

Multidisciplinary  
SCIENTIFIC JOURNAL OF  
MARITIME RESEARCH



University of Rijeka  
Faculty of Maritime  
Studies Rijeka

Multidisciplinarni  
znanstveni časopis  
POMORSTVO

## Noise as a source of marine pollution

Ivan Sarić<sup>1</sup>, Radoslav Radonja<sup>2</sup>

<sup>1</sup> University of Rijeka, Faculty of Maritime Studies Rijeka, Studentska 2, 51000 Rijeka, Croatia

<sup>2</sup> University of Rijeka, Faculty of Maritime Studies Rijeka, Studentska 2, 51000 Rijeka, Croatia

### ABSTRACT

The increased consumption of fossil fuels which are the basis of modern technological development and its inability of sustainability on known sources and resources causes an increase effort to investigate new feeds. Although the researches are conducting on the land area (lithosphere), in the last years, they are, globally speaking, particularly focused on the seabed, where the Adriatic Sea is no exception, what we can witness today. Seismic tests, using 'air guns', are just one of the anthropologically caused marine pollutant. The aim of this paper is to examine and analyse the causes of marine pollution by noise in order to achieve better understanding, awareness of the general public about its impact through recognition of the effects, and finally, to synthesize protection options to prevent further pollution of the Adriatic Sea, strategically significant for the Republic of Croatia.

### ARTICLE INFO

Pregledni članak  
Received 22 January 2014  
Accepted 17 April 2014

#### Key words:

Sound  
Noise  
Sea  
Pollution prevention

### 1. Introduction

The problem, anthropologically caused by excessive environmental pollution, is primarily related to the technological development and its dependence on fossil fuels as a limited resource to existing sources. Therefore, great efforts are made and large financial means invested to find new sources of fossil fuels, thus using the most advanced technological means in finding them. Such surveys are conducted globally, both on the mainland and the sea-bed and subsoil. The Adriatic Sea, although particular in many of its features and strategically important for Croatia, is not an exception, in witness of which is the increasing number of surveys carried out in it [7]. However, seismic surveys for fossil fuels (oil and gas) are not the only anthropological sources of marine pollution caused by noise. It can also be a noise from maritime transport or nautical tourism, different military equipments such as the sonar to detect submarines, etc.

The effects of marine noise pollution are not easily visible to the public and often unavailable.

After numerous cases of the stranding of whales (accompanied by media) and researches made to find the origin of these causes, which pointed out to the problems of marine pollution by noise, an increased public awareness of the harmful effects of such human activities on other marine organisms was raised as well as the need for their protection.

This paper aims at carrying out researches and at analysing the physics of the formation and propagation of

sound in seawater, the main sources of sounds in the sea, anthropological harmful effects caused by noise on marine organisms, and at synthesizing the possibilities of protection in terms of surveillance of activities and placing restrictions on excessive pollution in order to protect both the Adriatic sea and other marine areas.

### 2. The formation and propagation of sound in seawater

The sound is produced as a result of spreading pressure waves from a particular source that flickers within different types of substances (for example. air or water). When attempting to graphically display the sound wave, it would have looked like an ocean wave, but the difference is in the fact that, unlike the ocean wave, where the highest and lowest point is the level of the sea, within a sound wave they represent the highest and lowest pressure. Passing through the 'material' those 'points' oppress and extend molecules, creating vibrations.

Sound waves in water are longitudinal waves, because of their parallel spreading from the sources, having a characteristic of change in the level of pressure when moving through a medium, and they consist of two main components: a pressure component and a component of the motion of the particles. 'The pressure' means the force per unit area, and the 'motion of the particles' an oscillatory displacement/acceleration of real particles of the media in a particular location. Different types of marine organisms

**Table 1** Comparison of sound pressure levels between air and water [3]

Typical sound in air	Water standard (dB re 1μPa)	Air standard (dB re 20μPa SPL)
Threshold of human hearing (1,000 Hz)	(26)	0
Very quiet living room	(66)	40
Seal threshold underwater (1,000 Hz)	80	(54)
Normal speech (1 meter)	(86)	60
Beluga threshold (1,000 Hz)	100	(74)
Lion's roar (10 meters)	(116)	90
Jet airliner (10 meters)	(130)	104
Fin whale call (100 meters)	140	(114)
Human threshold of pain (at ear drum)	(166)	140
Some military artillery	(186)	160
Beluga echolocation call (1 meter)	220	(194)

**Note:** Bracketed levels are nominal levels after conversion to alternate medium.

may experience either of these two components (or both) and process them as a stimulus. [10, 11]

Sound waves are characterized by: *frequency* (ratio of oscillation of particles or: changing of pressure from the lowest to the highest and back to the lowest), *wavelength* (the distance between two maxima or minima in its pressure within one cycle), *amplitude* (proportional to the maximum pressure in one cycle), *phase* (time lag between the two wave fronts), *propagation speed* (the ratio by which the vibrations spread through the elastic medium, and depends on the properties of the medium) and *intensity* (a measure of its strength in the direction of expansion). [9]

In theoretical considerations, the sound is described by using the terms of frequency and intensity (volume). In this matter, the **frequency** is a function of the speed of the wave and its wavelength. Therefore, it is actually the number of wavelengths that pass a given point in one second. Each transition of the wavelength within one second is called the 'cycle' and appears as a frequency of 1Hz (Hertz). Thus, fewer cycles per second and longer wavelengths are the characteristics of the sound of lower frequencies and vice versa more cycles per second and shorter wavelengths are characteristics of the sound of higher frequencies. The **intensity** or the volume is a measure of its strength, and is represented by the amplitude or by the maximum height of the wave, so the sound waves with a higher amplitude are those who are felt like 'louder'.

The power of the sound is given by [5]:

$$dP = pu \, dA \quad (1)$$

where:

- $p$  – sound wave pressure;
- $u$  – oscillating particle velocity;
- $dA$  – part of the area through which the wavefront is transmitted.

In order to understand the definition of intensity, it is necessary to specify the meaning of the terms: *the wave fronts* which represent a surface where the particles with

the highest elongation lie and *wave beam* representing the name for the directed lines in the direction of the wave propagation and which are perpendicular to the wave fronts.

On this basis, *the intensity of the sound* is defined as the ratio between the average power and surface of the wave front through which it spreads and is measured in  $W/m^2$  (or as the product of pressure and oscillating speed). Furthermore, the *level of intensity (LI)* is defined as the ratio of the measured and the referent intensity, which is measured in decibels (*dB*), and allows an indirect comparison of the volume.

$$LI = 10 \log_{10} (I/I_{ref}) \text{ [dB]} \quad (2)$$

This ratio is based on the logarithmic scale, and an increase in intensity is not linear, but an increase of 10 dB means 10 times more power and an increase of 20 dB means 100 times more power. However, the reference level depends on the type of material/medium through which the sound wave passes, and for example, for air it is *dB re 20μPa*, while for example in the water it is *dB re 1μPa* making more difficult to compare the sounds. Comparatively to the air and water, Table 1 shows some common sounds, their frequency (Hz) and intensity (dB). Obviously, the experience of 'volume of the sound' is not the same for air and water due to the necessity of converting the reference level, and the same sound in the air can have a lower intensity level in dB than in water. Therefore, in order to answer the question: how much is a sound in the water 'noisy' (?), (in human perception), it is necessary to convert the resulting decibels in water into the appropriate decibels in the air. [3]

The sound wave is moving through different media at different speeds, but in such a case, *the speed* can be seen as a reflection of the amount of energy<sup>1</sup> the wave possess

<sup>1</sup> Kinetic energy as the consequences of the movement of particles in an elastic medium and potential energy as the consequences of stress generated in the medium due to this movement. [16]

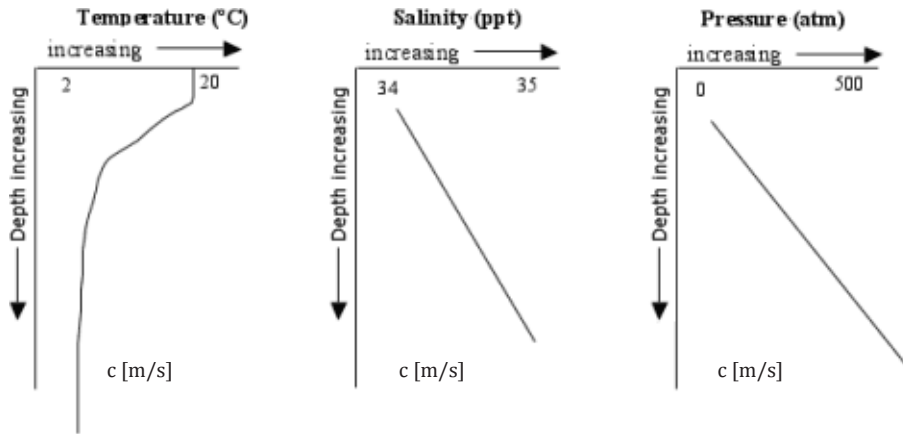


Fig. 1 The effects of temperature, salinity and pressure on sound speed

Source: Adapted from [16]

in a medium through which it expands and the *orientation* of its movement as the efficiency of the propagation of sound in a particular direction. Therefore, the density of the media has an important role in relation to both the speed and the intensity, because in dense media sound spreads faster and at the same time has lower power consumption, and its intensity decreases more slowly. That is of importance for understanding the audibility of sound because the sound intensity when, for example, it is heard by whale is different than when the sound is created, so the information about its distance from the source is to be known. Likewise, the expansion rate e.g. in the sea also depends on its temperature, depth (pressure), salinity, season, geographical location and time of day, and, generally speaking, it can be said that it changes within limits of 1440 to 1550 m/s (Figures 1 and 2). At the same time, to calculate the speed of sound in the sea, ‘different authors use different formulas’, and for practical applications in most cases a simplified Leroy’s formula can be applied [10]:

$$c = 1412 + 3,21 \cdot T + 1,19 \cdot S + 0,0167 \cdot Z \text{ [m/s]} \quad (3)$$

where:

- c – the speed of sound in m/s
- T – temperature in °C
- S – salinity in ‰
- Z – depth in meters.

From Figures 1 and 2 it is obvious that by increasing the depth the temperature and speed of sound are proportionally lowered, but it is of importance to note that the greatest change is in the surface layer (up to a depth of approximately 700 m) where the expansion rate decreases significantly with the depth, while in the deeper layers it is of a moderate decline. The speed of sound, when depending on the change of salinity, (in the area of 34–35 ‰) is almost a proportional increase (increase in salinity of 1 PSU results in the increase of speed by 1.3 m/s), as can be seen in the diagram on the pressure dependence, because when the depth and pressure increase, the speed increas-

es proportionally (increase in pressure by 1 Pa results in the increased speed of 1.7 m/s).

As can be seen in Figure 2, there is a maximum speed of expansion in the upper layers representing the seasonal thermocline, and a sudden drop and the minimum expansion rate that is achieved at the lowest layers of the permanent thermocline, while in layers representing the deep isothermal area the expansion rate increases proportionally.

To understand the impact of sound in water, it is necessary to distinguish between pulsating (single and multiple) and non pulsating sounds, and their differences in the effects on marine organisms. Single pulses are those that look like explosions, single air gun, or a single ‘ping’ of some sonar, while multiple pulses are those caused by e.g. multiple explosions, a series of air guns or some active sonar. Non

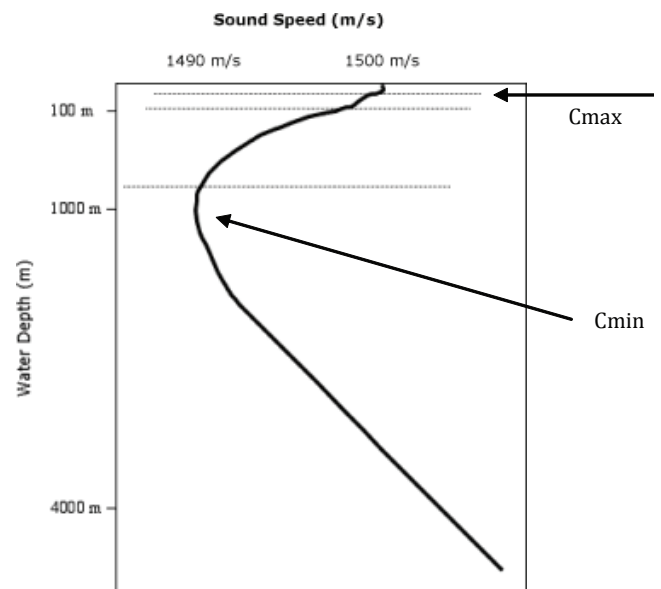


Fig. 2 A Typical relation of sound velocity and sea depth

Source: Adapted from [10]

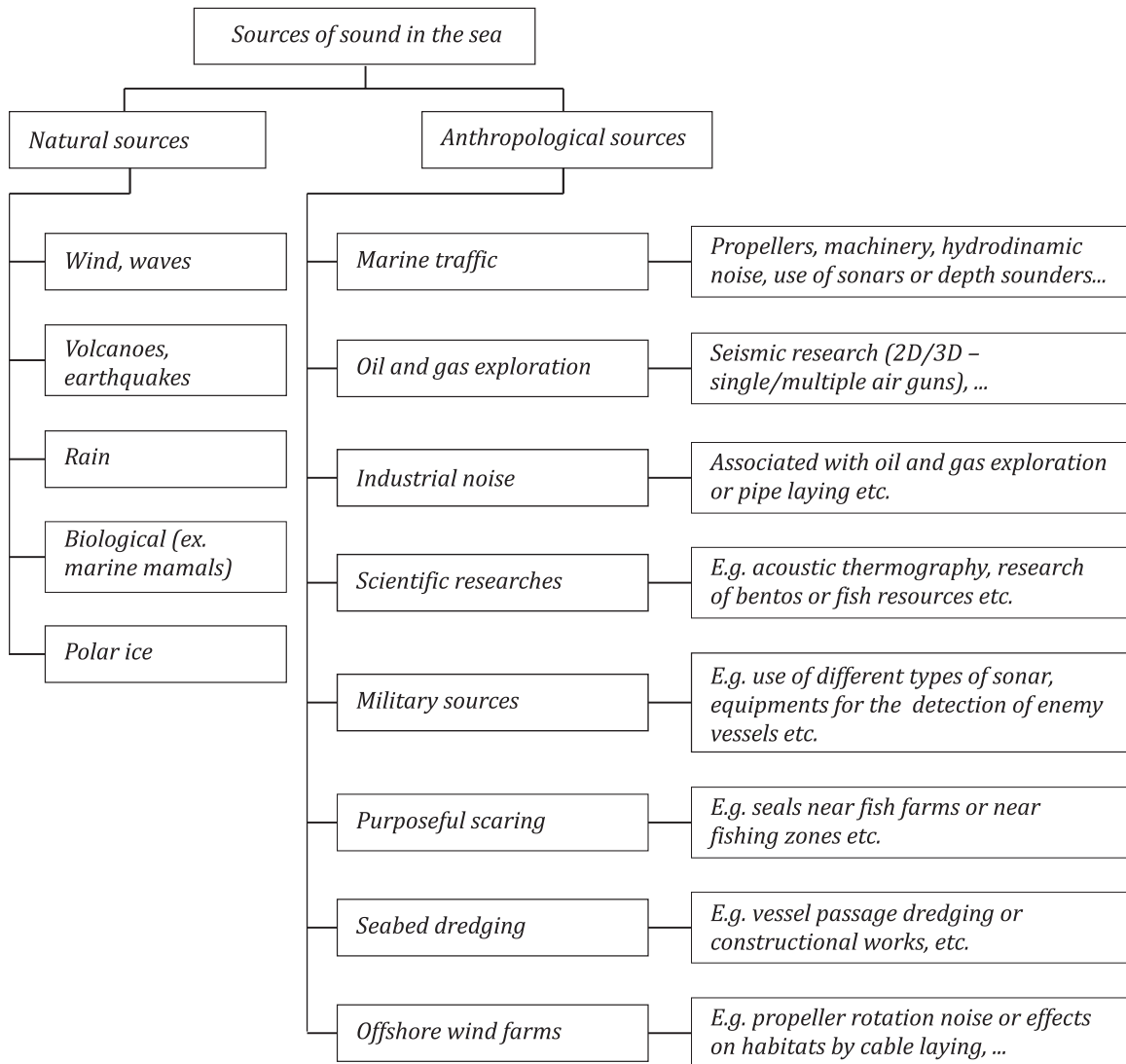


Fig. 3 Sources of sound in the sea

Source: Authors

pulsating sounds are those that are mostly caused by industrial or construction works, maritime or aircraft traffic, continued drilling of the seabed, etc. In addition, *transient* and *continuous* sounds<sup>2</sup> have to be distinguished.

To define the spread (propagation) of sound in the sea, simplified models, such as the SPRM – Source Path Receiver Model are in use and can be represented by the following equation [16]:

$$RL = SL - TL \quad (4)$$

where:

RL – received level  
SL – the level at source

<sup>2</sup> *Transient* sounds are characterized by short duration and clearly definable beginning and end, and described by maximum level or amplitude in dB. *Continuous* sounds are characterized by longevity and are usually described by the mean actual pressure.

TL – transmission loss (includes loss in expansion due to: the distance from the source, media absorption or various anomalies in the media).

### 3. The Main Sources of Noise in the Sea

Sources of noise in the sea can be divided with respect to their causes and can be either of natural or anthropological origin (Figure 3).

Sounds of natural origin are generally associated with the physical (e.g., seismic movements or earth tremors, winds, waves, etc.) or biological processes in the sea (e.g., vocation and communication of whales, dolphins, turtles, etc.). At the same time, the difference with respect to the frequency range should be noted [16]:

- Wind and waves:  $1 \geq 30\,000$  Hz;
- Volcanoes and earthquakes: 2-500 Hz;
- Rainfall: 100-500 Hz;

- Biological:  $1 \geq 100\,000$  Hz;
- Polar ice: 0.5 to 8000 Hz.

Out of anthropological sources, primarily emphasizes are given to *maritime transport* (Table 2) in which such noise sources are identified from: the ship's screws (e.g. rotation or cavitations of propeller), propulsion and auxiliary machinery (e.g. vibration, rotation, reciprocal motion, friction), hull (passing through the media), as well as the increasing use of sonars and echo sounders. Most of the noise caused by ships is in the frequency range below 1 kHz, while those of recreational boats are between 1 kHz and 50 kHz, which partially overlaps with the frequency range of whales' communication (social interaction, or echolocation to hunt prey). However, in recent times, efforts are made to alleviate the noise level thus produced in the very phase of the ship's construction, and they are designed to achieve greater efficiency and to reduce noise pollution, and, therefore, it can be concluded in principle that the newly built ships are 'quieter' than the older ones. Improvements are evident in optimizing:

- propellers to reduce cavitations and improve synchronization,
- ship's hull to reduce the resistance when sailing,
- ship's propulsion and auxiliary machinery and equipment in order to reduce vibration or friction (elastic fixing to basement, lubrication, etc.)

Another significant anthropological source of noise pollution in the sea is *oil and gas exploration*, and noise caused by industries associated with this research. In the initial phase of the research, the most common sources of noise are underwater seismic tests carried out by air guns<sup>3</sup>, and considering the applied technology they can produce two-dimensional (2D) or three-dimensional (3D) image. Applied technologies have different effects on marine organisms. Besides the different sound level, there is a difference in duration because they are characterized by a pulsating noise which is transient and lasts only until the explorations are conducted. In the two-dimensional test a single air gun and hydrophone are mostly used and the resulting image<sup>4</sup> gives little information, so it is used only for speculative or assessing research usually over a wide geographical area. Unlike them, the three-dimensional tests are using multiple air guns and multiple parallel hydrophones and the resulting image is of much higher resolution and provides better information about potential stocks in the area, and allows a smaller number of possible test drilling. In doing so, air guns produce sounds at a level between 215 and 230 dB re 1  $\mu$  Pa-m with frequencies between 10 and 300 Hz, and sometimes even up to 22 kHz. Although the propagation of the resulting sound wave is directed toward the bottom, the spread of the

sound comes in all directions, and marine organisms can sense them over long distances (e.g. 50–70 miles at depths of 25–50 m). [3, 16]

**Table 2** Summary of sound frequencies produced by shipping traffic and their source levels

Type of vessel	Frequency (kHz)	Source level (dB re 1 $\mu$ Pa)
650cc Jet ski	0.8–50.0	75–125
Rigid inflatable	6.3	152
7m outboard motor boat	0.63	156
Fishing boat	0.25–1.0	151
Fishing trawler	0.1	158
Tug pulling empty barges	0.037	166
	1.0	164
	5.0	145
Tug pulling loaded barges	1.0	170
	5.0	161
34m long (twin diesel engine) workboat	0.63	159
Tanker (135 m)	0.43	169
Tanker (179 m)	0.06	180
Supertanker (266 m)	0.008	187
Supertanker (340 m)	0.007	190
Supertanker (337 m)	0.007	185
Containership (219 m)	0.033	181
Containership (274 m)	0.008	181
Freighter (135 m)	0.041	172

Source: Adapted from [16]

When a potential deposit of oil or gas is found, test drilling are usually carried out, followed by the installation of drilling rigs and pumping, which appear to be new sources of noise pollution representing *industrial causes*. The most obvious examples are the construction and installation of platforms for the extraction or processing of oil and gas, pipeline and cable laying, traffic of supply vessels and helicopters, and the noise of the installed machines for drilling, extraction and processing as well as for the production of the necessary electricity. The noise produced by the industry generally represents the continuous pollution of the area and lasts for years.

*Scientific researches* can also be a cause of noise pollution. As an example may serve: an *acoustic thermography* which aims at getting the image of the temperature distribution in the sea (on the basis of measurements of the speed of sound from the initial source, because sound moves faster at higher temperatures); researches associated with the undersea mapping or those in connection with the distribution and migration of fish stocks, etc. This kind of pollution is temporary.

*Military sources* are the least accessible to the public, and with the exception of well known technologies, such as sonar and echo sounder, and the usual sources, such as those from maritime transport, there is not much knowledge of them and of their characteristics (especially

<sup>3</sup> The pneumatic devices that produce an acoustic signal with the rapid extrusion/'shooting' of the compressed air in the water column.

<sup>4</sup> By analysing the echoes recorded by hydrophones, it is possible to determine the type and thickness of the individual layers in the seabed, and the location of oil or gas.



of new technologies that are being used for military purposes and represent secret data). Such data most certainly include testing new weapons (e.g. explosion) and devices for the purpose of monitoring, defense and military activities at sea and in the sea, and also those ones regarding experiments and exercises conducted. In some cases, the perceived 'unusual' behaviour of marine mammals or their stranding, 'military sources' are assumed as a possible cause, [13]. Although not specifically noted as an anthropological cause, supersonic airplanes (especially military) in breaking the sound barrier can be included as an additional source of noise pollution.

Devices for the harassment of marine mammals in the vicinity of fish farms (AHD – *Acoustic Harassment Devices*) to prevent possible damage to the cages or those for the deterrent of marine mammals in fishing zones (ADD – *Acoustic Deterrent Devices*) to prevent damage to the fishing nets are also using sound as a means of action, and can cause permanent migration of marine mammals in a specific area.

*Construction works* in coastal areas and sea such as: explosion, excavation of trenches for laying communications cables or pipelines, construction of buildings or filling entire island for the purpose of building, dredging canals for the passage of ships, building bridges or tunnels under the sea, etc. also cause noise which effects are mainly local, and may be transient (buildings), but also durable (traffic bridges or tunnels) source of noise pollution.

Relocation of *wind farms* from land to sea areas and the construction of larger plants in wider locations certainly contribute to renewable energy sources, but their potential impact on marine organisms has not yet been explored.

#### 4. Adverse effects of anthropologically caused sounds on marine organisms

To be able to understand the possible harmful effects caused by the anthropological noise in the sea, it is necessary to know the way in which sound is used by marine organisms.

Due to the limited penetration of light into the depths of the sea, marine organisms are adapted to create different 'image' of the living environment which is essentially based on sound and acoustic perception. Therefore, obvious benefits of a sound can be seen which can reach further in the water and its intensity does not degrade rapidly with the distance, so marine organisms are able to locate, create or receive vocalizations over large distances by allowing them to interact with the environment (internal communications and maintaining 'family ties', detecting a prey or upcoming predators, etc.).

The adaptations of marine organisms to the possibilities of transmitting sound interactions are different. Marine mammals such as whales and dolphins who have the structure of an 'inner ear' which is very similar to the land mammals one, are adjusted in such a way that they do not have an 'outer ear', the sound vibrations are received

through the thin bone located in the jaw, which transmits them through the fat tissue to the 'middle ear' (its structure is still poorly understood) and then forwarded to the 'inner ear'. When creating and transmitting a sound, some whales and dolphins use 'air sacs' and nasal openings, and 'resonant air bags' to amplify the same before its emissions through fatty organ at the forefront of the head. These sounds can be in the form of short pulses, or clicks, and are used for echolocation by comparing the time and direction of their return in order to determine other 'objects' in the environment and their distances. The fish population has developed a dual structure of the inner ear and a lateral line that allows them to 'hear' (feel) the sound. The density of the fish body is similar to the density of water which allows the passage of the sound directly to the ear bones that have a higher density and therefore vibrate differently from other tissues, and this difference in vibration stimulates the 'fluffs' of the inner ear allowing perception, while a lateral line represents the sense organ that perceives moving through its kinetic component. By some fish adaptation is achieved by means of 'air or swim bladders' that allow them to stay in deep water compensating the difference in pressures, and which are constricted by a sound wave where the vibration is transmitted to the ear. Vocalizations such as 'clicks', 'grunts' or 'bumps' to attract the opposite sex or a warning against predators, are realized in different ways, and one of them is just drumming the sonic muscles over the air bladder. It should also be noted that all these developed auditory and sound organs are well adapted to distinguish background noise caused by other natural sources such as wind, waves, rain or seismic changes, while anthropological causes can significantly interfere. [3]

Basically, anthropological causes can have an impact on marine organisms through two types of **direct** harmful mechanisms [15]:

1. *physical* and *psychological* that cause a direct impact in some form of temporary or permanent damage, and
2. *behavioural changes* and deviations from usual routines.

In the physical effects, there are two types to be observed: *auditory* (causing temporary or permanent move of the threshold of audibility or severe damage of hearing organs, which are difficult to evaluate because of differences in the levels of thresholds and range of audibility for individual species) and *non-auditory* (which can cause permanent tissue damage, trauma or even extinction of the organism).

Psychological effects can be of the following type: *perceptual* (inability of acoustic interpretations of the environment), *masking communications* or other biologically important sounds, *intra sexual disorders* (disorders of the hierarchy within the same species, e.g. dominance over the territory), *inter sex disorders* (disorders in readiness for reproduction), and even *chronic stress*, which can be expressed in different ways (changes in feeding, growth

and reproduction, immunity decrease and the related increased sensitivity on the cumulative effects of other pollutants, hypersensitivity to noise or adaptation to the increased noise and staying behind the area where its effects are extremely harmful, etc.).

Changes in behaviour and deviations from the normal routine can be temporary or permanent, and can be identified through the example of frightening and straying away from usual habitat in which cases organisms are exposed to new groups of predators or to reduced food supply. However, changes in behaviour depend not only on the species but also on a variety of other conditions such as: environmental factors in the transmission of sound, location and source of the sound, individual sensitivity and tolerance, activities of individuals or groups at the time of receiving the sound (e.g., a particularly vulnerable group consists of mothers with their cubs).

However, apart from the direct effects, there are also **indirect** effects such as: reduced food availability outside normal habitat, increased exposure to predators or other risks (e.g. stranding or collision with other objects in the sea such as fishing gear or vessels), inability to timely surfacing (e.g. marine mammals during immersion have sufficient stock of air to re-emerge, but in the case of exposure to noise at greater depths and sudden change of direction as a result of escaping away from its source it may happen that they run out of stock) or rapid ascent without the possibility of pressure compensation which can cause severe damage to the organism and even mortality.

## 5. Possibilities to protect the sea from pollution by noise

The study of problems regarding marine environmental protection from noise must begin with the identification of the types of marine organisms (particularly marine mammals) in a given area and their lifestyles in order to be able to identify and prevent potential sources of anthropologically caused excessive noise that can cause harm. There is also other things to be taken into account: are these sources of a temporary (e.g. seismic surveys) or permanent characteristics (e.g. maritime transport or extraction of oil and gas), as well as the fact that the issue of 'marine noise pollution' has been recognized and its exploration has started in more recent time, and the possible long-term effects have yet to be explored. Therefore, at the current level of recognition of negative effects, preventive care is imposed as a possible solution that was implemented in the legislation of some countries. However, it is not to be expected that the adoption of regulations will completely remove the anthropologically caused noise in the sea, but it can be significantly reduced.

Systematic researches of marine organisms and education in the broadest sense may represent the first step towards the prevention of pollution, and the results can be used: as in the construction of ships where the elements of reducing the origin and transmission of vibrations as

one of the causes of noise should be entered in the stage of construction (which actually have been carried out already, but only in terms of the impact on humans, [8]), and so in the planning and execution of all types of construction work in the sea and coastal areas (because the coastal generated noise can be transferred to the vast sea area), and in all those activities connected with the oil and gas extracting industry drilling oil and gas from the seabed, etc.

There are many examples of the protection of marine organisms carried out mainly at local or national levels in a particular area such as:

- *designation of protected areas* (e.g. Ligurian Sea – Corso-Ligurian basin, Gulf of Lion and Corsica, 1999th by Italy, France and Monaco), which is based on the United Nations Convention on the Law of the Sea, which explicitly allows protection of all kind of pollution, including those caused by excessive noise;
- *adopting regulations on national and international levels*, e.g.:
  - U.S. law on the protection of marine mammals, in 1972 – *U.S. Marine Mammal Protection Act (MMPA)*, which is often used as a model of national protection, and is therefore relevant globally. The law initially prevented harassment and catch, but the amendments in 1994 clearly introduced the interpretation of harassment through two levels: **A** – potentially injuring and **B** – potentially disturbing that may cause a change in behaviour, migration, etc.
  - EU Directive on habitats and species – *The Habitats and Species Directive* (Council Directive 92/43/EEC of 21<sup>st</sup> May 1992);
  - *Agreement for Small Cetaceans of the Baltic and North Seas (ASCOBANS)* in 1992;
  - *Agreement on the Conservation of Cetaceans of the Black and Mediterranean Seas and Contiguous Waters (ACCOBAMS)*, 1996.

At the global level, the basis for the designation of protected areas and the introduction of regulations in the legislation is primarily provided by the: United Nations Convention on the Law of the Sea [12] and by MARPOL 73/78 [9], and by the guidelines of sustainable development as defined in Agenda 21 – The Action Plan of the United Nations Conference on Environment and Development [1]. However, at the regional level there are many other 'Protocols' (e.g. the Barcelona Protocol in 1994, or Kuwait Protocol in 1989.). In addition, some authors [16] argue that prevention of marine pollution by noise can be interpreted out of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, London 1972 [2] implying that such disposal generates a certain level of noise, as well as out of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, 1995 [4]. Many initiatives for cooperation on the prevention of marine pollution by noise have been raised on an international level by the International Whaling Commission.

From the foregoing fact, it is clear that the prevention of marine pollution by noise is difficult to implement on a global scale, but can be carried out at local or regional levels, including the Adriatic Sea, which primarily requests an agreement of the states within the region. However, in order to reach such a consensus, it is necessary to conduct scientific researches that will provide relevant information about the possible pollution of the sea by noise and endanger of marine organisms in a particular area, and on which results such protection will be enabled.

## 6. Conclusion

Sources of sounds in the sea may be of natural origin on whose intensities all marine organisms are adapted and do not represent any danger to marine organisms, or those of anthropological origin whose intensities or durability may reach such levels (noise) that actually pose a threat, generate the harmful effects and become the sea pollutant.

The consequences of marine noise pollution are not easily visible to the public and often unavailable. After numerous cases of the stranding of marine mammals and researches conducted to find the causes of these phenomena the results of which had indicated on the problems of marine pollution by noise, the public awareness about the harmful effects of noise caused by human activities on other marine organisms was increased, as well as the need for their protection. Seismic surveys for fossil fuels currently being conducted in the Adriatic Sea are not the only anthropological source of marine pollution caused by noise, but it can be also a noise from maritime transport or nautical tourism, industrial noise, noise from construction works in the sea and coastal areas, as well as from different military activities or equipments.

The sound is produced as a consequence of spreading pressure waves from a particular source that flickers within different types of substances, and the experience of sound 'volume' is not the same for different media because of the need for the conversion to the reference levels. The sound wave is moving through different media at a different speed, and the density of the media at plays an important role, because in dense media sound spreads faster and at the same time has a lower power consumption, and its intensity decreases more slowly. It is of importance to understand the sound 'audibility', because the sound intensity at a particular location is different from where the sound originated, and it is necessary to know the information about the distance from the source. Likewise, the speed of the propagation of the sound in water also depends on its temperature, depth (pressure), salinity, season, geographical location and time of day.

Due to the limited penetration of light into the depths of the sea, marine organisms are adapted to create different 'image' of the living environment which is essentially based on sound and acoustic perception, and by means of the sound they are able to locate, create or receive vo-

calizations over large distances which allow them to interact with the environment (internal communications and maintaining 'family ties', detect preys or upcoming predators, etc.). The adaptations of marine organisms on the possibilities for the transmission of sound interactions are different, and in doing all these they developed auditory and sound organs well adapted to distinguish background noise caused by other natural sources, while anthropological causes can significantly interfere.

Anthropological causes demonstrate their effects on marine organisms through direct or indirect harmful mechanisms in the form of temporary or permanent displacement of the threshold of audibility or substantial damage to hearing organs, permanent damage to the tissues of organisms, trauma or even extinctions, inability of acoustic interpretations of the environment, masking of communications or other biologically important sounds, intra or inter sexual disorders, chronic stress, behavioural changes and deviations from the usual routine, to temporary or permanent migration, which by some marine organisms can pose a serious threat.

The prevention of Marine Pollution by noise begins with knowing the type of marine organisms in a given area and their lifestyles in order to identify and prevent possible anthropological sources of noise. The results of scientific researches on marine organisms, especially marine mammals, may be used to prevent pollution even during the phase of building a ship, in the planning and execution of all types of construction work in the sea and coastal areas, as well as those related to the industry of extracting oil and gas or military industry, as well as a variety of other purposes.

Preventive protection, in the form of the declaration of special areas or by adopting regulations at national and international levels is allowed by different international conventions and intergovernmental agreements and protocols. However, it is not to be expected that such adoption will completely remove anthropologically caused noise in the sea, but it can be significantly reduced if the continuity of the researches and the education at all levels is carried on.

## References

- [1] Agenda 21 – action plan United Nations Conference on Environment and Development, 1992.; available at: <http://sustainabledevelopment.un.org/content/documents/Agenda21.pdf>, last access 15.1.2014.
- [2] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972.; available at: <http://www.austlii.edu.au/au/other/dfat/treaties/1985/16.html>, last access 15.1.2014.
- [3] Covi, M., Eulie, D., Swain, D., Watkins-Kenney, S., *Noise in the Ocean: A Review of the Issues, Science and Policy Relating to the effects of Noise on Marine Life*, Coastal Resource Management CRM6100, East Carolina University, 2008.
- [4] Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, 1995.; available at: <http://www.gpa.unep.org>, last access 15.1.2014.



- [5] Henč-Bartolić, V., *Inženjerski priručnik – Akustika*, Školska knjiga Zagreb, Zagreb 1996., str 194.–200.
- [6] <http://www.dosits.org/>, last access 15.1.2014.
- [7] <http://www.h-alter.org/vijesti/ekologija/mzoip-u-jadran-nije-okolis-fotogalerija/print:true>, last access 15.1.2014.
- [8] <http://www.zakon.hr/z/125/Zakon-o-za%C5%A1titi-od-buke>, last access 15.1.2014.
- [9] IMO – ‘MARPOL’ – *Consolidated Edition, 2011*, London, 2011.
- [10] Jambrošić, K., *Zvuk i okoliš – 1. Osnove zvuka*, available at: [http://www.fer.unizg.hr/\\_download/repository/ZIO\\_01\\_Osnove\\_zvuka\\_2013.pdf](http://www.fer.unizg.hr/_download/repository/ZIO_01_Osnove_zvuka_2013.pdf), last access 15.1.2014.
- [11] Jambrošić, K., *Zvuk i okoliš – 5. Utjecaj buke na čovjeka*, available at: <http://www.zmz.hr/download/utjecaj-buke-na-čovjeka.pdf>, last access 15.1.2014.
- [12] The UN Convention on the Law of The Sea, available at: [http://www.un.org/Depts/los/convention\\_agreements/texts/unclos/closindx.htm](http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm), last access 15.1.2014.
- [13] Pavan, G., *Effects of Underwater Noise on Marine Mammals*, Università degli Studi di Pavia, 2006., available at: [http://www.unipv.it/webcib/edu\\_noise\\_uk.html](http://www.unipv.it/webcib/edu_noise_uk.html), last access 15.1.2014.
- [14] Pionić, O., *Širenje zvuka u morskoj vodi*, “Naše more” 51 (5–6)/2004.
- [15] Potter J., Delory E., *Noise sources in the sea and the impact for those who live there*, Acoustic Research Laboratory, Tropical Marine Science Institute, EE Dept., National University of Singapore, 1998., available at: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.34.7310>, last access 15.1.2014.
- [16] Simmonds, M., Dolman, S., Weilgart, L., *Oceans of noise 2004.*, A WDCS Science Report, 2004., available at: [http://www.wdcs.org/submissions\\_bin/OceansofNoise.pdf](http://www.wdcs.org/submissions_bin/OceansofNoise.pdf), last access 15.1.2014.