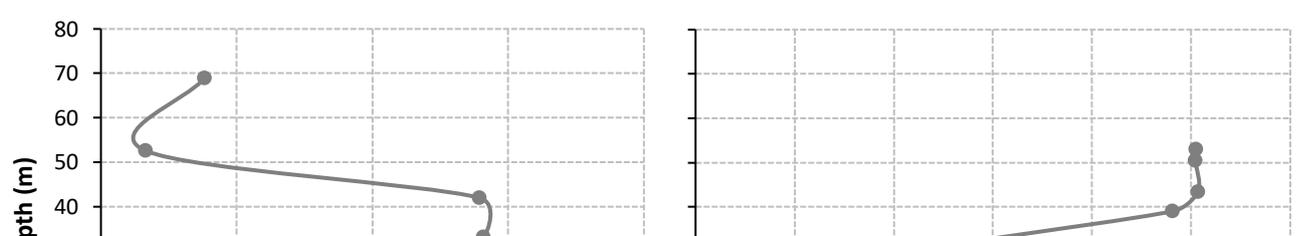


Figure 7- Average water temperature values registered in Aveiro during the winter (top left), in the summer (bottom) and in Algarve during the spring (top right) according to the site depth.



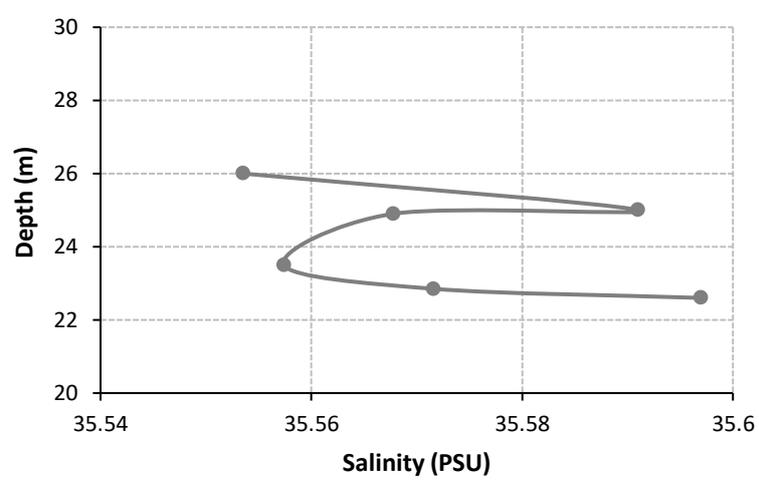


Figure 8- Mean salinity values recorded in Aveiro during the winter (top left), in the summer (bottom) and in Algarve during the spring (top right), according to the site depth.

4.2 BACKGROUND NOISE LEVELS

To evaluate and compare the ambient noise levels among snapshots, mean values of the broadband sound pressure levels (Figure 9 and Table 3), power spectral density (Figures 10, 11 and 13) and the levels in the third-octave bands (Figure 12) were analysed. These analyses were conducted for the acoustic recordings obtained with the two different methods: the bottom mounted systems (PAM stations) and the surface-based system.

4.2.1 PAM STATIONS

The background noise values determined varied between the sampling sites and according to the PAM stations and seasons (Figures 9, 10, 11 and 13).

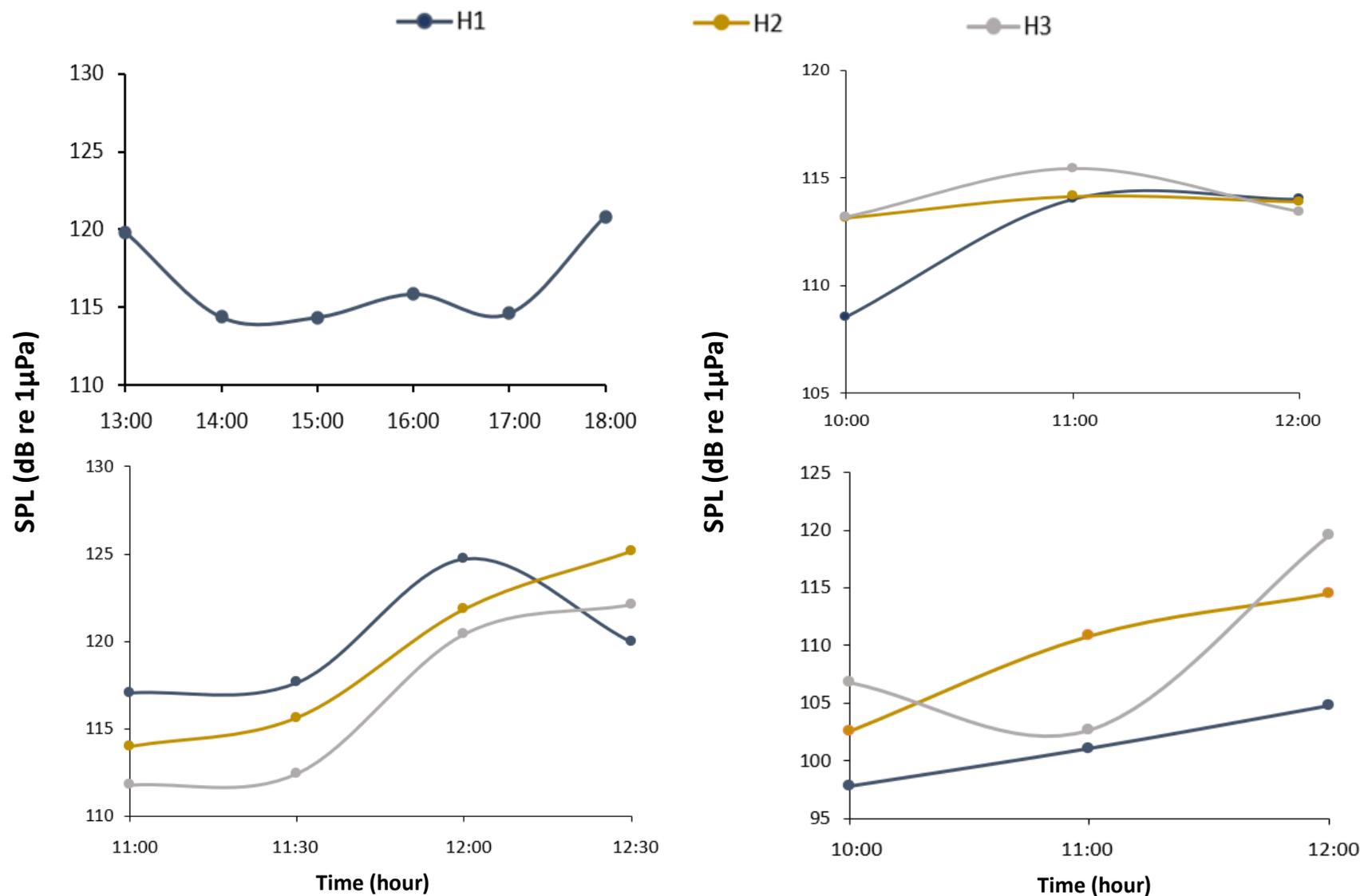


Figure 9- Average broadband sound pressure levels (SPL) recorded over the snapshots in Aveiro (top) during winter (left) and summer (right) and over the snapshots in Algarve (bottom) during autumn (left) and spring (right).



For the snapshots carried out in Aveiro, higher average SPL values were obtained in winter (from 114 to 121 dB re 1 μ Pa) for the hydrophone deployed at a shallower depth (H1). In summer, the hydrophone deployed at a greater depth (H3) had the highest mean SPL level (115 dB re 1 μ Pa), while the H1 obtained the lowest mean SPL value (109 dB re 1 μ Pa).

In Algarve, the highest noise levels were measured in the autumn (between 111 and 125 dB re 1 μ Pa; Figure 9). In this season, the lowest overall SPL values were obtained for H3 (112-122 dB re 1 μ Pa) while the highest mean SPL value was recorded for H2 at 12:30 am (125 dB re 1 μ Pa). For the snapshot carried out in spring, the hydrophones H2 and H3 had the highest noise levels (from 103 to 115 dB re 1 μ Pa and 107 to 120 dB re 1 μ Pa), while the hydrophone deployed at a shallower depth (H1) presented the lowest noise levels (between 98 and 105 dB re 1 μ Pa, Figure 9).

When comparing the average SPL values between the two sampling sites, the Aveiro snapshot during summer showed the lowest results. The highest results were obtained in Algarve during autumn and this sampling site presented more variability in background noise levels (Figure 9).

As for the PSD values displayed in Spectral Probability Density plots (Figures 10 and 11) the snapshots conducted in Aveiro obtained in general higher values at frequencies between 100 to 1000 Hz.

For the data collected in Aveiro, the snapshot carried out during winter presented higher PSD values at the lowest frequencies (between 10 Hz and 100 Hz) in relation to the H1 of the snapshot conducted in summer (Figure 10). Differences were also found in the noise levels between the hydrophones deployed in the summer. For instance, the H3 had higher noise levels at both the lower frequencies (from 10 to 100 Hz) and the higher frequencies (between 10 kHz and 100 kHz) compared to the other hydrophones (Figure 10).

In relation to the data collected in Algarve, the snapshot carried out during spring presented lower PSD values at the frequencies between 1000 Hz and 10 kHz in relation to the snapshot conducted in the autumn (Figure 11). When comparing the noise levels between the hydrophones, further differences were found for the snapshot conducted in the spring. For example, the H2 showed greater noise levels at higher frequencies (between 1000 Hz and 100 kHz) compared to the other hydrophones, while the H3 presented higher PSD values at lower frequencies (from 10 to 1000 Hz, Figure 11). For the snapshot carried out in the autumn, the H3 had greater noise levels at the highest frequencies (between 10 kHz and 100 kHz) in comparison to the other hydrophones (Figure 11).

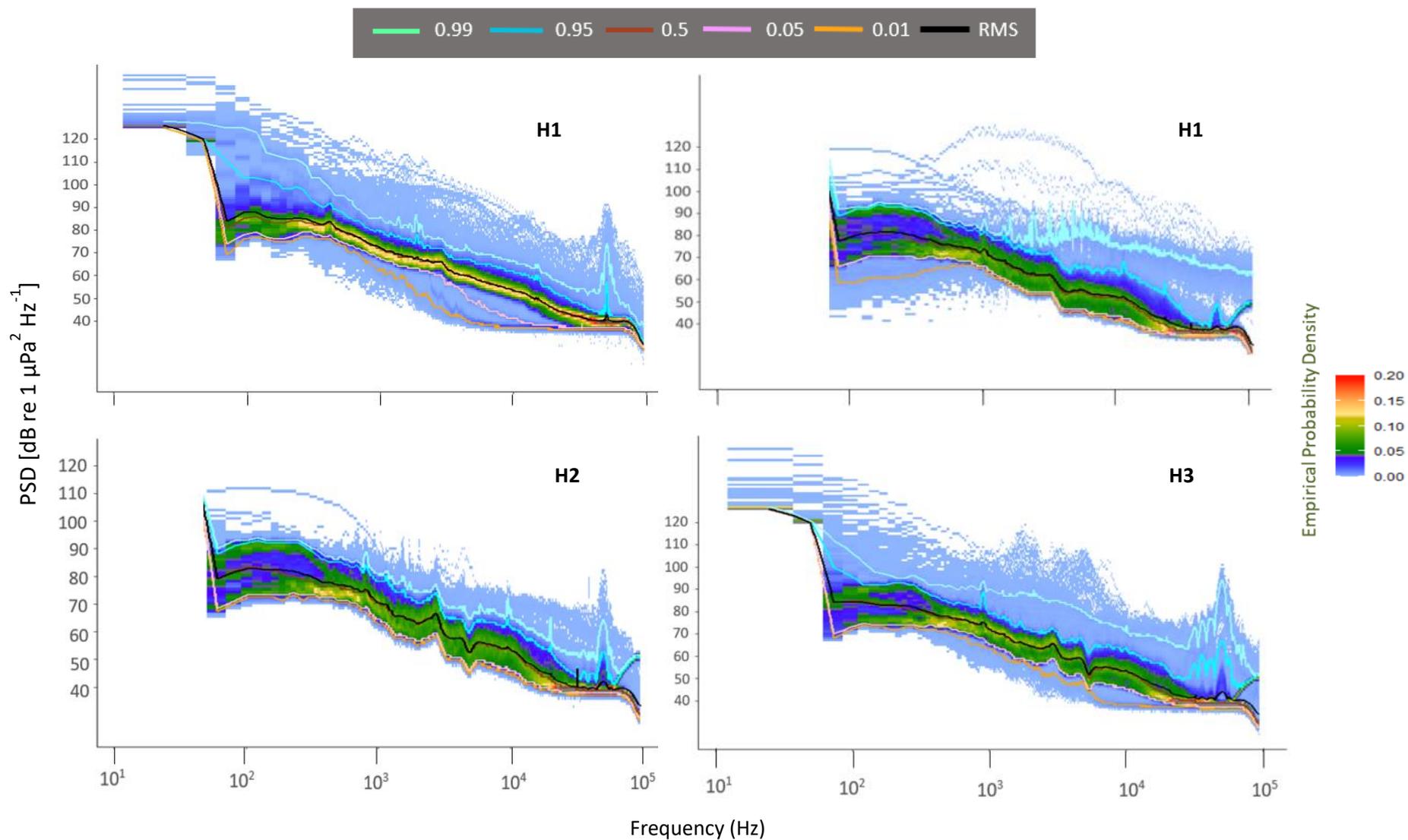
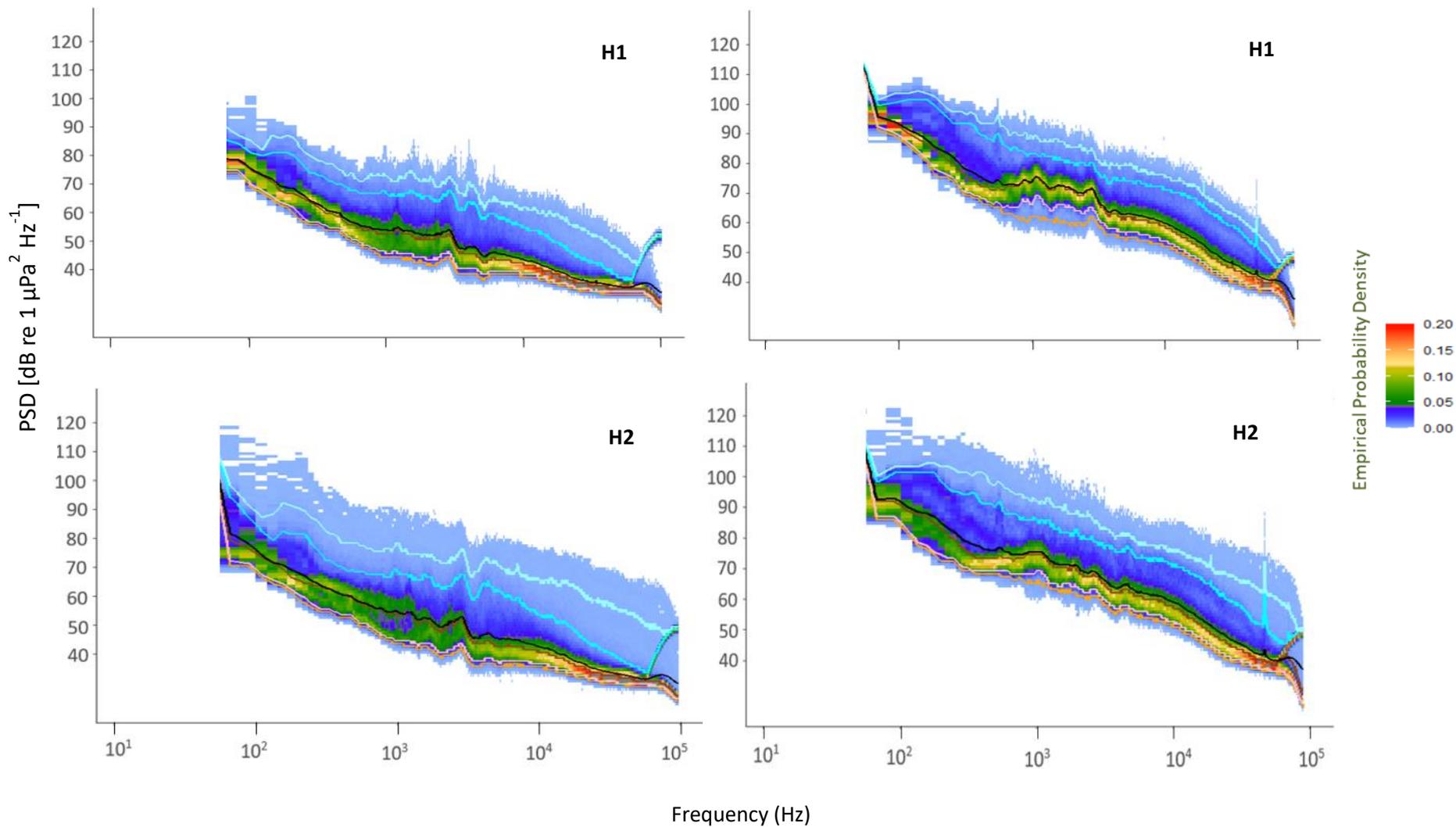
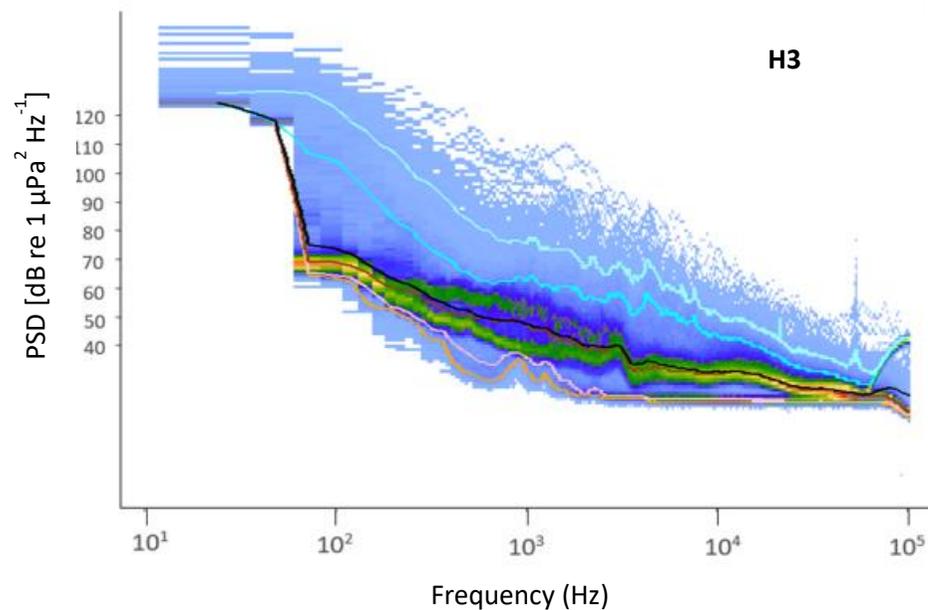


Figure 10- Level of spectral probability densities (SPDs), root-mean-square (RMS) and percentiles obtained in the two snapshots conducted in Aveiro during winter (top left) and during summer (top right and bottom).





Empirical Probability Density

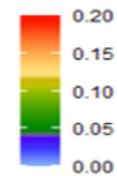
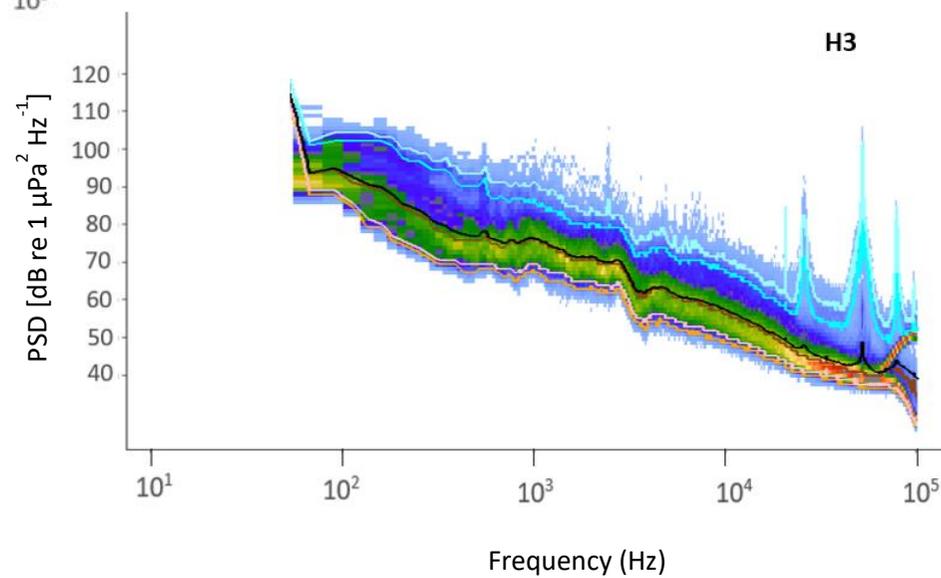


Figure 11- Level of spectral probability densities (SPDs), root-mean-square (RMS) and percentiles obtained in the two snapshots carried out in Algarve during spring (left) and during autumn (right).





Similarly, TOL values varied according to the hydrophones, seasons, and sampling sites (Figure 12). For the snapshots conducted in Aveiro, both 63 Hz TOL and 125 Hz TOL presented higher values in winter (85.7 ± 7.2 and 101.1 ± 5.9 dB re $1\mu\text{Pa}$) than in summer for H1 (82.9 ± 11.3 and 98.0 ± 8.0 dB re $1\mu\text{Pa}$) (Figure 12). During summer, the hydrophone deployed at a greater depth (H3) showed the highest values of 63 Hz TOL (95.2 ± 9.7 dB re $1\mu\text{Pa}$) (Figure 12).

In Algarve, the highest values of 63 Hz TOL and 125 Hz TOL were obtained in autumn (Figure 12). In this season, the hydrophone H1 exhibited the highest values for the 63 Hz TOL (110.3 ± 2.1 dB re $1\mu\text{Pa}$), while in spring higher values were obtained for H2 (95.7 ± 9.6) (Figure 12).

When comparing the two sampling sites, the Algarve showed in general the highest values of 63 Hz TOL (Figure 12). As for the 125 Hz TOL values, Aveiro only presented lower values compared to the snapshot conducted in Algarve during autumn (Figure 12).

4.2.2 SURFACE-BASED SYSTEM

The background noise levels obtained with the surface-based system varied according to seasons and between sampling sites (Table 3 and Figure 12).

Table 3: Average, minimum and maximum broadband sound pressure levels (SPL) recorded during all snapshots using the surface-based system.

SPL (dB re $1\mu\text{Pa}$)	Aveiro		Algarve	
	Winter (16/03)	Summer (02/07)	Spring (14/05)	Autumn (29/09)
Average	145	128	138	138
Minimum	140	120	138	136
Maximum	147	136	139	139

In relation to the average, maximum and minimum SPL values, for the snapshots conducted in Aveiro, the highest noise levels were obtained during winter (Table 3). Regarding the snapshots carried out in Algarve, the maximum and mean SPL levels were similar for both seasons (Table 3).

When comparing the two sampling sites, the snapshot conducted in Aveiro during winter had the highest noise levels while the summer snapshot presented the lowest SPL values (Table 3).

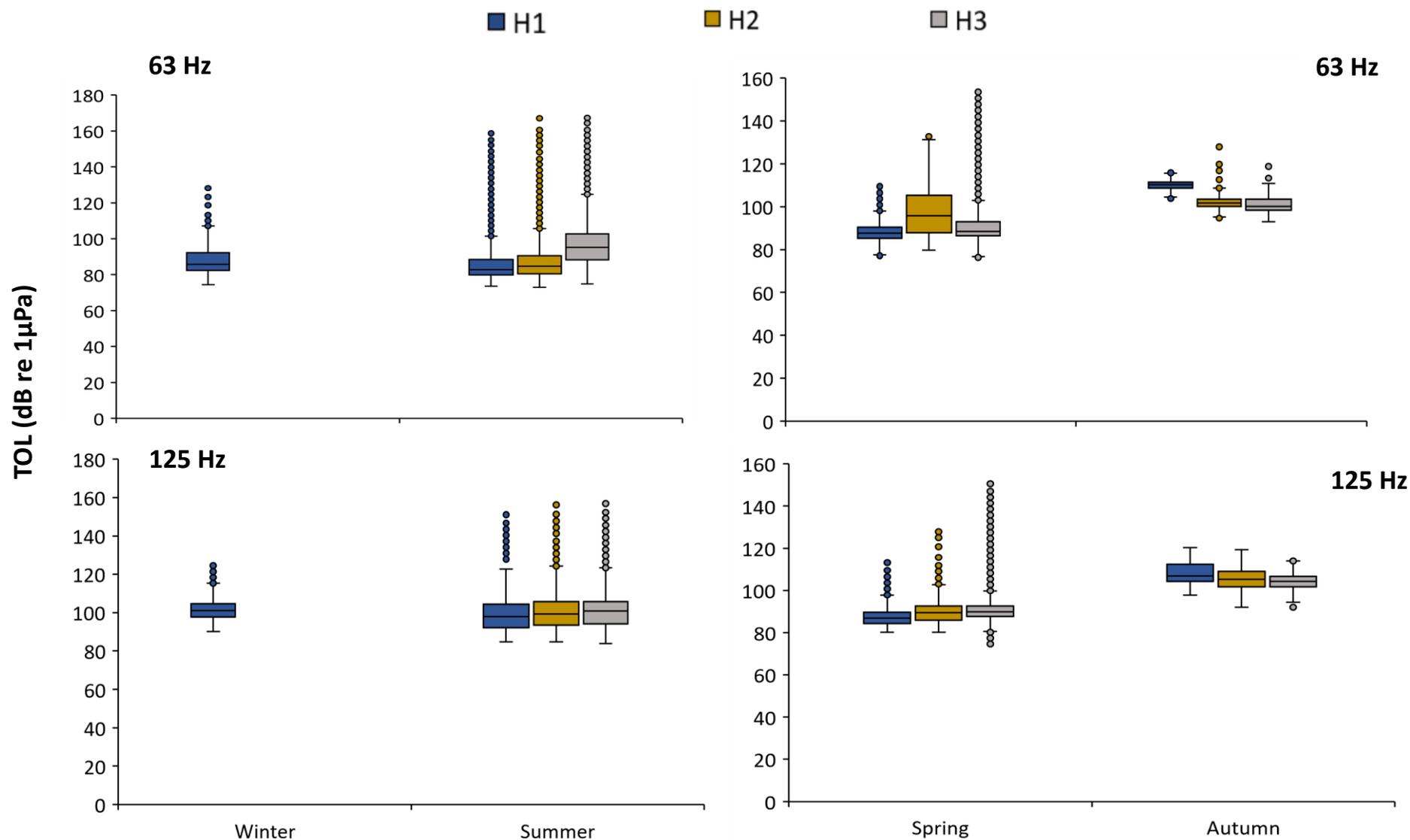


Figure 12- Levels in the third-octave bands (TOLs) with centre frequency of 63 and 125 Hz obtained in the two snapshots conducted in Aveiro (left) and in the other two snapshots carried out in Algarve (right).



Some differences were also found in the PSD values according to both seasons and sampling sites (Figure 13). For data collected in Aveiro, the snapshot carried out in winter presented higher noise levels at lower frequencies (from 20 to 1000 Hz) than in summer. These results are similar to those obtained for the bottom-mounted systems. At 10000 Hz the snapshot conducted in summer showed the highest noise level (Figure 13).

For the snapshots carried out in Algarve, the PSD values were higher in autumn at frequencies between 1000 and 10000 Hz compared to the spring snapshot (Figure 13), as well as the results obtained for the PAM stations.

When comparing the two sampling sites, the snapshot conducted in Aveiro during winter showed higher noise levels at lower frequencies (from 100 to 1000 Hz) in relation to the two snapshots carried out in Algarve (Figure 13). At the higher frequencies (from 10000 Hz to 100 kHz) the highest PSD values were obtained in the two snapshots conducted in Algarve (Figure 13).

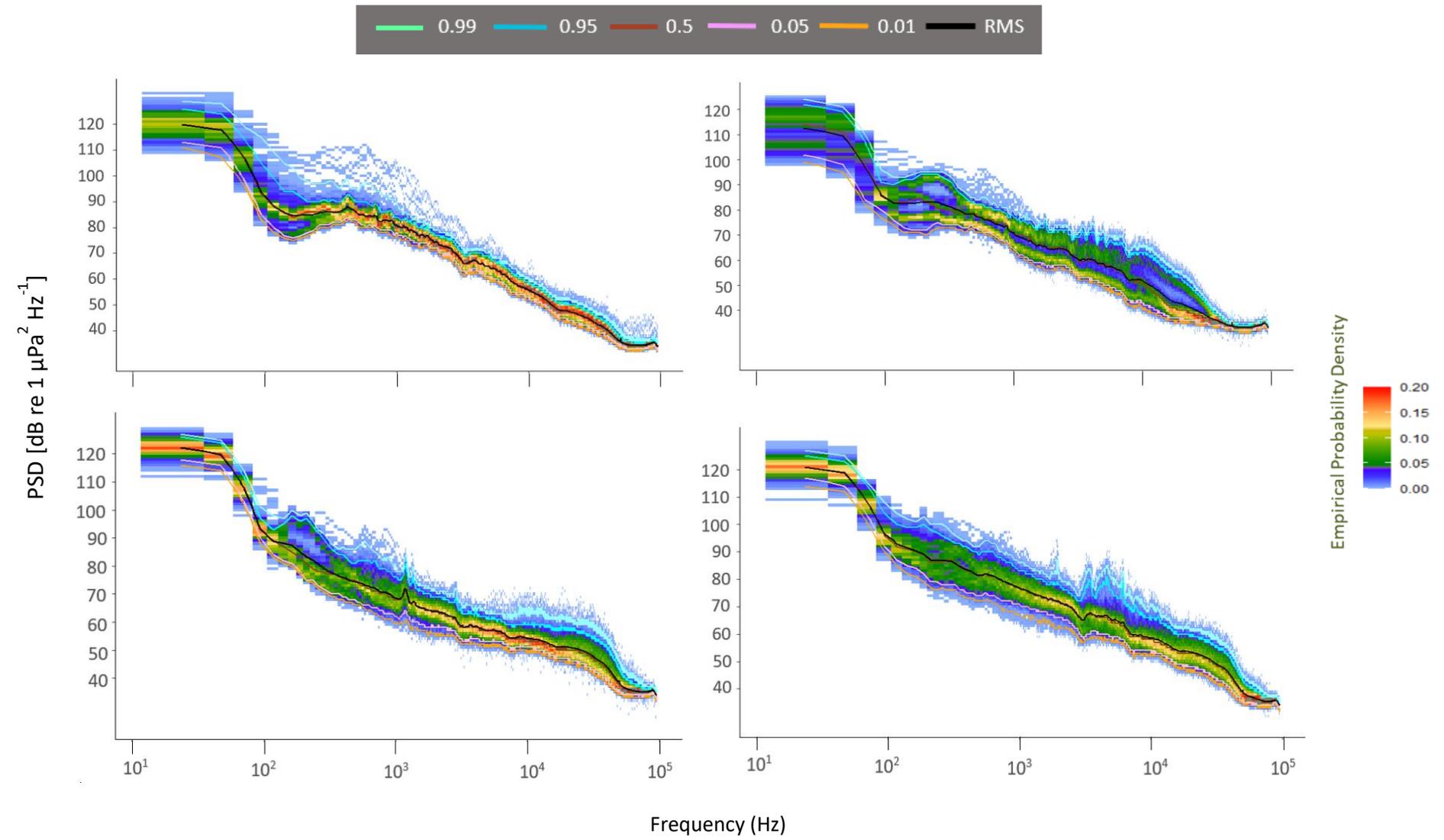


Figure 13- Level of spectral probability densities (SPD), root-mean-square (RMS) and percentiles obtained in the snapshots conducted in Aveiro (top) during winter (left) and summer (right) and in Algarve (bottom) during spring (left) and autumn (right).



5 DISCUSSION

The background noise levels obtained in this study for the two studied sites derived from a range of sources such as natural physical origin like the wind, biological origin, and anthropogenic sources (Hildebrand, 2009; Peng et al., 2015). Human-generated sounds dominated the soundscape with different vessel types and noise sources depending on the seasons and the sampling sites.

5.1 PAM STATIONS

The bottom mounted systems showed that noise levels for both sampling sites varied between the season, location, and hydrophone.

Regarding the season, the SPL values obtained indicate that in Aveiro the noise levels were higher in the winter for H1, which may be related to the higher wind speed values and the greater number of vessels. In fact, previous studies have shown an increase in noise levels due to wind speed (Wenz, 1962; Soares et al., 2019; Vieira et al., 2021). The noise from vessels can also affect the soundscape by increasing significantly and temporarily the background noise levels in that area (Hildebrand, 2009; Romagosa et al., 2017). These results agree with the PSD values where higher noise levels were obtained in winter for H1 at the lowest frequencies (< 100 Hz), which is typical for large vessels, such as cargo ships (Romagosa et al., 2017). In contrast, in the data collected during summer, peaks in the 99% and 95% percentiles were obtained at the highest frequencies (between 1000 Hz and 100 kHz), which indicates the presence of smaller vessels such as high-speed boats, that can increase ambient noise levels in the frequency bands from 1000 Hz to 125 kHz (Li et al., 2015).

An increase in PSD values and the 99% and 95% percentiles at a very high frequency (± 70 kHz) was obtained in the H1 snapshot during winter. Sounds of biological origin may have contributed to these results, since these values are within the frequency range of the dolphins' echolocation clicks (Au et al., 1974; Au, 1993). Plus, the vocalizations registered in the acoustic recordings are complemented with sightings of short-beaked common dolphins during this snapshot.

For the snapshots carried out in Algarve, the SPL values obtained indicate that noise levels were higher in the autumn. This might be correlated to the greater number of boats observed near the hydrophones area, compared to the spring snapshot, and the presence of vessels supplying nourishment to aquacultures (Hildebrand, 2009; Romagosa et al., 2017). In both the autumn and spring snapshots, mainly small vessels and fishing boats (outboard motors, motorboats, and trawlers) were sighted, which is in agreement with the PSD values where peaks in the 99% and 95% percentiles were obtained in the frequencies between 1000 Hz and 10 kHz (Hildebrand, 2009; Romagosa et al., 2017). Smaller vessels with inboard or outboard engines emit sounds in the frequency range from 1000 Hz to 5 kHz (Hildebrand, 2009; Romagosa et al., 2017; Soares et al., 2019). However, the PSD values at these frequencies were, in general, higher in the autumn, which is in accordance with the greater number of boats observed in the hydrophones area in this snapshot.



The noise levels of the acoustic recordings carried out with the bottom mounted systems also varied between hydrophones. In the snapshot carried out at Aveiro during the summer, the PSD values were higher for H3 at lower frequencies (between 10 and 100 Hz) which coincide with some frequencies of larger vessels. Thus, indicating vessels such as cargo ships and tugboats that were sighted in the area passed near this hydrophone (Hildebrand, 2009; Romagosa et al., 2017). Furthermore, higher PSD values were obtained in H2 during the spring snapshot in Algarve at frequencies from 10 kHz to 100 kHz. It is known that smaller boats and dredging produce sounds with frequencies values up to 1000 Hz. Since these vessels were observed in the area during the snapshot, the results obtained suggest these were also present close to the hydrophone H2 (Greene, 1987; Romagosa et al., 2017; McQueen et al., 2018).

When comparing results between the two sampling sites, there were also differences in the noise levels. The snapshot conducted in Algarve during autumn obtained higher SPL levels than the two snapshots carried out in Aveiro. Although in Algarve the hydrophones were deployed in a fishing restricted area, around this zone many different types of noise sources were sighted, such as fishing, recreational and commercial boats, dredging activities, aquacultures, and vessels supplying them with nourishment. On the other hand, the snapshots carried out in Aveiro presented fewer sources, namely commercial and recreational vessels (Bart et al., 2001; Hildebrand, 2009; McQueen et al., 2018). These results are supported by the 63 Hz and 125 Hz TOL values, regarded by the MSFD as a measure of distant shipping noise, which were higher in Algarve during the autumn (Van der Graaf et al., 2012; Romagosa et al., 2017, Vieira et al., 2021).

Regarding the TOL values obtained at the same sampling site for different seasons and hydrophone locations, they are also, in general, consistent with the SPL values. For example, in Aveiro during winter, higher noise levels were obtained for both 63 Hz TOL and 125 Hz TOL compared to H1 in summer, and in Algarve lower values were obtained during spring compared to autumn. For the snapshot conducted during the summer in Aveiro, the hydrophone that was deployed at a greater depth (H3) obtained the highest values of 63 Hz TOL.

When comparing the SPL values obtained with the bottom mounted systems with previous studies, some differences were observed, for example, in a study conducted by Merchant et al. (2012) in the English Channel during the summer, noise levels ranged from 86 to 148.6 dB re 1 μ Pa. In the summer snapshot carried out at Aveiro, the highest average SPL value was 115 dB re 1 μ Pa, that is, lower noise levels were obtained in this snapshot compared to the English Channel study (Merchant et al., 2012). The lower noise levels obtained in this study are due to the English Channel being one of the busiest routes worldwide, where about 45,000 vessels transit every year (McQuinn et al., 2011; Merchant et al., 2012).

In another previous study conducted in the Ria Formosa, at Faro-Olhão inlet, during winter and summer, the SPL values ranged from 97 to 109.7 dB re 1 μ Pa (Soares et al., 2019). These noise levels are lower compared to the ones obtained in the two snapshots carried out in Algarve, where in the spring the mean SPL values varied between 98 and 120 dB re 1 μ Pa and in the autumn from 111 to 125 dB re 1 μ Pa. It should be noted that the Ria Formosa has been a protected area since 1987, with the



aim to preserve the lagoon system, protect the migratory species, the flora, fauna, and habitats, and promote the natural resources and the land orderly use (Soares et al., 2019). Soares et al. (2019) carried out noise measurements inside the Ria Formosa, while in this study they were conducted outside this location, which may explain these results.

5.2 SURFACE-BASED SYSTEM

In the data collected with the surface-based system, the noise levels showed differences depending on the season for the snapshots in Aveiro and between the two sampling sites. The SPL results indicate that the highest noise levels were obtained in Aveiro during winter. These results may be related to the higher wind intensity, the wave motion, and the noise from the hydrophone cable (Wenz, 1962; Cato, 2008; Hildebrand, 2009; Robinson et al., 2014). From the PSD values of the winter snapshot, an increase in noise levels due to wind-generated noise is observed at frequencies between 500 Hz and 1000 Hz, as the peak frequencies of these noises are between 500 Hz and 25 kHz (Hildebrand, 2009). The flow noise caused by the hydrophone cable, leads to increased noise levels at lower frequencies (less than 100 Hz) that can be found in the winter PSD values from 20 Hz to 100 Hz (Cato, 2008; Robinson et al., 2014).

Conversely, the snapshot conducted in Aveiro during the summer registered the lowest SPL values. Although some anthropogenic noise sources were sighted in the area, such as fishing boats and commercial ships, they were more than a mile away, which, due to the attenuation of sounds at great distances, makes it difficult to detect these noises through the hydrophone (Hildebrand, 2009).

For the snapshots carried out in Algarve, the SPL values were very similar, which agrees with the records made. In fact, in both snapshots several anthropogenic noise sources were sighted near the hydrophone area, such as fishing (trawlers), commercial (tugboat) and recreational (outboard motors and speedboats) vessels and aquacultures. However, differences were found in the PSD values where higher noise levels were obtained at frequencies between 1000 Hz and 10 kHz in the autumn snapshot.

Sounds of biological origin may be related to these results, since the autumn snapshot contained the typical peak spectrum between 2000 Hz and 5 kHz from snapping shrimps (Everest et al., 1948; Au & Banks, 1998; Hildebrand, 2009).

Regarding the PSD values, snapshots conducted in Algarve resulted in higher values at the frequencies of 10000 Hz to 100 kHz compared to the snapshots in Aveiro, which may be related to the higher number of small vessels in the hydrophone area, especially the high-speed boats (Li et al., 2015).

When comparing all the SPL results obtained with the two data collection systems, the values were higher for the surface-based system. These results support one of the drawbacks mentioned in previous studies of the surface-based system, the noise from the hydrophone cable, that can contaminate the acoustic recordings and thereby affect the results (Dekeling et al., 2014; Robinson et al., 2014; Vukadin et al., 2018).



6 CONCLUSIONS

The acoustic soundscape in Aveiro coastal area and in the zone surrounding Armona Island in the Algarve, was characterized by different types of noise sources, both of natural (physical and biological) and of anthropogenic origin. The background noise levels varied between the two sampling sites, seasons, PAM stations and among the two acoustic measurement systems. For the bottom mounted systems, the noise levels were highest during winter in Aveiro and during the autumn in Algarve. While with the surface-based system, the noise levels were also higher during the winter in Aveiro, but for the Algarve snapshots there were no differences between the two seasons. When comparing the results between the two sampling sites, the bottom mounted systems obtained lowest noise levels for the snapshot in Algarve during spring, whilst the surface-based system recorded lower values in Aveiro during summer. It should be noted that the measurements with the surface-based system were mostly carried out at different locations from where the bottom-mounted systems were deployed. Through this study it can also be concluded that the best system to measure and monitor the underwater noise, fulfilling the goals and requirements of the MSFD, is the bottom mounted system.

In this study, the anthropogenic noise sources dominated the acoustic soundscape and sources of low, medium, and high frequencies were recorded. The lower frequencies were dominated by commercial vessels, like cargo ships, while the mid-high frequencies were dominated by smaller boats, such as recreational vessels (mainly outboard motors and motorboats). The lower, medium, and higher frequencies emitted by the vessels can affect the vocalizations and hearing of different marine species, such as fishes, which usually have better hearing sensitivity at frequencies below 1000 Hz. Similarly, baleen whales emit sounds with fundamental frequencies under 1 kHz and the odontocetes (e.g. dolphins and porpoises) specialize in the use of high-frequency sound (Romagosa et al., 2017; Soares et al., 2019; Erbe et al., 2019; Vieira et al., 2021). These results highlight the importance of measuring and monitoring underwater noise levels to understand what sources of anthropogenic noise are dominant in a given area and, thus, determine what impacts they may have on marine biodiversity.

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8 ANNEX I. LIST OF ABBREVIATIONS

CTD	Conductivity Temperature and Depth
jUMP	Joint Action: a stepping-stone for underwater noise monitoring in Portuguese water
MSFD	Marine Strategy Framework Directive
PAM	Passive Acoustic Monitoring
PSD	Power Spectral Density
SPD	Spectral Probability Density
SPL	Sound Pressure level
TOL	Third-Octave Levels





underwater noise
JUMP