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Abstract

Underwater noise pollution (UNP) has become a major concern in marine habitats, which is intense anthropogenic noise in the marine (aquatic) environment. It is caused by ship traffic, oceanographic experiments, and use of explosives in geophysical research, underwater construction, active sonars and seismic survey techniques. Oceans are much nosier than 1960s. Narrow and shallow channel noisy aquatic environments where noise levels reach the highest value is not surprising. The Strait of Istanbul (SoI; Bosphorus) is one of the most important maritime passages (app. 50 000 vessel/year or 140 vessel/day) which is situated between the Black Sea and the Aegean Sea are also biologically extremely important gateway not only it provides access to a channel. Many of the varieties of fish migration hunting value are realized through the TSS. Local maritime traffic is another important acoustic sources which are more than 3 000 elements (Kesgin and Vardar, 2001) of everyday local traffic in SoI, which are causing noise in the 2 and 10 kHz range. Large vessels create signals both in bands below 1 kHz (main engine, electrical instruments) cavitation noise creates higher frequency bands. Almost all elements of marine traffic in SoI located therefore encountered UND in all bands.

Keywords: Strait of Istanbul, Underwater noise pollution, Ocean ambient noise, acoustic ecology.

Introduction

Since the industrial revolution, the soundscape of the marine environment (ME) has responded to the changes in anthropogenic impacts. A soundscape is a combination of sounds that characterize and describe an ocean environment, as known as acoustic ecology-environment (AEE) which has doubled in each of the past four decades (McDonald et al., 2006). The disruption of the natural AEE which is categorized by spatial and time dependent variability will be caused by the anthropogenic UNP (Etter, 2012).

Environmental noise in the ocean is an important aspect of marine habitats and is composed of natural and artificial sounds (Hildebrand, 2009). Since 1960s, the increase of human activities along coastlines worldwide and in the sea has caused an commensurate increase in the Ocean Ambient Noise (OAN), especially in the low frequency range (<500 Hz) where noise produced by many anthropogenic activities is concentrated with physiological, behavioral, and population effects on marine animals (Slabbekoorn et al., 2010; Sebastianutto et al., 2016). However, over the recent decades UNP has come to the attention of scientists as a rising problem around the world's oceans (McDonald et al., 2006).

Sound is an extremely proficient way to propagate energy through the ocean for far distance and some marine life forms exploit this property for communicate their own kind and most of them use for navigate and migration. Ocean Ambient Noise is one of the important features of marine life forms for navigation (Richardson et al. 1995, Halpern et al. 2008). Fish utilize sound especially for navigation, surviving, procreation and communication (Ketten and Wartzok 1999; Bass and McKibben 2003, Simpson et al. 2005; Hildebrand, 2009; Gazioğlu et al., 2015). Accordingly, worldwide OAN has increased correspondingly due to amplified anthropogenic activities, which describe as UNP (Kastelein et al., 2008). Sound is known as significant navigational indication for all organisms in aquatic environs especially marine mammals. In general, since the amount of anthropogenic noise is higher in the low frequency range, fish were potentially more damagingly impacted by the noise conditions than marine mammals in the same area (Sebastianutto et al., 2016). Animals are capable of amazing feats of migration and navigation. Directed long-distance migrations Animals are capable of amazing feats of migration and navigation. Directed long-distance migrations occur in creatures. The migration mechanisms related with too many parameters such as magnetic, celestial, olfactory, environmental signatures both concern and independently. According to latest investigations, OAN is one of the most important orientation mechanisms for aquatic creatures (Herrnkind and Kanciruk 1978; Hamilton and Russell 1982; McKeown 1984; Swartz et al. 1987; Bowen et al. 1989; Berhold 1991; Hobson 1998; Popper and Carlson 1998; Tolimieri et al., 2000; Etter, 2012; Gazioğlu et al., 2015; Sebastianutto et al., 2016).

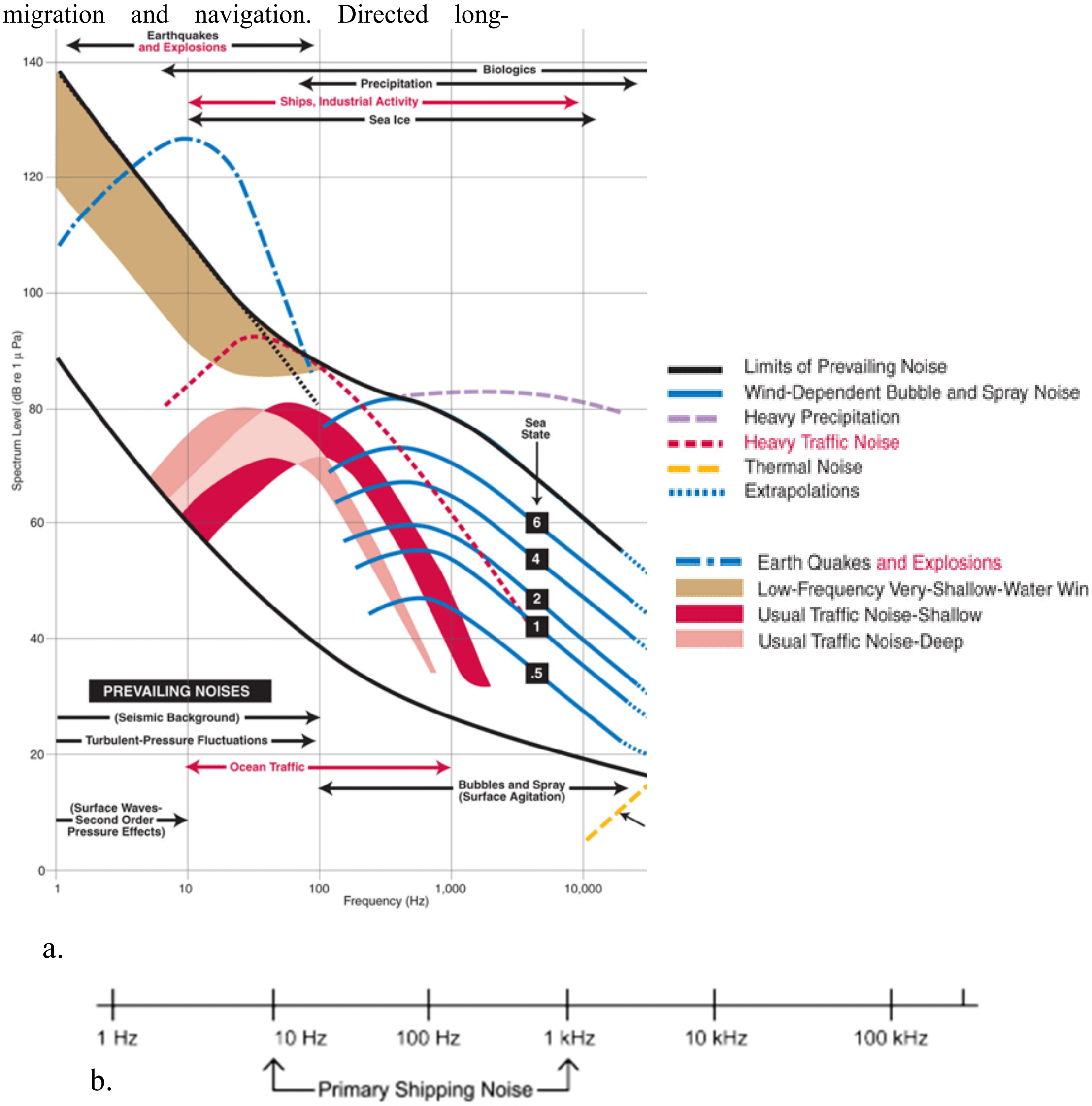

Fig. 1 a. OAN Spectra. Adapted from Wenz (1962) b. Marine Traffic Spectra.

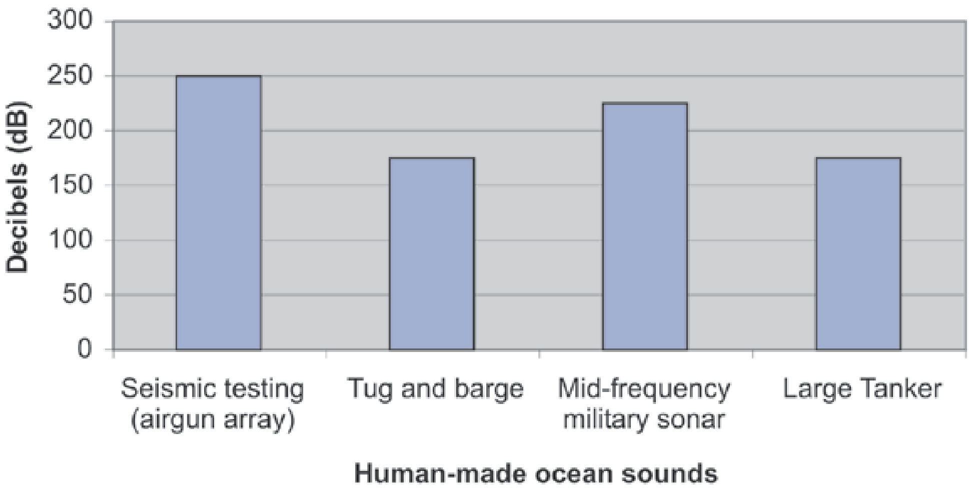

Fig 2. Example sources for acoustic ecology-environment.

Ship noise (SN) is generated primarily from propeller cavitation, propeller singing and propulsion or other reciprocating machinery Fig. 1a-b (Richardson et al., 1995; Wales and Heitmeyer, 2002; Hildebrand, 2009, Veirs et al., 2016). Ship noise has become the main sound source in coastal areas and may have effects on the AEE (Richardson et al., 1995; Tyack, 2008; Castellote et al., 2012). Higher frequency signals, between 2 and 10 kHz created by small ships. Large vessels create signals both in bands below 1 kHz due to main engine and electrical instruments and in higher frequency bands due to cavitation noise (Wenz, 1962; Arveson and Vendittis, 2000; Aguilar Soto et al., 2006; Bittencourt, et al., 2014). Ship noise of close range and through strait is differentiated from traffic noise at open seas. It may be identified by short term variations in the OAN characteristics, such as the temporary form of narrow band components and a comparatively rapid rise and fall in noise level. Ship noise causes short-term variations in the OAN characterized by the temporary appearance of narrow-band. Marine traffic is pervasive throughout the ME, particularly at low frequencies and is therefore a key concern regarding the effects of chronic noise exposure on marine creatures Fig.2 and Table 1. (Merchant et al., 2012a). Ship noise characteristics base is broad so that individual differences blend into an average source characteristic (Wenz, 1962).

Table 1. Ocean Sound intensity in water dB.

Ocean Sound	**Sound intensity in water dB (Rounded off)**
Seismic testing (airgun array)	<200
Tug and barge (18 km/hour)	170±5
Mid-frequency military sonar	<235
Tanker (<80 000 DWT)	<185
Sea floor volcanic eruption	<255
Lightning strike on the ocean's surface	<260

Shipping plays an unquestionably important role in the nowadays world's economy and commercial ship traffic has tripled in the last 75 years, resulting in a 3-5 dB increase per decade of noise in the oceans. A large modern tanker reaches more than 190 dB in normal condition cruise. Some research suggested that SN has increased at a rate of about 1/2 dB per year (Ross, 2005) and it will be carry on.

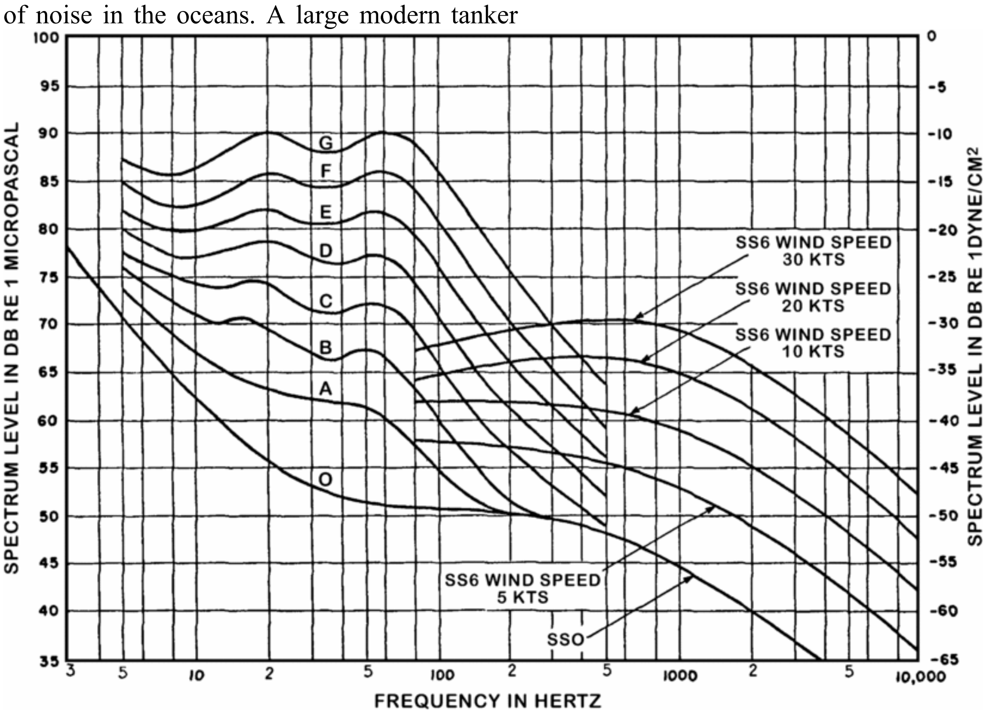

Fig. 3. Ambient noise due to shipping and wind (Ross, 2005: modified from Wenz, 1962)

The areas between the lines in figure 3 until that used to be in the B to C region (typical of the Pacific Ocean 1960-1980) have moved up into the D to E region; and areas that used to be in the D to E region at the time these curves were developed have moved up into the F to G region. In addition, two more curves have been required going up to 95 and 100 dB to encompass data acquired for the eastern Atlantic and moreover for the Mediterranean in nowadays (Fig. 3 modified from Wenz, 1962).

Low and mid-frequency impulsive sound (10Hz-10kHz) where the focus is SN. (Dekeling et al., 2013). The average yearly sound levels in third-octave bands with center frequencies at 63 Hz and 125 Hz have been set as the indicator for the second attribute. Third-octave bands are described by the sum of the sound power occurring within defined frequency bands, one third of an octave wide. Propeller cavitation noise, from vessels underway, is known to peak in the frequency range 50–150 Hz (Ross, 1976). These two third-octave bands are therefore considered to capture the anthropogenic contribution from shipping while also minimizing the input from natural sources (Tasker et al., 2010; Van der Graaf et al., 2012).

Measurements of low-frequency third-octave levels have taken place at many locations around the world and range from short- (minutes) to long-term (<10 years) (Garrett et al., 2016):

- continental slope offshore California, within 10–500 Hz for 7 years (Andrew et al., 2002),

- offshore British Columbia at < 1.6 kHz for 4 months (Merchant et al., 2012b),
- shallow archipelago in Croatia with touristic boating activity for 5 month–2 years (Rako et al., 2013),
- deep waters: channel in the Atlantic, Indian, and Pacific Oceans using hydroacoustic explosion-monitoring stations at < 125 Hz for 42 months (van der Schaar et al., 2014),
- the North Atlantic and the North Pacific from the 1950s through the 1970s, Ross (2005) showed an average noise at 50 Hz (mainly due to shipping) was increasing 5.5 dB/decade,
- Salish Sea: inland waters of Washington State and British Columbia for 28 moths (Veirs et al., 2016).

Surface wave motion and turbulence as hydrostatic OAN source of the effects of low frequency (<100 Hz) is evident which decreases with increasing depth where the recipient resides. Wind turbulence induced depends on sea conditions, spray, bubbles, and effects such as foam, usually dominant at frequencies above 500 Hz (Urick 1983). However, this effect creates waves breakage, occur in a significant way in the deep seas and high wind speeds. The measurement of the work done and the conditions into account, OAN to a large extent dominated by the noise source is understood that the sea traffic. Across the spectrum of SN and/or maritime traffic noise of 10 - 1000 Hz frequency range is given by recent references (Veirs, 2016).

Measurements at the Turkish seas have shown that the OAN in the SoM is about 95 dB and 4 dB (decibel) noisier than surrounding seas (Mutlu 2005). According to latest acoustic investigations show that data showed that the noisiest area is located between Beşiktaş and Üsküdar in the southern part of the SoI, where the noise levels are 120 dB at low and mid frequencies (Tombul and Alpar, 2016). This is due to heavy local shipping, turbulence and the noise from the nearby suspended bridge (Ülüğ, 2009).

Method

Location (Study Area)

The TSS is a series of internationally significant waterwards in northwest Turkey that connect the Aegean and Mediterranean seas to the Black Sea. They consist of the strait of Çanakkle (SoÇ: Dardanelles), the Sea of Marmara (SoM) and the Strait of Istanbul (SoI: Bosphorus). The TSS is one of the most crowded sea lanes in the world used for international navigation which in the straits is highly congested by merchant ships: approximately 50 000 vessel/year or 150 vessel/day (Terzi and Gazioğlu, 2016).

Turkish Strait System (TSS) not only one of the most important channel for merchant but also significant biological channel for all kind of aquatic creatures of Black sea and Mediterranean Sea. The SoI is north part of TSS (Yüce and Gazioğlu, 2006; Terzi and Gazioğlu, 2014). Many of the varieties of fish migration hunting value are realized through the TSS where have been and continue to be one of the most important waterwards in the World. The SoI is generally a noisy channel, no comparisons between current and past OAN levels.

There is also very heavy ferry traffic for domestic transport on the SoI. In addition to merchant and domestic passenger ships, the marine traffic is busy by vessels with various aims. Additionally local maritime traffic is another important acoustic sources which are more than 3 000 local traffic elements in SoI (Kesgin and Vardar, 2001).

In shallow and narrow channel such SoI the noise levels are extremely variable in time and space and are generally higher than levels recorded in the deep sea, because of the depth and the presence of different sound sources. Shallow water (< 200 m) OAN are predictable to be louder (Wenz, 1962) and more variable than in deep water (Urick, 1983; Richardson et al., 1995; Jr and Moore, 1995; Merchant et al., 2012a;).

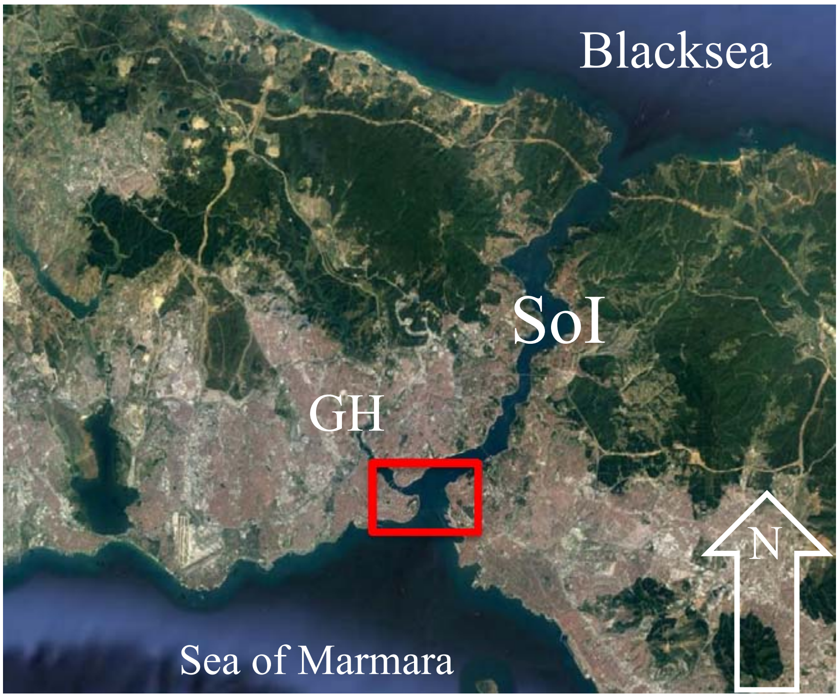

Fig. 4. Measurement Station (MS_{SoI}); SoI: Strait of Istanbul; GH: Golden Horn; SoM: Sea of Marmara; YP: Yenikapı Port; HP: Haydarpaşa Port; SP: Sirkeci Port; KP: Karaköy Port.

Channels and shallow water reflection, interference, scattering to be more of such events increases transmission losses of the sound waves emitted at longer distances. Therefore, these types of media, buyers reaching sound waves are emitted from the intense noise sources in the closer distance

Measurement station

Measuring station (MS_{SoI}) with an intense and continuous traffic flow in the Golden Horn where it opens SoI was established in the northern foot of the bridge (Fig. 4). Around this point, it is the best platform to measure the effects of transiting ships, but intense local traffic in an area located approximately 750 meters radius (etc: interior city lines ferry ports in Karaköy and Eminönü; car-ferry dock in Sirkeci, local boat lines TURYOL dock is situated in east side of MS_{SoI}). The presence of a large number of boats that pass under the bridge, pier of intense activity and brings to the MS_{SoI} an intersection during maneuvers of ships and boats. The MS_{SoI} has approximately 40 meters depth.

Measurement was carried out by international patent received booster for this survey EP2975432 by Gazioğlu et al. (2016). In shallow water, the audio channels are often in regions close to the surface. Therefore, in shallow water, hydrophones deployed close to the surface to transmit voice is getting better. Records made during the current listening, due to intense maritime traffic in the region already characterized the OAN in the higher dimensions, and ship maneuvering of vessels (astern, uncomfortable, slow down, bow trust is run etc.), noticeable changes were observed. Ambient noise of SoI could be saved as data using by non-directional hydrophone.

According to Urich (1983) ve Hodges (2010) OAN could descripe as; except for the sound of their instruments and equipment used for measurement is defined as continuous and discontinuous noise from all sources in the AEE. Analysis of components of different frequencies that make up the OAN is possible with frequency analysis. In this study, the frequency analysis carried out, the distribution of the frequency of the noise levels are examined using bu "Sigview" program to generate 1/3 octave graphics which shows relationship between sound level (*dB re 1µPa*) and the frequency bands (*Hz*). 1/3 octave band analysis method was used in sample station which is situated in month of Golden Horn and south part of SoI. Graphics are produced according to this method. These graphs overall sound level (dB re 1µPa), frequency bands (Hz) shows the variation. Octave bands; frequency axis (values) in certain parts of width (tapes) are separating system. The lower limit for each band has a center frequency and the upper limit values.1/3 octave band in the band limits approximately, is calculated as follows:

$$F_{lwr} = 10^{(-\frac{1}{20})} \times F_C$$
$$F_{top} = 10^{(\frac{1}{20})} \times F_C$$

"Flwr" lower frequency value, "Ftop" high frequency and "FC" represents the center frequency. 1/3 octaves of bandwidth, fixed as a percentage increase of approximately 23.2% (Erbe, 2011).

The average volumes of the entire record made in the estuary about are focused 20 -900 Hz frequencies (3 – 18 bants) of sample station. Maximum number of peaks observes in 40-200 Hz. Our work is fully compatible with Wenz (1962) sea traffic curves which are given in Fig. 1a. In this case, the OAN is dominated by maritime traffic in MS_{SoI}.

All record 1/3 octave band analysis; The average maximum sound level measurements we did in the MS_{SoI} 10 points in bands (125 Hz) serves approximately 116 dB re 1 µp to. This value is changing over time during the volume measurement shows the average of the current frequency. If the measurement is that all measurement or thinning out the traffic during certain parts of the section instead be analyzed; In SoI local marine traffic is causing noise in the 2 and 10 kHz range. The assessment of marine traffic noise in SoI is complicated by the presence of both intermittent noises from SoI and OAN from distant shipping. Noise of sailing ship from north to south is 10±3% less than sailing ship from south to north part of SoI is observed in MS_{SoI}. Strait of Istanbul represent one of the greatest challenges to the management of anthropogenic noise due to anthropogenic use, the presence of complex sound fields, and the variety of sources, including from a range of vessel types and numbers. Certain parts of the section instead be analyzed; Maritime traffic in the MS_{SoI}, the impact on underwater OAN will be determined more clearly.

Results

Underwater Noise Pollution is also being linked with behavioral changes that have been seen in marine creatures around the world, which is a particularly flexible phenomenon both in space and time in aquatic environments. In recent decades UNP from anthropogenic activities has increased dramatically. This increase is set to carry on and poses a potentially major threat to marine creatures of many kinds worldwide. It is extremely important that we make sure that all the sounds we produce are at a low enough OAN level that we are sure that there are no anxiety, disruptions and displacement to marine creatures.

Table 2. 1/3 Octaves Bants MS_{SoI}

Bant	F_{lwr} (Hz)	F_C(Hz)	F_{top}(Hz)	**Bant**	F_{lwr} (Hz)	F_C(Hz)	F_{top}(Hz)
1	14,1	16	17,8	**16**	447	500	562
2	17,8	20	22,4	**17**	562	630	708
3	22,4	25	28,2	**18**	708	800	891
4	28,2	31,5	35,5	**19**	891	1000	1122
5	35,5	40	44,7	**20**	1122	1250	1413
6	44,7	50	56,2	**21**	1413	1600	1778
7	56,2	63	70,8	**22**	1778	2000	2239
8	70,8	80	89,1	**23**	2239	2500	2818
9	89,1	100	112	**24**	2818	3150	3548
10	112	125	141	**25**	3548	4000	4467
11	141	160	178	**26**	4467	5000	5623
12	178	200	224	**27**	5623	6300	7079
13	224	250	282	**28**	7079	8000	8913
14	282	315	355	**29**	8913	10000	11220
15	355	400	447	**30**	11220	12500	14130

The pilot results showed that features of OAN in SoI is very high due to natural channel structure and shallow waters. South part of SoI is much nosier than north part of it due to local marine traffic. Additionally small boats which are technical equipment as lower quality are used for local marine traffic as it is well known that noise created by different types of boats diverse and depended on several features such as engine (capacity, size, type, etc.), shape, speed and size of them. Ships are armed with current technology, use controllable pitch propellers to handle speed changes in conjunction with medium speed diesels which are some 20 dB noisier for the same horse-power than traditional ones. Additionally more powerful generators of various sizes and much more electric and liquid fuel engines equipped with ships which are nosier than ever. They put out line spectra with a 7 Hz fundamental across the entire low frequency band, since their average rpm is 450 ± 100. The present trend toward using medium-speed diesels shown in this figure may have a very significant impact on noise in the future.

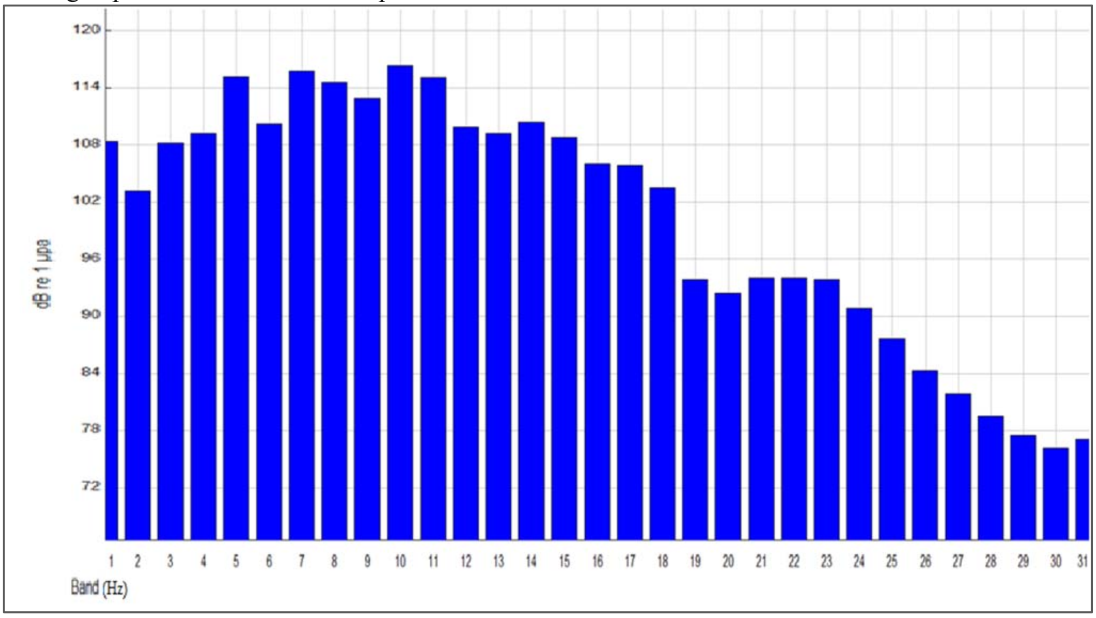

Fig. 5. 1/3 octave band frequency analysis histogram of MS_{SoI}

The marine traffic noise recorded in the MS_{SoI} is shown in Figure 6. Sound intensity in octave band analysis of the highest, average and lowest sections due to marine traffic in the register of the MS_{SoI}. The whole record was selected and analyzed in amplitude-time graphs, in units of 30 seconds through the "Sigview" program. Three 30-second segments for average loudness and two 30-second segments for lowest loudness. When this choice is made, the parts of the sea traffic effect that are most intense in the noisy environment are preferred.

Table 3. Ship mean broadband sound pressure levels (20–40,000 Hz) in sample station.

	dB
All Classes combined in SoI	110 ±4
Bulk Carrier	112 ± 5
Container	116 ± 5
Tug	108± 3
Cargo	113 ± 3
Tanker	111 ± 2
Fishing	121 ±2
Local Boats	97 ± 1

The chart of the ship-generated sea traffic noise was produced as a characteristic curve in general in MS_{SoI} (Fig. 6). Each of the curves has a wide hill in the region of 20 - 900 Hz (3.18 bands). These peak shape and frequency domains are similar to Wentz (1962) marine traffic curves (Figure 1a, 3). The peaks on the curves in the graph, each curve is different because of sound characteristics of the selected recording parts for the highest, average and lowest sound intensity. In the peak loudness curve, the peaks are more pronounced and sharp than the other curves. This is due to the fact that a boat with extreme acoustical properties suppresses other audio sources in the environment at certain frequencies, and the recorded underwater environment is dominated by the noise at that frequency. The propeller that emanates from a boat with extreme acoustics, and the frequencies at which machine sounds dominate, appear to be distinctive peaks. The peak at the highest and the mean loudness curves and at the 10th lane in the entire recording is not significant in the lowest loudness curve. Due to the marine traffic which is very close to the measuring point and dominates the whole records with a track record in the low volume it is due to the relatively far away. Band 10 (112 - 141 Hz) Fig. 5 and Table 2 is a frequency zone that contains both propeller and machine effects. As mentioned before; the more reflection, interference, scattering phenomena such as channel and shallow water increase the transmission losses of sound waves spreading over long distances. Ship mean broadband sound pressure levels (20–40,000 Hz) in sample station given in Table 3. On the 1/3 octave band analysis chart of the whole record (Figure 5), the distinct peak in the 5th band is not found in the graphics of the recording tracks dominated by the sea traffic noise (Fig. 6). This shows the presence of an audio source with a different character, which affects the entire recording, apart from the marine traffic.

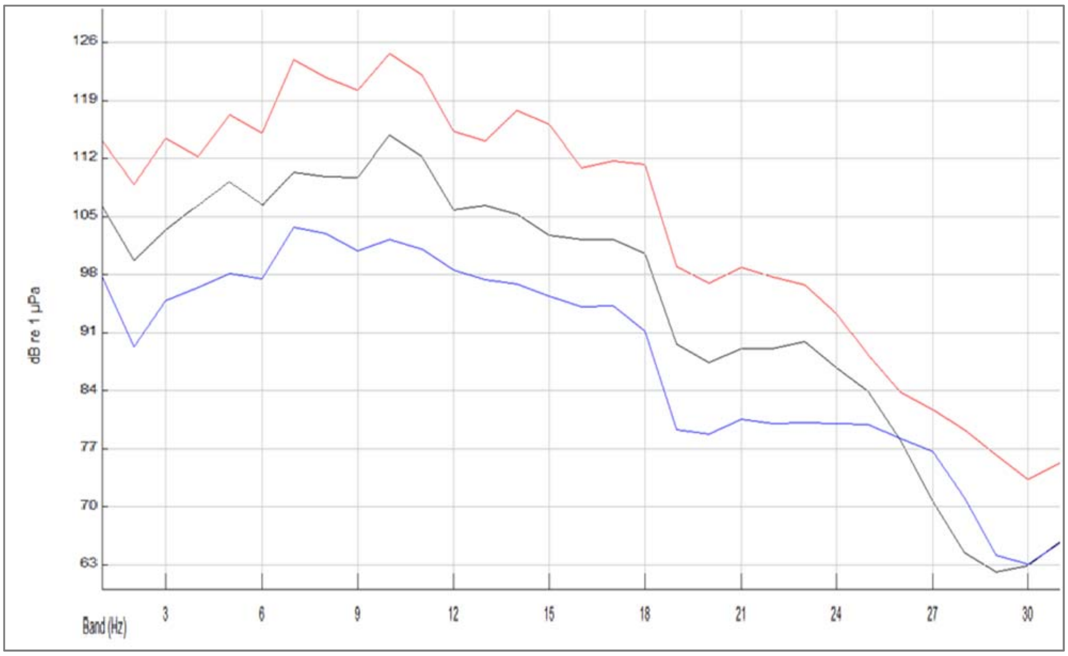

Figure. 6. Compare 1/3 octave band analysis of 30 second parts of highest (Red Line), average (Black Line) and lowest sound (Blue Line) intensities in MS_{SoI}

It is known that sound waves radiating in an environment move towards regions where sound velocity is low. Differences in depth, temperature, pressure and salinity cause stratification in the seas. This situation changes the propagation speed of the voice in the ME.

The movement of sound waves in the underwater environment, where the sound velocity is low, causes the sound channels to form at various depths and thicknesses. The band is acting like a pipe that focuses on the sound energy. The most prominent oceanographic feature of the SoI is a stratified structure. For this reason, there are interventions between the OAN_{top} measured along the top layer and the OAN_{mix} measured in the mixture layer and the bottom layer. In order to investigate the properties of these initiatives, it is necessary to develop hydrophones suitable for the layered system.

Organizations have begun to address the problem of sound propagation due to UNP, urging that governments work together. According to United Nations (UN) Convention on the Law of the Sea forbids all kind of pollution that can damage marine wildlife. The recent years it has seen a remarkable increase in awareness of OAN as an issue that must be addressed multilaterally. The understanding of UNP and its impacts needs to be investigated by the international scientific institutions (IPCC, IOC, IMO, etc.) which must be supported long-term records and measurements in diverse marine environments. UNP affects marine organisms are fully understood, with only some aspects and an extremely small proportion of the marine organisms having been investigated. A delegation of representatives from several of the organizations working on the UNP issue attended the 5th Informal Consultative Process on the UN Convention on Oceans and the Law of the Sea to increase awareness among governments about the need to address UNP which has to be developing international standards regulating UNP in the world's oceans. This will help to document the past changes in OAN besides to provide a baseline for future changes. The EU's Marine Strategy Framework Directive requires member states to attain Good Environmental Status in their seas by 2020, the one of the most important challenge to determine UNP will be pollutant.

The UNP is getting steadily increasing and growing worse for another reason. As we're making more noise, we're also making the ocean better at transmitting it. Carbon dioxide, which is directly anthropogenic activities by the global ocean, induces major changes in oceans chemistry that could have dramatic impacts on both biological ecosystems in the ocean surface and it will be the cause of the increased OAN. Specifically CO2 spewed into the atmosphere by burning of the fossil-fuel dissolves into the sea causes more acidic condition in oceans which as a strong connection between chemical oceanography and sound propagation.

Underwater could define acoustic emissions as a new category of pollutant. Additionally Underwater Noise Pollution could be added in conception of ship oriented pollution. Some environmental ethic limitation might be proposed on VTS, ADCP, etc. equipment by IALA for ship detection and on sonars by IHO/IMO for marine surveys.

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