Underwater Acoustic Pollution: Sources and Biological Impact

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Abstract*. Humans perceived the underwater noise in a limited way, which has led him to make an abusive use of some systems that perturb the underwater environment. The main human activities that generate Underwater Noise Pollution (UNP) are dredging and construction, drilling and production of oil and gas, shipping, geophysical investigations, active sonars, underwater explosions and oceanographic research. The noise pollution affects the maritime flora and fauna since the moment that the development of habitual behaviour is altered. Pollution levels of a particular sound and its morphological and physiological impact depend on the exposure time and the intensity of the received signal as well as the species.*

1 Introduction

The sea has never been a quiet environment. The fact that it is an elastic means allows the movement of the particles and therefore the transmission of acoustic wave. Noise always has existed in the sea (Fig. 1): natural, such as waves, wind and rain or biological such as that produced by living things.

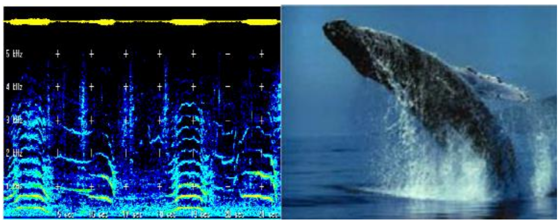

Fig 1. Biological Noise.

Human is not adapted to the aquatic environment so not perceives the underwater ambient noise totally, finding it quiet and relaxing. This limited perception has led him to make an abuse of some underwater systems that perturb the environment without considering the repercussions that could result.

Underwater Noise Pollution can be defined as the excess noise (defined as excessive and annoying sound) caused by humans that modifies the normal environmental conditions in a given area and produces negative effects on auditory and physical health of living beings. Although apparently the noise not accumulates, continuous exposure may impair the quality of life of living beings (harassment, avoidance, difficulty in communication, feeding interruption and mating, etc), and even cause damage although the noise comes from recurring emission of very short duration.

2 Characterization of Underwater Noise Sources

Sound sources are characterized by: frequency (Hz) of emission, intensity/source Level (dB ref 1 µPa @ 1 m), length of time (seconds or ms), working cycle (%), bandwidth (Hz), directivity, output power (W) and persistence. Propagation of noise radiated by an acoustic source depends on temperature and salinity of seawater (according with depth), depth, type of seabed and depth of noise source.

There are two types of acoustic noise:

- **BroadBand Noise**: It is a broad-spectrum noise, that is, the level of acoustic energy is a continuous function of frequency. The acoustic energy is spread to a wide range of frequencies. Typical broadband noises are the produced by shafts and propellers of ships or hydrodynamic noise produced by the passage of water through the hull of a ship.
- **NarrowBand Noise**: It is a noise spectrum that has a small band centered at a particular frequency (discrete frequency or tone).
  Typical narrowband noises are the generated by machinery such as diesel engines of vessels or produced by the auxiliary equipment such as generators.

The radiated noise usually exists as a continuous spectrum over which are overlapped tones. Both components, continuous and discrete, decrease with increasing frequency.

3 Underwater Noise produced by industrial activities

3.1 Noise produced by dredging and constructions

The marine dredging, tunneling and various construction activities in and near the sea creates underwater noise. The dredging is used to make deeper channels and ports, to create either immersed or ground platforms and for undersea mining. The noise generated may exceed ambient levels over long distances.

Malme y Krumhansl measured noise generated at 50 meters from Robbins machinery used to build a tunnel of 8 meters. Broadband sounds were predominant, being strongest below 10 Hz, decreasing the energy when increasing the frequency to 500 Hz. Farther strongest components of 30 Hz to 100 Hz appeared, caused by resonance effects related to water depth.

3.2 Noise produced by drilling and exploitation of oil and gas

The perforations can be made from natural or artificial islands, platforms or ships. The perforations performed from natural or ice islands generate a very low noise. The sound range is typically in the 2 km away the working area, at frequencies of 200 Hz. In the shallow arctic waters, during the winter, frequencies below 350 Hz are generated, suffering an attenuation of 125 dB at a distance of 130 m and of 85 dB at a distance 2 km.

Drilling from artificial islands produce a noticeable noise but still low. The tones can become detected at 0.5 km without drilling and 3.7 km drilling. There is noise related with the assemblage of elements of facilities, eg conductive pipe, in which industrial hammers are typically used.

The noise generated by drilling platforms is not well studied. There have been some measures in which it is concluded that the noise is not detectable with sea state levels> 3.

Drilling can be performed on two types of vessels, semi-submersibles and drill ships. The noise generated by drilling vessels is higher. Depends on the type of machinery used and the age of it.

The noise in the production of oil and gas is very low because these facilities have little contact with surface water.

Table I shows frequencies and levels of noise produced by drillings and oil & gas workings.

Actividad	**Frecuency (Hz)**	**Level dB ref. 1 μPa**	**Dist**
Drilling (Artificial islands)	20 - 100 20 and 40 predominant	8 - 10 dB Over background	5 km
Platforms Installations	30 – 40 and 100	131 – 135 100 – 106 Broadba nd	1 km
Platforms drillings	5 (1,2 kHz higher)	119 – 127	
Semi-submersibles	29 and 70	125 and 154	13 –
Oil & Gas Production	30 and 120	89 – 94	34 m

Table I. Underwater Noise produced by drillings.

3.3 Noise produced by transport

Air platforms

Sound transmission in air-water modifies the characteristics of sound received underwater. The sound level produced by aircrafts (Table II) depends on frequency, receptor depth, water depth, airplane altitude, airplane shape and sound level of source. Normally, a peak level received by a receiver decreases with increasing aircraft altitude or depth of receptor. Dependence with the aspect of the aircraft is such that if the angle between the line of the plane and the receiver is greater than 13 º most rays are reflected and do not penetrate the water if low sea state, deep sea or waters non-reflective backgrounds. Furthermore, if the wavelength of the sound waves emitted is larger than the wavelength of the waves of the sea surface, this behaves as a fully reflective surface.

The depth and bottom features influence the propagation and levels of underwater noise. The lateral propagation is better in shallow water, especially when the seabed is reflective. As a result, the limit of 13 ° is not always the same, even runtime measured in a submarine aircraft receptor is increased in shallow water by reflections in the bottom.

The aircraft used piston machines or turbines. Each type of motor can be driven propeller or rotor (helicopters) and turbines turbojets or turbofans. The sounds of machinery piston are dominated by the switching on frequency of the piston, which causes a family of tones in the spectrum (harmonics).

Turbine engines are characterized by the whistle of the blades within the different phases of the motor. The tones are produced from a few Hz up to frequencies above 1 kHz. The primary sources of noise generated by aircraft with turbines turbojet or turbofan are propellers and rotors. The rotation of the blades produces fundamental frequency tones that depends on the rotational speed and the number of blades. The spectra of the noise generated by aircraft and helicopters are generally below 500 Hz

The duration of the sounds received by a submarine receptor is lower than received by a non-submarine receiver. For instance, the sound produced by a helicopter BELL 214ST is received in the air four minutes before it passes over the receiver, while the water is detectable 38 s @ 3 m 11 s @ 18 m before it passes over the receiver. The duration increases with increasing altitude of the aircraft, tending to be more audible in deep water than in shallow water.

Naval Platforms.

The noise generated by ships is the largest contributor to underwater noise (Fig. 2). The levels and frequencies of the sounds produced depend on the size and speed of the vessel, generating broadband noise and narrowband. The typical sources of broadband noise are the propellers / shafts (below 100 Hz), hydrodynamic noise and some propulsion systems. Typical sources of narrow band noise are the pumps, motors, power equipment and propulsion systems.

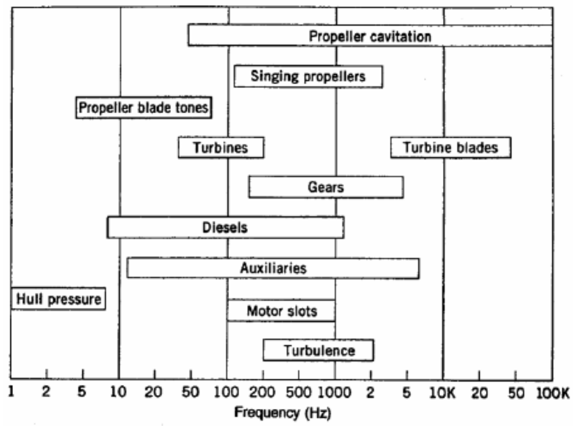

Fig 2. Range of Frequencies emitted by ships.

Aircraft **(Frequency)**	**Altitude** **(m)**	**Received Level** **(dB ref a 1 µPa)**	**Estimated level of the source** **(dB ref @ 1 µPa - m)**	**Estimated spectral density level of the source dB ref 1(1 µPa - m)^2/Hz**			
				1000 m	**2000 m**	**3000 m**	**4000 m**
Helicopter **BELL 212 (22 Hz)**	152 305 610	109 107 101	149 151 151	111	107	101	93
B-N Islander **(70 Hz)**	152	101	142	102	97	91	75
Twin Otter **(82 Hz)**	457 610	107 100	147 150	105	98		
P-3 Orion **(56-80 Hz)**	76 152 305	124 121 114	162 162 160				
P-3 Orion **(890-1120 Hz)**	76 152	112 107	150 148	124			

Table II. Sound Levels of Aircrafts

3.4 Noise generated in geophysical researches

The geophysical investigations use sound sources to generate seismic waves (Table III). These sources are characterized by generating a noise very high energy, low frequency and short duration. This type of sound is detectable hundreds of kilometres from the source. The most used sources are: air guns, Sleeve Exploders, gas guns and Vibroseis.

The Air-Guns systems are the currently most widely used. The Air-Guns are able to generate pulses every 10 to 15 s. In some areas, the low frequency energy can travel long distances through the bottom sediments, coming back to the source through the water. The speed of sound is higher in sediment from the bottom that in the water, in fact, a receiver located at a distance, will receive first a transmitted through the bottom followed by a pulse transmitted through water.

The Sleeve Exploders and Gas-Guns are loaded with a mixture of oxygen and propane to generate the sound pulse. The resulting signal is similar to those generated by a small air-gun. As is the case with the Air - Guns, with increasing distance decreases not only the level but also increases the duration of the pulse, so that high frequencies (200 Hz) in the generator, arrive at the receiver as low frequency (70 Hz).

Vibroseis is a method used in ice based on an array of hydraulic devices that hit the ice. The frequency of the signals used is 10 - 70 Hz, although harmonics may range up to 1.5 kHz. The generated signals are transients of 5-20 s duration being able to generate signals with levels of 187 dB ref 1 µPa @ 1 m to 50 Hz during a sweep of 10 to 65 Hz. The attenuation factor is 22.5 dB / km at 10 Hz and 31.5 dB / km at 60 Hz.

3.5 Noise produced by Active Sonars

Active sonar is based on the emission of a pulse and measure the echo that occurs when the pulse bounces on a surface. They can be classified according to type and use: variable depth sonar, commercial fishing, to measure currents and maritime research, and military to detect ships, for object detection and used in weapons like torpedoes.

The Sonar frequencies ranging from a few hundred Hz as in the case of sonar of search for long range up to several hundred kHz as in sonar used in the search for mines, marine cartography and generally those systems that require discriminate small objects.

Source Type	Depth (m)	Level dB ref 1 µPa @ 1 m
Array Air - Gun		
GSC 7900		259
ARCO 4000	10	255
GECO Array 3100	7,6	252
GSI Array Jonsson 200	6,1	249
SSL Array 1460	7,6	242
GECO 594 Subarray	8,2	235
Air- Gun Simple		
Small	9,1	216
Medium	9,1	225
Big	9,1	232
Sleever Exploder		148 – 153 @ 8 km 115 – 117 @ 25 km
Gas - Gun		123 @ 0,9 km 117 @ 14,8 km

Table III. Noise produce by seismic generators.

Sonar pulses (Table IV) may have a high level. For example, the sonar used to map the seabed generates a pulse of 210-230 dB ref 1 µPa @ 1 m. The pulse duration can be from a few microseconds to a second.

Tipo de SONAR	Frec (kHz)	Duración (ms)	Nivel (dB)
Variable Depth	12+	10-1000	180
Bottom profile	0,4-30	0,1-160	200-230
Side scan	50-500	0,01-0,1	220-230
Navegation	7-60	3-40	180-200
Search & Surveillance	2-57	4-1000	230+
Mines & obstacles avoidance	25-500	1-30	220+
Weapons	25-200		200
Submarine Telephone	5-11	Continuo	180-200

Table IV. Noise produced by Active Sonars.

3.6 Noise produced by explosions

The underwater explosions produced by man are the most powerful except underwater submarine earthquakes or volcanic eruptions. The pressure pulses generated by them produce noise capable of causing physical injury or death of marine mammals. Even small detonations may be detectable at hundreds of miles if they propagate in the sound channel. For example, depth charges (100 kg) detonated in the deep sound channel in Australia have been detected in Bermuda.

3.7 Noise produced by oceanographic scientific researches.

Some scientific studies use acoustic energy to analyse the characteristics of seabed and water, needing more acoustic power the study of the bottom. Acoustic energy is also used to study the sound transmission loss properties and the oceanographic masses.

Since WWII were used loads of 0.9 kg to study the propagation of sound and bottom features. This charge located at depth of 18 or 244 meters generates a peak pressure at a distance of 1 km of 208 dB ref 1 μPa, the pulses of bubbles have a frequency of 8 Hz and 50 Hz and the impulse estimated at 1 km is 7.1 Pa. In tomographic acoustic are used projectors that generate pressure levels of 165 dB ref 1 μPa @ 1 m for short-range devices and 190 220 dB ref 1 μPa @ 1 m for devices long range. The working frequencies are between 50 Hz and 200 Hz.

Thermometric acoustic specializes in long range studies in which ocean temperatures are obtained basing on the measurement of the variation of the speed of sound. In 1991, The Heard Island Feasibility Test was performed. Three types of 57 Hz signals were projected in the sound channel at a depth of 175 m, every half hour for 7 days. An array of transducers that generated levels of 220 dB ref 1 μPa @ 1 m was used. At such levels were detected 160 dB at 1 Km, 137 dB at 72 km depth 80 m and 120 dB at distances of 100-1000 km, depending on the depth of the receivers. The signals were detected up to a distance of 17,000 km.

4 Impact of underwater noise on marine animals

To that noise pollution affects living things not only if acoustic trauma occurs, they are affected since the moment the development of habitual behaviour is not possible. This contamination scares them (decreased catches) and makes them change their migratory routes and behaviour, in addition to complicate their perception abilities, to affect communication, prey location, orientation, etc.

Noises of medium frequency (1-10 kHz) and obviously the higher intensity are the most dangerous noises produced by humans, since cause lethal damages and non-lethal (temporary or permanent) damage to most marine mammals.

It is considered that a higher level of 160-165 dB causes physical damage to marine animals. In Tables V and VI are shown, at a discrete series of distances, the intensities provided as an estimated value from different sources and different types of propagation.

Source	Nivel dB ref 1 μPa @ 1 m	1 km	2 km	20 km	200 km
Cylindrical Spreading					
Outboard	162	132	129	119	109
SONAR MF Medium power (1 a 10 kHz)	220	190	187	177	167
SONAR LF (0,1 a 1 Khz)	230	200	197	187	177
SONAR MF (1 a 10 kHz)	235	205	202	192	182
Echosounder Multibeam and Parametric (HF > 10 kHz)	235	205	202	192	182
Explosion	250	220	217	207	197
Air guns	270	240	237	227	217

Table V. Underwater noise Levels, cylindrical spreading.

Source	Level dB ref 1 µPa @ 1 m	1 km	2 km	20 km	200 km
Spherical Spreading					
Outboard	162	103	97	77	57
SONAR MF medium power (1 a 10 kHz)	220	161	155	135	115
SONAR LF (0,1 a 1 Khz)	230	171	165	145	125
SONAR MF, Parametrics (1 a 10 kHz)	235	176	170	150	130
Explosion	250	191	185	165	145
Air guns	270	211	205	185	165

Table VI. Underwater noise Levels, spherical spreading.

Pollution levels of a particular sound and its morphological and physiological impact depend on the exposure time and the intensity of the received signal as well as the species. Levels and frequencies used for each of these activities is different for each species.

Therefore one of the priority issues is to know the intensity and minimum exposure time to an emission in order to decrease the hearing sensitivity at these frequencies, both in temporarily and permanently way.

Apart from the damage to the auditory system, other more harmful physical effects are produced as cerebral haemorrhage, pulmonary damages, tissue trauma, strandings, etc.. Therefore, another important issue is to determine the minimum distance to a sound source to be safe from any of these effects, which is a function of source type, intensity and position as well as the propagation characteristics.

To mitigate these effects, any proposal includes a number of good practices, such as those of: see if there is presence of marine mammals at least half an hour before starting to transmit, start with low-emission power to progressively increase it (soft starts) and interrupt emissions if the presence of cetaceans and other marine mammals within the area of influence is confirmed.

5 Conclusions

The insufficient current knowledge of the hearing ability of marine species and their dependence on this sensory perception is the greatest obstacle to define a protocol to harmonize human activities with respect to the environment.

In this sense, cetaceans, due to their relationship vital and almost exclusive dependence with acoustic information, may represent the best biomarker of the effects of marine noise pollution.

Certain actions are being taken into account to mitigate as far as possible the impact of this pollution may represent.

References

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