THE SOUNDSCAPE OF THE INNER IONIAN ARCHIPELAGO AS EVINCED THROUGH THE WEST PATRAIKOS GULF AMBIENT AND SEISMIC NOISE MONITORING PROJECT.

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Abstract: *Impacts of man-made acoustic noise on the marine environment are associated to the frequency and timing of any activity as well as the distribution and abundance of marine life. Offshore commercial operations, shipping activities, energy exploration and pile driving add noise to the already established ambient noise levels. Attention has been raised by the years to the topic of underwater noise and its effects on marine life, but the effects of underwater noise are not yet fully understood. As the adoption of the European Marine Directive (MSFD 2008/56/EC - Descriptor 11) has given great impulse to the research in this field, governments, companies and institutes are working to specify the background ambient noise levels. Those studies have formed the guidelines and have set the protocols for performing safer offshore operations, which are adopted by the major energy companies. Hellenic Petroleum S.A. has undertaken a Marine Seismic Survey in West Patraikos Gulf waters in Greece between January and February 2016, which was coupled with an intensive sound noise monitoring program. Acoustic data were collected around Marine Protected Areas of the Inner Ionian Archipelago during three monitoring phases: 1) the pre-start, 2) the concurrent and 3) the post-completion ones. Sound pressure levels (SPLs) were collected using drifting hydrophones deployed on a frequent schedule, spanning 1.5 months, collecting more than 130 hours of data. The ambient noise data gave insight into the footprints of the anthropogenic and biogenic factors on the soundscape of the Inner Ionian Archipelago. Most importantly, the recorded SPLs of the impulsive seismic and the continuous shipping noises were studied against the bearing and distance to the corresponding sound sources.*

Keywords: *ambient noise, seismic noise, ship noise, acoustic monitoring, Ionian sea*

1. INTRODUCTION

Hellenic Petroleum S.A. has undertaken a Marine Seismic Survey (MSS) in West Patraikos Gulf waters in Greece between January and February 2016. The MSS included acquisition of 3D seismic data from the Polar Empress R/V (Dolphin Geo). The purpose of this MSS was to better describe subsurface geology within the area and more accurately define potential prospective petroleum targets for exploration drilling. An Exclusion Zone of 750 m around the sound source, has been determined based on mathematical modelling, and monitored using the ACCOBAMS protocol [1], to ensure that noise levels were within the designated limits and to avoid adverse effects to marine mammals.

The effects of underwater noise on marine life are not yet fully understood. One reason for this is that only for a few species of mammals and fish, tests have been performed to identify hearing range and sensitivity and yet it is not sure how they react or what damage will be done to them. However, loud impulse noise and ambient (continuous) noise should be distinguished. The disturbance from shipping (from fishing, recreational and liner vessels) lies in particular in the fact that the noise input from these activities can be continuous and persistent in time. On the other hand, loud impulse sounds may instantly be more potentially harmful but they usually last for just some days (e.g. seismic surveys or pile driving). If the dedicated environmental protocols are followed, (e.g. soft start, exclusion zone etc. as in JNCC [2]) then the effects on marine life can be minimized. To accomplish this, the adoption of the European Marine Directive (MSFD 2008/56/EC - Descriptor 11) has given a great impulse to the research in this field and governments, companies and institutes have already performed a great amount of studies on the topic [3-6]. Those studies have set the protocols for safer offshore operations, adopted by the major energy companies. To ensure that the level of noise disturbance on the marine environment caused by offshore industrial and seismic survey operations is within the nominated limits, strict acoustic noise monitoring surveys are compulsory.

In the case of the MSS in West Patraikos Gulf waters, acoustic monitoring data have been recorded during three monitoring phases: 1) prestart, 2) seismic survey and 3) post completion so as to compare the soundscape before, during and after the seismic survey. Passive acoustic monitoring has been realized through spot measurements with drifting hydrophones [7] on a frequent schedule, which lasted for about 1.5 month, collecting more than 130 hours of raw underwater sound recordings from 4 pre-specified areas. Dense sound recordings were acquired and processed from as close to the seismic source to as far as possible away from it and sound pressure levels were estimated using all standardized metrics. It was verified that, in all cases, the seismic noise was well below the nominated limits. What was equally intriguing to investigate though, is the ambient noise monitoring data, as they were able to give greater insight into the footprints of the anthropogenic, mostly due to ship traffic, and biogenic factors on the local soundscape.

2. STUDY AREA

The zone where the 3D seismic survey took place in West Patraikos Gulf covers an area of 1892 km², with a mean and maximum sea depths of 158 m and 466 m respectively (Fig.1). It supports a diverse marine mammal fauna, including several species listed by IUCN as endangered or vulnerable. In addition, the survey area is in proximity to four Marine Protected Areas (MPAs), designated as Natura 2000 sites, that are almost completely surrounding it, thus making a strict seismic noise monitoring plan close to their boundaries essential. Four locations and specifically along the coasts of Ithaki, Atokos, Modi and Oxia islands, were monitored using portable hydrophones, for all the phases of the project. Those locations are situated at the outer limits of the MPAs at the Northern extent of the survey area.

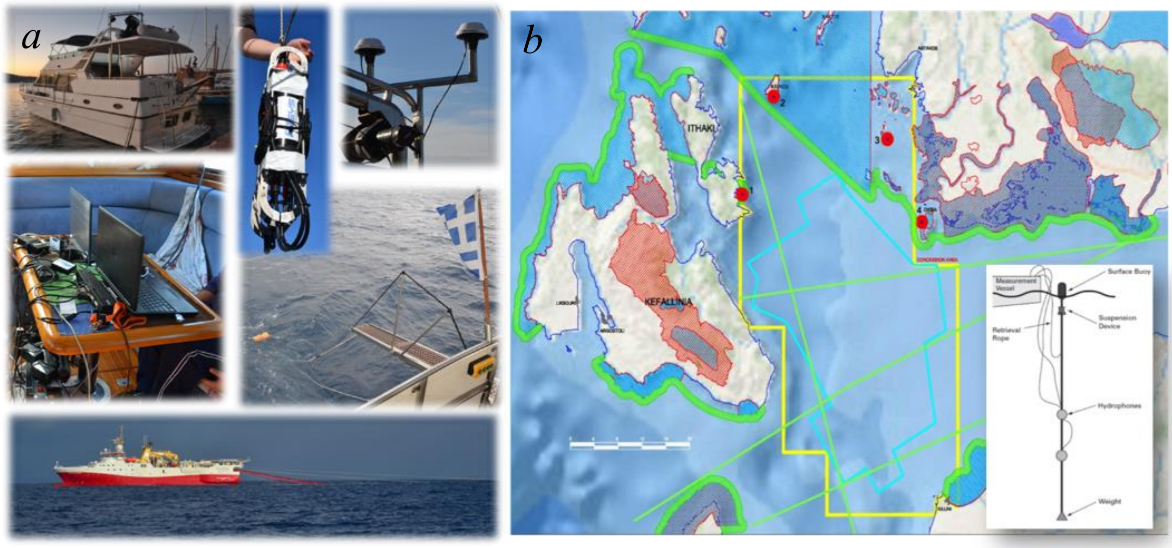

Fig.1: (a) Photographs from the monitoring and seismic vessels and the equipment used, (b) Map showing the seismic survey area (cyan polygon), the extents of the MPAs (green polygons) and the 4 locations (red dots) where spot acoustic measurements took place

3. MATERIALS AND METHODS

3.1. Equipment

Two pre-calibrated EA-SDA14 (RTsys) compact embedded recorders, able to connect to up to four hydrophones each were rented. Their broadband analog inputs allow over 500 kHz bandwidth with a dynamic range greater than 100 dB, guaranteeing efficient signal to noise ratios. Recorders came with 2 hydrophones each, a high sensitivity (170 dB dynamic range with 215 dB sensitivity) and a low sensitivity one (215 dB dynamic range with 170 dB sensitivity). Both channels were recorded at 24 bits, with a sampling frequency of 78,125 Hz. Using dual sensitivity hydrophones guaranteed that all dynamic ranges and amplitudes were successfully recorded without any signal clipping. All hydrophones were thoroughly calibrated by RTsys to be compatible with all international regulations. Apart from the recording units and hydrophones, the research vessel was also equipped with a Hemisphere VS101 GPS, to acquire accurate positioning data in real time.

3.2. Sound pressure level metrics

Noise sound pressure levels (SPLs) have been estimated regarding the zero to peak (SPLpeak), peak to peak (SPLp-p) and root mean square (SPLrms) definitions, as well as the sound exposure level (SEL), all integrated for 1s durations. All above SPL metrics have also been examined as a function of sound frequency components and specifically using a total 30 third-octave bands (from 16 to 20,000 Hz centre bands), according to the standard ANSI S1.6-1984 formula [8]. Finally, power spectrum densities (PSD) have been estimated using the Welch's method [9], being the power in the signal per 1 Hz unit frequency integrated over a duration of 30 s. To meet the above estimations in an automated fashion, a suite of MATLAB codes has been implemented to perform analysis and reporting of the acquired acoustic data.

3.3. Ambient noise monitoring

The ambient noise monitoring program was divided in two distinct stages, the pre-start and the post-end, each lasting for about 10 days of sound recordings. This was to compare any differences that might have occurred in the natural soundscape of the area before and after the 3D seismic survey. Realization of spot measurements, spanning wide spatiotemporal scales, has been decided to be the most cost effective and efficient approach for the acoustic monitoring survey. More precisely, instead of mooring several hydrophones at the monitoring stations for the full survey period, the monitoring research vessel changed locations between the specified station locations in a daily schedule, performing spot acoustic noise measurements. For each station the research vessel turned off the engines to avoid any mechanical acoustic noise and deployed the underwater recording unit at 20m water depth to uninterruptedly acquire sound data for 3 to 6 hours. In each deployment the vessel was left drifting in the winds and the sea currents, hardly stabilized by using a floating anchor. Whenever the vessel had drifted far from the intending position, correction movements were realized, the time and duration of which were noted in the logbook to be excluded from the post-survey analysis. More than 70 hours of raw data recordings have been acquired during the pre-start and post-end ambient noise monitoring stages.

3.4. Seismic noise monitoring

Spot measurement have also been realized for the needs of the seismic noise monitoring stage, which lasted 22 days. The recording schedule had been carefully planned in accordance to the prespecified survey-lines pattern of the seismic vessel, so that at the end of the seismic survey, dense acoustic noise monitoring data would have been acquired from as close as possible to the seismic source (900 m) to as far as possible away from it (60 km). During the seismic noise monitoring phase, the navigational data of the seismic vessel were sent to the acoustic data processing team in a daily fashion after a valid exchange data format had been agreed. Those data included time stamped positions of the seismic vessel, for time intervals that airgun shots occurred. More than 60 hours of raw seismic noise sound recordings have been acquired during the seismic noise monitoring stage. Transient sounds (pulses) were detected automatically for which their 90% pulse energy duration was estimated. A peak detector to the RMS smoothed signal was first applied to locate each airgun impulse and then the 5% - 95% rise time period of the cumulative squared signal was estimated. For this duration all sound pressure level metrics, as described in paragraph 3.2, have been estimated and analysed as a function of distance and bearing to the seismic source.

3.5. Monitoring the exclusion zone

Monitoring the exclusion (mitigation) zone around the seismic vessel (900m<d<3,000m) was a challenging task, both regarding the field-work planning as well as the data processing queue. The research vessel deployed the sound recorder at 20m depth, standing in positions agreed with the navigation team of the seismic vessel, as the latter was approaching executing its prearranged 3d seismic survey lines. Attention has been paid so that sound measurements were obtained from both the forward and broadside directions relative to the fore-aft axis of the air-guns. Each recording station lasted for about 30 to 40 minutes. A high pass filter over 50Hz was applied to the sound data to remove any self-noises. The navigational data of the seismic vessel were sent to the data processing team in a daily fashion. In order to study the attenuation of impulse (transient) sounds around the seismic source, the relative position of the monitoring vessel and each emitting airgun was estimated, putting the seismic sources at the centre and converting the Cartesian coordinates to polar.

4. RESULTS

4.1. Seismic noise

Spot measurements with drifting hydrophones, apart from being cost effective, were proven to be a very efficient means for seismic noise monitoring. They holded the advantage of retrieving acoustic data not only from an isolated position but also from a buffer around it, making the estimated SPLs more statistically representative. Following carefully planned recording agendas, in regard to the seismic vessel's prearranged daily survey-lines, spatially dense acoustic data were managed to be acquired. This practically replaces the need for moored hydrophones, minimizing at the same time the required equipment items, increasing the spatial coverage of the measurements as well as the flexibility of the monitoring team in terms of service capacity. Fig.2 presents the high spatial density of the seismic impulses that have been recorded from the Modia station, that lead to an almost continuous SPL vs distance graph (Fig.2b).

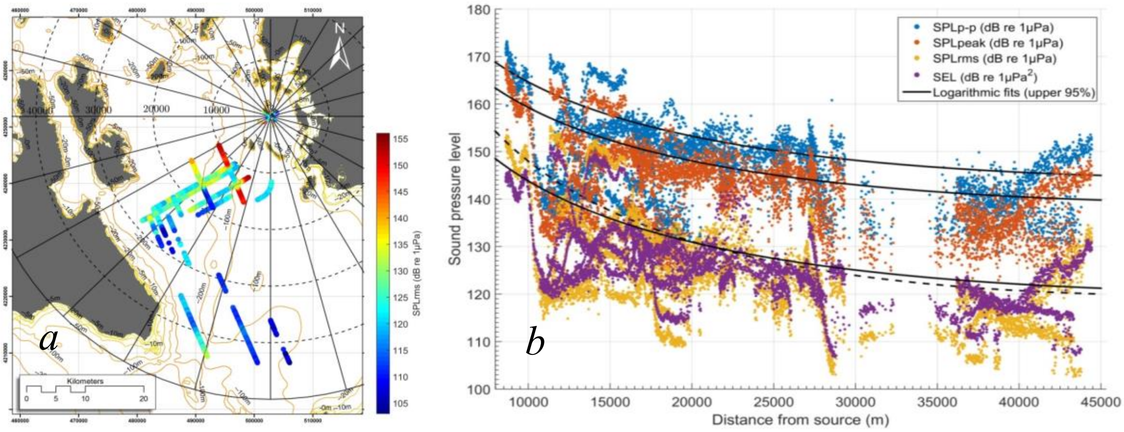

Fig. 2: a) Spatial density of recorded seismic pulses at Oxia station (center of the polar diagram) and b) impulse SPL vs distance to the seismic source.

It was clearly shown that the exclusion zone of 750 m around the seismic vessel adequate, as it received SPLs less than 200 db re 1μPa, far below the nominated limits for temporary or permanent hearing loss of marine mammals (Fig.3a). This result is in good agreement with the modelled by D'Apollonia transmission loss in the exclusion zone, which was used for the exclusion zone determination, and especially for the case of spherical spreading. The latter was a worst-case scenario, quite above the actual measurements (Fig.3b).

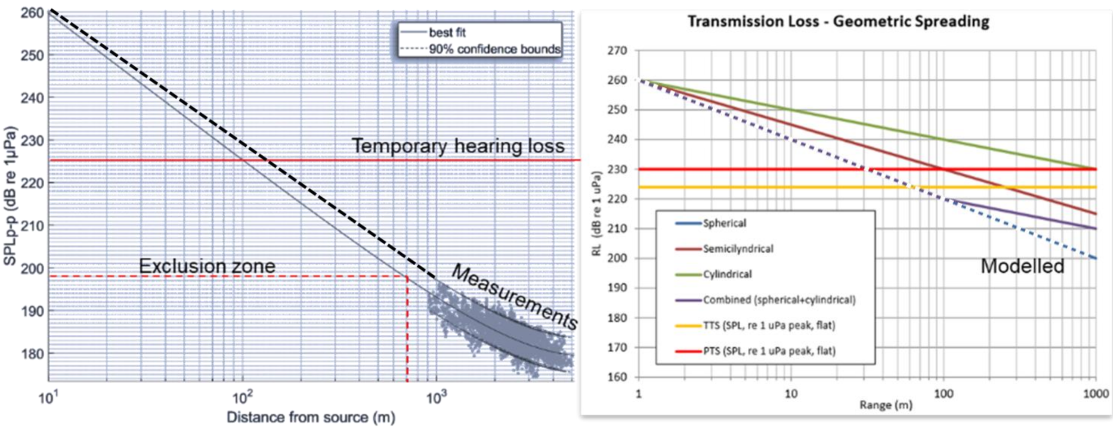

Fig.3: Measured and modelled verification of the exclusion zone. Dashed lines correspond to the modelled results for the case of spherical spreading, which suits well with the upper limits of the average measured SPLp-p in the area.

Apart from the core seismic noise monitoring results, some other intriguing findings were extracted from the collected seismic monitoring data. Those include the attenuation and frequency modulation of the seismic impulses in regard to their distance to the seismic source. Towards that, Fig.4a shows the spectrogram of the acoustic noise as the seismic vessel approached the recorder, exhibiting clear increase of both the mechanical noise of the vessel and the seismic impulse levels. Fig.4b shows the third- octave bands of each individually detected seismic impulse, with distance to the seismic vessel. The frequency modulation of the seismic impulses seems to be towards losing both its low but mostly its higher frequency components, which is also clear in their corresponding spectrograms.

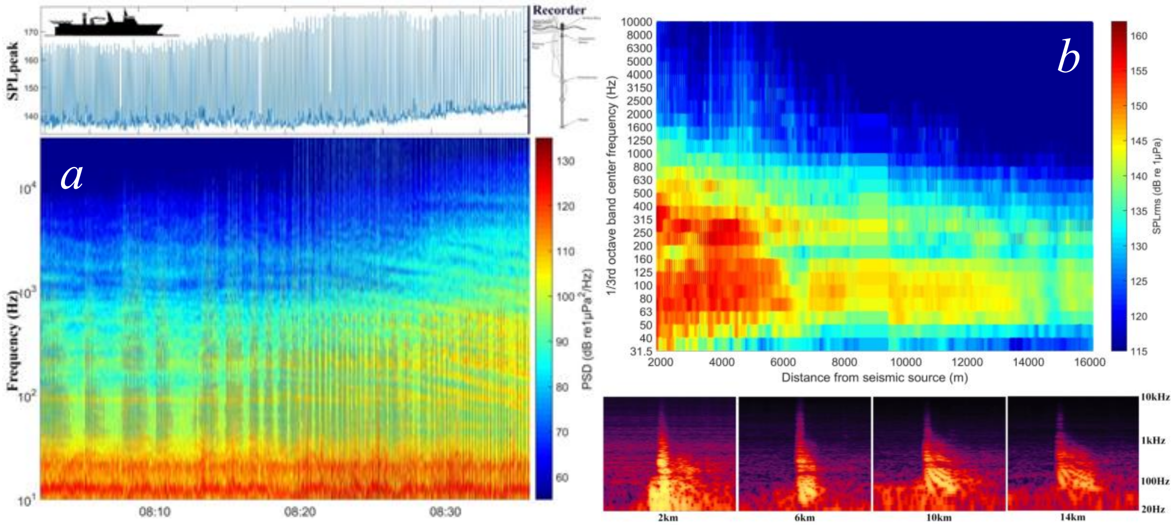

Fig.4: a) Spectrogram of the acoustic noise as the seismic vessel approaches the recorder and b) 1/3 octave bands of each individually detected seismic pulse with distance to the seismic vessel and corresponding spectrograms.

4.2. Anthropophony and Biophony of the ambient soundscape of Inner Ionian

The soundscape in West Patraikos was analysed during the ambient noise monitoring phases. It was realized that the anthropophony of the area is dominated by fishing but mostly liner passenger vessels, as well as sea-farm coastal noises. Fig.5 shows characteristic spectrograms of liner ships passing about 4 km and 6km away from Oxia station, increasing the ambient noise levels for 25dB and 10 dB respectively.

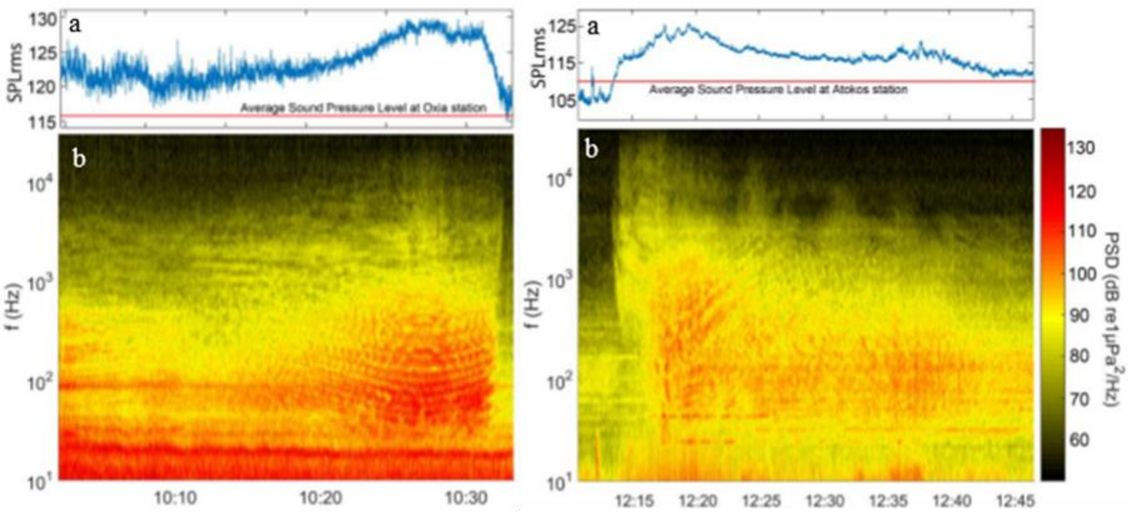

Fig.5: Spectrograms showing two instances of ship noise from two liners, one passing 4km away and another 6km away the recording unit.

Fig.6 provides a comparison of SPLrms between the ambient noise, the seismic activity (integrated over time unit or detected impulse) and the traffic in the same area, both in regard to 1/3 Octave bands and total SPL. It is clear that the traffic noise adds on average 20 dB to the ambient noise while the seismic activity adds about just 10 dB more (30dB). Integration per time unit (1s) over the full seismic activity period, resulted in 10 dB less than the traffic noise equivalent. It is also interesting that while seismic noise contributes greater in below 1kHz, maximum SPL_{rms} from ship traffic exhibits almost equal noise levels with the maximum seismic noises at frequencies higher than 1kHz.

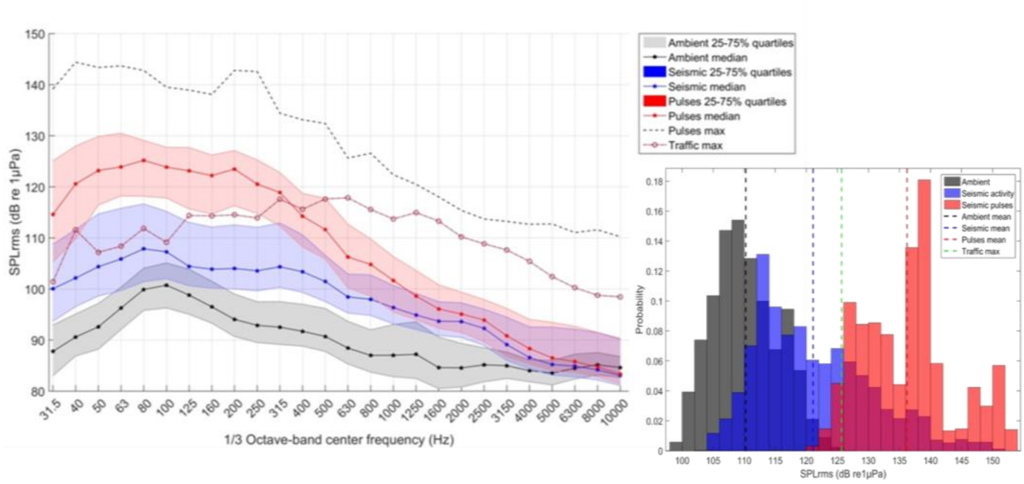

Fig.6: Comparison between the 1/3 octave-band SPLs (left) and the average SPLs (right) in the cases of seismic noise, seismic impulses, ship noise and ambient noise.

Biophony was a strong component of the soundscape in the area. Crustaceans produced characteristic click sounds (snapping shrimps), and dolphin whistles were recorded in a dozen of instances. Measuring benthic habitats through passive acoustics is a popular scientific topic nowadays [5,6] and drifting hydrophones could potentially greatly aid towards quantitative habitat mapping, as demonstrated in [7].

Eco-acoustic indices can offer the means for assessing the rate of biophony versus anthropophony in the marine soundscape. A popular index, the Normalized Difference Soundscape Index (NDSI) [10], seeks to "estimate the level of anthropogenic disturbance on the soundscape by computing the ratio of human-generated (anthrophony) to biological (biophony) acoustic components". NDSI varies between -1 and +1, where +1 indicates a signal containing no anthropophony. Here, the anthropophony frequency bands were defined as shipping (< 1 kHz) and sonar (> 10 kHz). A preliminary application of the aforementioned index at two instances of liner ship and seismic noise showed that they yielded a totally different NDSI pattern (Fig.7).

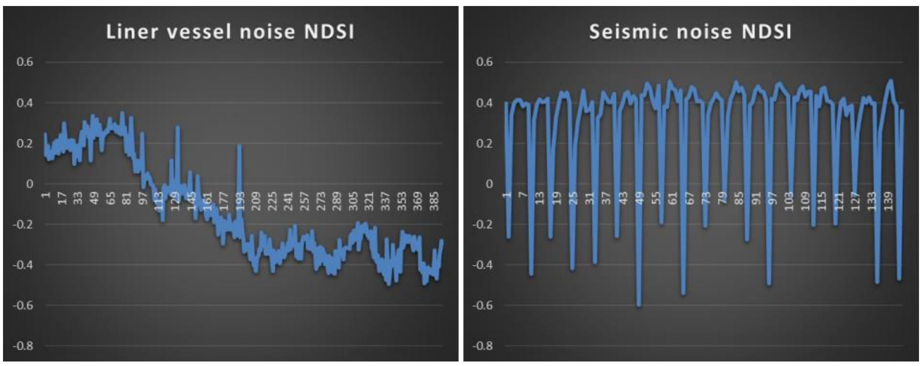

Fig.7: NDSI eco-acoustic index for two cases: Left: liner ship noise and right: seismic noise at the same station (Atokos). Recording duration was 5 min in both cases.

While ship noise produced a gradual degradation of the ecological status for the full duration of the ship passage, seismic noise (impulses) produced the same rate of degradation but with regular "jumps" from good to bad environmental status, following the airgun shooting rate pattern. Although ship noise exhibited lower mean NDSI than the seismic noise for the considered period, no safe assumptions can be made about the consequences of the one or the other type of anthropogenic noise on the marine environment.

5. CONCLUSIONS

The data collected, and the methods used for the seismic and ambient noise monitoring during the MSS in West Patraikos Gulf, were proved to be important both for investigating the induced seismic noises as well as other anthropogenic disturbances that dominate the soundscape of the area, such as ship noise. The seismic monitoring results showed a very good agreement between the modelled and the recorded SPLs in the exclusion zone. The seismic noise was proved to have always been lower than the nominated limits, especially outside the exclusion zone, but it was also realized that the ambient soundscape of west Patraikos Gulf experiences quite high and insisting anthropogenic disturbances due to sip noise. The diversity of anthropophony and biophony in West Patraikos, spanning from dolphin whistles and snapping shrimps, to "deafening" liner ships and sea farm noise was captured and eco-acoustic indices were showcased against their suitability for assessing anthropophony dominance in the marine soundscape.

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