MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Underwater assessment of anthropogenic noise sources using a field recording method

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ABSTRACT

Concern about underwater noise has been increasing due to the high number of projects needing environmental impact assessment to know how the underwater environment could be affected by pollutant noise, especially when living beings are involved. Since in countries like Chile there is no current legislation about anthropogenic underwater noise, the main objective of this work was to face this topic in Chile. To achieve it, noise sources present in rivers from Valdivia City -located in south center Chile- were evaluated. Underwater and airborne noise emissions measurement, coming from a high number of anthropogenic noise sources, both mobil and stationary, were carried out under controlled conditions and low natural background noise. Measurements were carried out both in summer and winter seasons, between December 2015 and March 2017. To have a database of sources measured with low background noise, takes a relevant value when working with mathematics models of acoustic prediction.

Keywords: Underwater noise, Environmental impact, Anthropogenic noise source
I-INCE Classification of Subject Number: 70
(see http://i-ince.org/files/data/classification.pdf)

1. INTRODUCTION

Valdivia is located in the south hemisphere of America, latitude $39^0 48' 3''$ S and longitude $73^0 14' 30''$ W, south-center Chile. In front of it, there is the confluence of the rivers Calle-Calle, Valdivia, Cruces and Cau-Cau. This characteristic makes Valdivia a very attractive city, showing important movement regarding vessels involved in touristic activities, transport, fishing and water sports. Valdivia grew and has grown around its rivers. On or near their banks there are universities, households, shops, industries, shipyards and an aerodrome.

In countries like Chile, where there is no legislation about anthropogenic underwater noise, to start working on this issue appears as highly important. Hence acquiring the

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necessary knowledge, experience and equipment to contribute with our environment protection through the carrying out of research or studies [2] [3], especially when living beings are involved.

Due to above, two objectives were stated for this study. The first one is to implement a low-cost system for the correct measurement of underwater noise. The second one is to obtain a database of anthropogenic noise sources wide enough to start to face the issue of underwater noise pollution inside the country.

2. METHOD

2.1. Recording system

The measurement system consisted of a hydrophone Cetacean Research Technology, model C55/736, lineal response from 0.15 Hz to 44 kHz, 30 m wire, a digital recorder Tascam model DR-680MKII, possessing quantization rates Q: 16/24 bit and sampling frequencies fs: 48/96/192 kHz and a computer with the software SpectraPLUS-SC 5.1D, which provided the noise descriptors used.

Owing to the lack of equipment and facilities to carry out the calibration of the system under the water, an aerial method inside an anechoic chamber was used to measure the sensitivity of the hydrophone-recorder system, which is valid for a determined frequency interval. Although, assuming a linear response of the hydrophone (which is indicated by the manufacturer), it may be extrapolated to the whole interval of interest frequencies. This calibration method corresponds with the norm EN 60565/2007 [4], ″Free field calibration by comparison″, which permits calibration on the air and free-field conditions, replacing the reference hydrophone by a calibrated microphone. The process was made inside the anechoic room of the Acoustic Department from Universidad Austral de Chile, whose dimensions are 2.45 m wide, 4.45 m long and 3.8 m high, with a chamber cut-off frequency of 120 Hz and a wedge cut-off frequency equal to 170 Hz [5].

Figure 1: Whole measurement system, Kayak, recorder, buoy, microphone and hydrophone.

Figure 1 shows the complete measurement system, composed by the kayak, plus its digital sound recorder and GPS, plus the buoy with the hydrophone and microphone. Figure 2 shows a measurement carried out to the dredger Ernesto pinto; where the microphone may be seen on the upper side of the buoy

Figure 2: Measurements carried out to the dredger E. Pinto in Valdivia River.

2.2. Noise sources assessed and study area

A total of 24 anthropogenic underwater noise sources were assessed. Nineteen are originated by vessels measured during movement and the other 5 sources correspond to factory activities or noisy events such as machine works in the shipyards, vehicle movement loading material in a quarry, a food factory, a passing airplane arriving to a nearby airdrome and piles driving during the construction of a quay. Table 1 and Table 2 show evaluated mobile sources and evaluated stationary sources, respectively.

Figure 3 shows a general view of the study area. The most habitual routs of vessels and the position of evaluated stationary noise sources, located on the rivers banks are depicted here.

Figure 3: General view of the evaluated area, where vessels routs and the evaluated noise activities are appreciated.

2.3. Measurement and noise descriptors

In this study, under and over-water noise level was simultaneously measured only to have a contrast between under and over-water levels and show that both sound environments can be very different and unrelated. Concerning environmental conditions during measurements, they were without rain or wind and with a Beaufort wind scale

Name	*Length* m	*Power* Hp	*Size*
Solar III	9.5	5	small
Iceberg	10.3	75	small
Daniela Isidora	12.45	90	small
Outboard boat 1	2.8	6	small
Outboard boat 2	4.2	50	small
Outboard boat 3	5	80	small
Bahia II	10.5	120	small
Bahia Patagonia	15.5	200	medium
Zodiac Marina	13.5	200	medium
Discovery	16.83	240	medium
Explorador	13	150	medium
Reina Sofia	17.5	320	medium
Bahia Princesa	12.66	160	medium
M. de Mancera	21.8	320	large
Dredger E. Pinto	53.7	1129	large
Patagon VIII	69.5	ND	large
Ferry Cullamo	48.4	400	large
Neptuno	25.2	400	large
Calle Calle	29.9	115	large

Table 1: Characteristics of the assessed vessels.

between 0 and 1 [8]. Regarding the hydrophone, it was allowed going with the tide, this way, the low frequency noise produced by the relative velocity between the water and the hydrophone, and located between 10 Hz and 100 Hz, was eliminated. Measurement depth was always 4 meters.

The noise descriptors used were $L_{eq,T}$ and L_{peak}. $L_{eq,T}$ is commonly used to assess airborne noise and gives a unique number representing the sound pressure level of a constant noise possessing the same acoustic energy as that possessed by the fluctuating noise under evaluation, in the same measurement time interval T. Regarding impulsive noise, such as piles driving, the descriptor usually used to evaluate this type of airborne noise is L_{peak}, which gives the sound pressure level obtained from the highest instant sound pressure $p(t)$ inside the considered time interval. The formulae for $L_{eq,T}$ and L_{peak} are given by

$$L_{eq,T} = 10 \log[\frac{1}{T} \int_0^T (\frac{p(t)}{p_0})^2] \ dB, \tag{1}$$

$$L_{peak} = 10 \log(\frac{p(t)_{peak}}{p_0})^2 \ dB, \tag{2}$$

The measurement method consists of measuring the noise emitted by the tested ship during its passage in front of the hydrophone, though it is different from some standardized measurement methods where a single rms level is measured during the time the passage of the ship lasts, called "data window period (DWP)" [6] [7]. In this work the noise emission is measured by 10-second integration intervals and the highest measured

Activity	*Description*
Airplane noise	Twin-engined plane landing on an airdrome.
Shipyard	Sandblasting of vessel out of water.
Shipyard	sandblasting + emery polishing of vessel out of water.
Shipyard	sandblasting + metallic bumps inside vessel out of water.
Shipyard	Riveting inside a berthed ship.
Shipyard	Metallic bumps inside a berthed ship.
Quarry	Dozer loading stones over a truck.
Factory	General working of a yeast factory.
Quay	Piles driving, 61cm in diameter, during the construction of a quay.

Table 2: Description of assessed noise activities.

level is saved. This way, considering the highest level obtained during the measurement as the one emitted by the ship, we are also considering the most unfavorable situation regarding noise emission.

2.4. Correction by distance and frequency analysis

Knowing the noise level emitted by the source at a distance of 1 m (Source Level) is important as database to contrast different noise sources and to work with more accurate information during environmental impact assessment EIA, where underwater acoustic contamination needs to be assessed. To obtain source level the following expression was used

$$L_{p,1m} = L_{eq,T} - 15Log(\frac{1}{d})\ dB, \tag{3}$$

where $L_{p,1m}$ is the source level and d is the distance to the source from where $L_{eq,T}$ was measured. Due to the depths presented by Valdivia Rivers, between 3 m and 14 m, a spherical propagation is scarcely provable [9], unless the receptor is too close to the source, relative to the depth. That is the reason why the decision was to consider a propagation between spherical and cylindrical (Equation 3), which was better adjusted to the empirical results obtained.

When the spectral content of a signal is used to assess possible hearing damage undergone by a certain species exposed to it [11] [12], the right thing to do is to deliver the spectrum of this signal using a 1/3 octave bands analysis and contrast it with the curves of the hearing threshold of the exposed species. In frequency bands where the signal amplitude overcomes the hearing threshold amplitude, the individual will certainly perceive the signal. The damage or reaction suffered by the exposed species will depend on the magnitude of the value by which the signal amplitude overcomes the hearing threshold in a determined frequency band [8] [13].

Marine mammals present hearing systems possessing similar characteristic to that of the human being, with its own hearing threshold curve [8] [15]. Due to this similitude between hearing systems of marine mammals and human mammals, it can perfectly be assumed that each type of marine mammal possesses their own critical bands within their hearing range; although this has not rigorously been empirically proven. That is the reason why, when seeking to determine how one species is affected by a signal or noise, it is necessary to contrast 1/3 octave band noise spectrum with the hearing thresholds of the exposed individuals [14] [16].

3. RESULTS

3.1. Levels and spectra

As previously indicated, 24 noise sources were assessed; among them, there were boats, industry activities and noise events. Measurements of background noise were made in many points where measurements were executed. In this work, background noise is understood as that noise existing at a determined place in the absence of any other sound source to be evaluated and absence of wind and rain. Table 3 shows the background noise levels measured.

Due to field work reasons, measurements were carried out at different distances d of the evaluated sources and at a constant depth of 4 meters. This is observed in Tables 4 and 5, where columns two and three show the highest measured values, and between brackets those distance at which measurements were carried out. Columns four and five show the estimated levels for a distance $d = 1$ meter from the source (source level), obtained through the Equation 3 of propagation. These source levels permit comparison and determination of the noisiest source. Column six and seven show the airborne noise emitted by the noise sources.

	L_{eq}, dB $re.1\mu Pa$	L_{peak}, dB $re.1\mu Pa$
Background 1	92	94.2
Background 2	88.4	92.9
Background 3	94.5	98
Background 4	86.9	90

Table 3: Natural environmental noise levels measures throughout the assessed routs.

The amplitude shown by the 1/3 octave bands spectra corresponds to the Lp_{rms}, where the integration time interval T covers from the beginning of the evaluated event until the moment bands reach the highest amplitude, thus, permitting to assess again the most unfavorable situation, about noise emission. Therefore, these spectra can be used to work considering the most unfavorable situation.

Small vessels present spectra possessing different dynamics, especially the electric vessel Solar III, whose spectrum is completely different and presents very low amplitude (see Figure 4). Spectra of boats classified as medium-sized or big are observed to show

Vessel name	L_{eq}, dB $re.1\mu Pa$	L_{peak}, dB $re.1\mu Pa$	$L_{p,1m}, dB$ $re.1\mu Pa$	L_{peak}, dB $re.1\mu Pa$	L_{eq}, dB $re.20\mu Pa$	L_{eq}, dBA $re.20\mu Pa$
Solar III:	116.4 (d=20m)	123.3 (d=20m)	135.9 (d=1m)	142.8 (d=1m)	65.8 (d=20m)	52.4 (d=20m)
Solar III: (docking)	109.7 (600m)	113.8 (600m)	151.3 (1m)	155.5 (1m)	66.7 (600m)	53.8 (600m)
Iceberg:	124.8 (15)	129.2 (15)	142.4	146.8	67.5 (15)	56.5 (15)
Daniela Isidora:	116 (70)	116.8 (70)	143.7	144.5	63.3 (70)	52.8 (70)
Outboard boat 1:	129.5 (8)	135 (8)	143	148.5	73.9 (8)	63.9 (8)
Outboard boat 2:	121.7 (10)	130.7 (10)	136.7	145.7	68.1 (10)	56.7 (10)
Outboard boat 3: (very fast)	128.8 (60)	131.3 (60)	155.5	157.9	64.9 (60)	52.9 (60)
Bahia II:	124.9 (40)	126.4 (40)	148.9	150.4	64 (40)	52.6 (40)
Bahia Patagonia:	134.6 (15)	136.2 (15)	152.2	153.8	62.2 (15)	52.9 (15)
Marine Zodiac:	124.1 (95)	127.5 (95)	153.8	157.2	79.3 (95)	57.5 (95)
Discovery:	137.2 (40)	139.8 (40)	161.2	163.8	73.8 (40)	59.9 (40)
Explorador:	132.3 (30)	135.7 (30)	154.5	157.9	69.1 (30)	56 (30)
Reina Sofia:	124.9 (150)	126.5 (150)	157.5	159.1	61.5 (150)	56.2 (150)
Bahia Princesa:	128.2 (20)	131.8 (20)	147.7	151.3	58.2 (20)	49.9 (20)
Marquez de Mancera:	127.6 (250)	129.9 (250)	163.6	165.9		
Dredger E. Pinto: (againts the tide)	156 (150)	157.7 (150)	188.6	190.3		
Dredger E. Pinto: (sailing downstream)	144 (25)	146.8 (25)	165	167.8	67.9 (25)	55.8 (25)
Dredger E. Pinto: (ralenti)	133 (25)	140.2 (25)	154	161.2	67.1 (25)	55.2 (25)
Patagon VIII: (docked/accelereted)	133.5 (20)	136.2 (20)	153	155.7	64 (20)	52.1 (20)
Ferry Cullamo: (sailing downstream)	126.7 (100)	129.2 (100)	156.7	159.2	62.5 (100)	53.4 (100)
Ferry Cullamo: (againts the tide)	147.9 (100)	150.9 (100)	177.9	180.9		
Neptuno:	119.6 (70)	121.3 (70)	147.3	149	65 (70)	52.6 (70)
Calle Calle:	126.7 (50)	129.2 (50)	152.2	154.7	72.8 (50)	57.9 (50)

Table 4: Noise levels measured, generated by the assessed vessels.

Activity	L_{eq}, dB $re.1\mu Pa$	L_{peak}, dB $re.1\mu Pa$	$L_{p,1m}, dB$ $re.1\mu Pa$	L_{peak}, dB $re.1\mu Pa$	L_{eq}, dB $re.20\mu Pa$	L_{eq}, dBA $re.20\mu Pa$
Airplane noise: Twin-engined plane landing on an airdrome.	119 (d=100m)	130 (d=100m)				
Shipyard: Sandblasting of vessel out of water.	91.5 (240)	103.8 (240)	127.2 (1)	139.5 (1)	76 (240)	75.6 (240)
Shipyard: sandblasting + emery polishing of vessel out of water.	91.8 (200)	97 (200)	126.3	131.5	74.8 (200)	74.4 (200)
Shipyard: sandblasting + metallic bumps inside vessel out of water.	93.8 (150)	96 (150)	126.4	128.6	71.4 (150)	67.5 (150)
Shipyard: Riveting inside a berthed ship.	104.7 (550)	111.5 (550)	145.8	152.6	53.6 (550)	47.3 (550)
Shipyard: Metallic bumps inside berthed ship.	108.1 (400)	123.8 (400)	147.1	162.8	63.5 (400)	55.3 (400)
Quarry: Dozer loading stones	91 (150)	96 (150)	123.6	128.6	66 (150)	58 (150)
Factory: Yeast	100 (140)		132.2		75.3 (140)	64.9 (140)
Factory: Yeast	103 (95)		132.7		76.5 (95)	65.3 (95)
Factory: Yeast	106.4 (50)		131.9		78.5 (50)	66.8 (50)
Dock: Piles driving 61 cm in diameter.		162 (225)		197.3	100 (225)	
Dock: Piles driving 61 cm in diameter.		177 (25)		198	120 (25)	

Table 5: Noise levels over and under the water resulting from the assessed industrial activities.

a similar distribution of energy with frequency, with increasing sustained amplitude; starting from high frequencies toward medium-low frequencies, and subsequently producing abrupt drop of amplitude around the frequency interval between 100 Hz and 300 Hz (see Figure 5 and Figure 6).

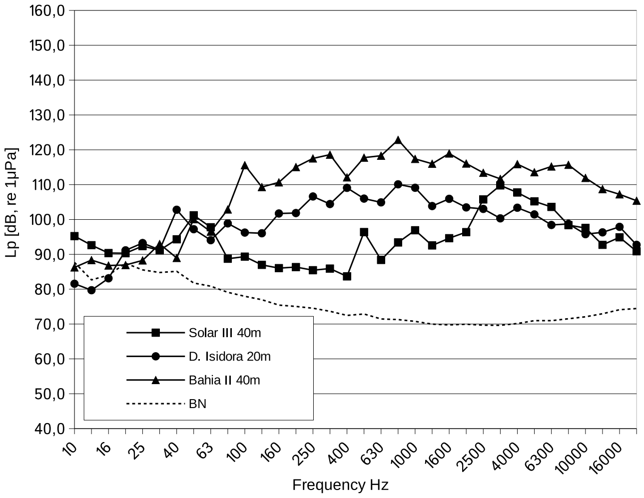

Figure 4: 1/3 octave band analysis of Small Vessels. Solar III (measurement distance d:40 m), Daniela Isidora (d:20 m), Bahia II (d:40 m) and mean background noise BN.

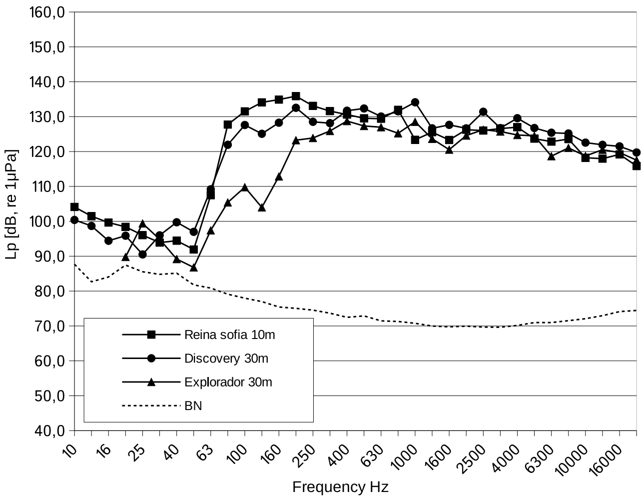

Figure 5: 1/3 octave band analysis of Medium-Sized Vessels. Explorador (measurement distance d:30 m), Discovery (d:30 m), Reina Sofia (d:10 m) and mean background noise BN.

4. DISCUSSION

To count on a database of noise emission sources such as those assessed in this work, measured under field conditions and in absence of environmental noise produced by environmental conditions such as wind, waves and rain, takes a significant value when working with acoustic predictions mathematics models, where information must be as

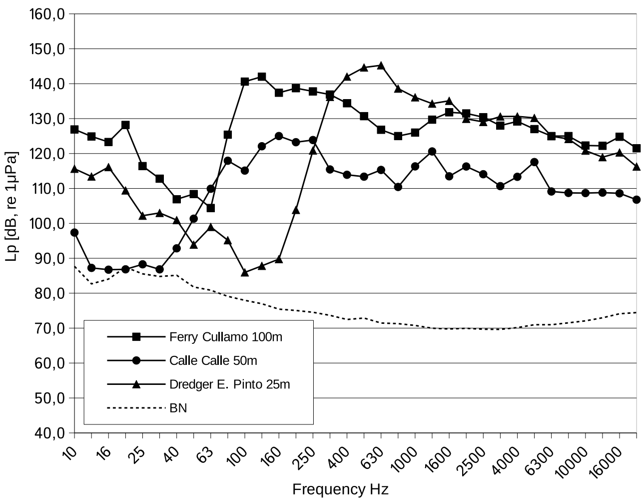

Figure 6: 1/3 octave band analysis of Big Vessels. Ernesto Pinto (measurement distance d:25 m), Calle Calle (d:50 m), Cullamo (d:100 m) and mean background noise BN.

accurate and reliable as possible, close to the acoustic characteristics of the noise sources considered.

The measurement method for the evaluation of noise emitted by anthropogenic noise sources presented in this work is a field method that uses a digital recorder through which the noise emitted from the evaluated source is recorded, under environmental conditions of low background noise. Subsequently, using a software, the desired noise descriptors are obtained. A database of anthropogenic sources of underwater noise is provided, whose values of noise emissions coincide with levels given in other works [8] [10]. Most ships were measured within an area of speed limit up to 11.1 km/h, thus database may be used directly to evaluate the acoustic impact this type of boats may produce in protected areas with similar speed limits.

Results in Table 4 column seven show that in the open air the evaluated ships are not noisy, since all levels are found under 60 dBA (re.20μPa). These emissions basically correspond to those coming from the output duct for the combustion engine gases.

Under the water, levels of noise emitted by vessels are higher, obviously partly because the reference pressure for the fluid water is lower (1μPa). Noise emitted by boats under the water is composed by the engine airborne noise directly transmitted to the water through the boat hull, by means of the engine vibration transmitted to the hull and afterward to the water; and by the noise produced by the propeller interacting with the water. Table 2 and Table 4 clearly show how emission level increases as the size and power of the vessel increases.

In small vessels, for example Solar III, which has an electric engine fed by solar energy, it emits a level comparable to that of large boats when operating (maneuvering) to get close to the dock. During displacement, the boat Solar III is the ship emitting the least noise; being very silent if we contrast its emission spectrum with the noise spectrums of the background noise of the place (see Figure 4).

Table 5 shows which industrial activities or noise generating events, such as a passing plane, a bulldozer moving earth and stones, or the repairing of a boat taking place near the water, though out of it, produce noise levels considerably lower than those emitted by small vessels. This makes sense due to the well-known reflection phenomenon produced in the interface air-water for large incidence angles; angles, which as in this case, happens

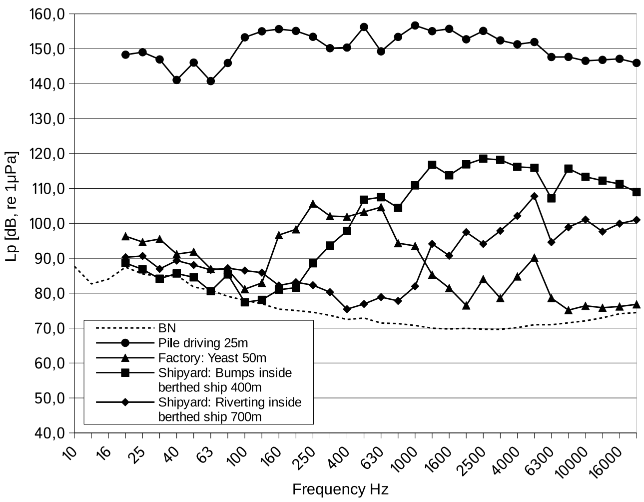

Figure 7: 1/3 octave band analysis of the assessed industrial activities. Pile driving, pile diameter 61 cm (measurement distance d:25 m), Bumps inside a berthed ship (d:400 m), Riverting inside a berthed ship (d:700 m), Yeast factory (d:50 m) and mean background noise BN.

due to the position of the noise sources relative to the water. Now activities of riveting and bumps, carried out inside boats which are in the water and not out of it, show noise levels comparatively higher since noise is transmitted directly through the boat hull to the water (see Figure 7).

Within these industrial activities, outstand those noise levels obtained for piles driving and yeast factory, which were measured at different distances from these two noise sources. The decay by distance shown by these results fits very well the propagation equation chosen for this work (Equation 3), confirming sound propagation between cylindrical and spherical for the depths between 3 and 14 meters present in the rivers. The Figure 7 shows the high level of noise achieved by pile driving activity.

In the area where most part of the evaluated boats move and some of the assessed fixed sources are located, for many years there has existed a colony of sea lions, which apparently does not present any type of behavior or reaction attributable to their exposition to these noises. It would be good to count on an audiogram of a member of this colony to compare it with the analyses in bands of 1/3 octave and determine the sonority with which they are perceiving noise present surrounding their habitat. The idea is to analyze the spectra emitted by each source starting from the measured hearing threshold and, thus, obtain a dB value equivalent to dBA applied to human beings. Only in this way, it is possible to know how high or how low wolves are perceiving noise and to appraise the possible damage they are exposed to.

5. REFERENCES

[1] Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P., Wasser, S.K., Kraus, S.D. . Evidence that ship noise increases stress in right whales. Proc. R. Soc. B Biol. Sci. 279 (2012) 2363-2368.

[2] Codarin, A., Wysocki, L.E., Ladich, F., Picciulin, M. . Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). Marine Pollution Bullettin 58 (2009) 1880-1887.

[3] Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., Thompson, P. M. . Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Marine pollution bulletin 60 (2010) 888-897.

[4] EN 60565. Underwater acoustics, Hydrophones, Calibration in the frequency range 0,01 Hz to 1 MHz., 29-30, 2007.

[5] EN ISO 3745. Acoustics, Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for anechoic rooms and hemi-anechoic rooms. 2012.

[6] ISO/PAS 17208-1. Acoustics, Quantities and procedures for description and measurement of underwater sound from ships. Part 1: General requirements for measurements in deep water. 2012.

[7] ANSI/ASA S12.64. Quantities and Procedures for Description and Measurement of Underwater Sound from Ships. Part 1: General Requirements. 2009.

[8] Richardson, W.J., Greene Jr., C.R., Malme, C.I., Thomson, D.H. . Marine mammals and noise. Academic Press Inc., New York. 1995.

[9] Farcas, A., Thompson, P.M., Merchant, N.D. . Underwater noise modelling for environmental impact assessment. Environmental Impact Assessment Review 57 (2016) 114-122.

[10] MMO. Modelled Mapping of Continuous Underwater Noise Generated by Activities. A report produced for the Marine Management Organisation, pp 50. MMO Project No: 1097. ISBN: 978-1-909452-87-9. 2015.

[11] Williams, R., Erbe, C., Ashe, E., Beerman, A., Smith, J. . Severity of killer whale behavioral responses to ship noise: A dose response study. Marine Pollution Bulletin (2014) 254-260.

[12] Merchant, N.D., Pirotta, E., Barton, T.R., Thompson, P.M. . Monitoring ship noise to assess the impact of coastal developments on marine mammals. Marine pollution bulletin 78 (2014) 85-95.

[13] European association for aquatic mammals. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic mammals 33 (2007) number 4.

[14] Moore, B.C.J. . Introduction to the Psychology of Hearing. Emerald (2012) 67-74.

[15] Ketten, D.R. . Marine mammal auditory system noise impacts: evidence and incidence. Advances in experimental medicine and biology 270 (2012) 207-212.

[16] Nedwell, J.R., Turnpenny, A.W.H., Lovell J., Parvin, S.J., Workman, R., Spinks J.A.L, Howell D. . A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. Subacoustech Report No. 534R1231. 2007.