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Environmental Impact of Underwater Noise

Abstract

The description of sound as a form of energetic pollutant is very complex as is also its impact on aquatic life. Human activities causing continuous and implosive underwater noise, such as marine traffic, maintenance of ships, coastal tourism, marine research, military, offshore energy platforms, generation of ocean energies and construction operations are expected to increase. The paper analyses current approach to minimise the impact of underwater noise and limit its emissions, examines regulatory approach and discusses the possibilities to control this type of pollution in order to ensure the preservation of natural underwater soundscape. The timely implementation and further development of the European Marine Strategy Framework Directive and its provisions related to underwater noise is of exceptional importance for the Adriatic Sea, which is facing increasing pressure from various industries generating underwater noise.

Keywords: underwater noise, anthropogenic activities, soundscape, Marine Strategy Framework Directive

1. Introduction

Modern research into underwater acoustics began in the 19th century, when the speed of sound was calculated to be 1435 m/s, which is only 3 meters below today's accepted values. The experiment showed that a small amount of energy can travel great distances without dissipating significantly [1]. Because the release of noise into the marine environment is a non-material discharge, it is unfortunately less comprehensively and systematically regulated in international and national law than "classical" impacts such as fishing, shipping, or physical-chemical pollution. The major obstacle is the current knowledge gap. Underwater noise generated by various activities could as well be considered as inefficiency or wasted energy [2].

One of the most significant international events in which noise pollution of the marine environment from underwater or anthropogenic noise received increased attention was the stranding of whales on the Greek coast in 1996. It also pointed to the regulatory challenges posed by the presence of a transboundary pollutant in the international arena, given that the sonar, the source, was owned by the U.S. government, the vessel was owned by 16 nations of NATO and was German flagged, while the experiment was conducted in Greek waters. Public perception of low-frequency sonars was also affected by demise of the Cold War [1].

The article introduces the physical characteristics of underwater noise, analyses the ocean soundscape and its effects, examines the regulatory approach as well as various measures to control underwater noise, and discusses the limits and possibilities to control this type of pollution and ensure the preservation of natural underwater soundscape.

2. Definitions and physical characteristics of underwater sound

Sound as defined by International Standardization Organization constitutes the alteration in pressure, stress or material displacement propagated via the action of elastic stresses in an elastic medium and that involves local compression and expansion of the medium, or the superposition of such propagated alterations. The scientific meaning of sound therefore has no judgemental connotation and is strictly confined its physical meaning. The acoustic environment represents the sound at the receiver from all sound sources as modified by the environment. In marine acoustics it is currently used synonymously with the term soundscape which, however, in terrestrial acoustics represents a subjective perception, i.e. the acoustic environment as perceived by the listener [3]. Ambient sound is the sound that would be present in the absence of a specified activity. Ambient sound includes ambient noise [4].

Sound is thus a vibration that travels as a wave by causing pressure changes in a fluid. While light and chemical cues are effective at small spatial scales only, sounds travel fast through water and are capable of conveying significant information over considerable distances. Given that sound transmission in seawater is almost five times that in the air and the generally limited transparency of marine waters, marine species use sounds for numerous different functional processes. The sounds in marine habitats are thus fundamental for the life cycle of marine animals [5].

The lower the frequency of sound, the further it can travel in the ocean. Low frequency sound (below 1000 Hz) can travel thousands of kilometres and interfere with the communication and navigation of many marine mammals. In addition, seawater has a frequency-dependent absorption coefficient, so low-frequency sounds remain perceptible at great distances from the source compared to the overall acoustic environment. Underwater sound is also affected by the properties of the interface such as depth, structure, and composition of the seabed [3].

The unit decibel (dB) does not represent a physical metric, but simply indicates that the preceding number is proportional to the decimal logarithm of the ratio between the property and the reference value. The standard reference pressure for ocean sounds is 1 micro-Pascal (1µPa), while the standard reference pressure for air sounds is 20 micro-Pascals (20 µPa). Therefore, the loudness of an underwater sonar cannot be directly compared to that of a jumbo jet. The perception of sound by different species of animals must also be considered. In addition, there is no clear correlation between the sound level in the air that is harmful to a human and that which is harmful to an animal in the water. In addition, the nature of noise in water is a multi-source [1].

3. Soundscapes

Soundscape is the characterization of the ambient sound in terms of its spatial, temporal, and frequency attributes, and the types of sources contributing to the sound field [4]. It represents the sum of sounds in particular area. Soundscapes are changing rapidly as the number of sound-producing animals decreases, human-induced noise increases, and the contributions of geophysical sources such as sea ice and storms change due to climate change. As a result, the sound of the Anthropocene ocean is fundamentally different from that of the pre-industrial era, with anthropogenic noise having a negative impact on marine life. Indeed, marine animals have evolved a variety of receptors to perceive sound, which have been well studied for marine mammals but only recently described for invertebrates such as jellyfish [6]. Unfortunately, the acoustic behaviour of most fish species remains unknown. On the other hand, sounds produced by snapping shrimp have been shown to cause bottlenose dolphins to change the frequency of their echolocation clicks to be outside the band of snapping shrimp. Marine mammals produce sounds to communicate, navigate, and detect underwater objects. They are known to communicate the presence of food, danger, or other animals, as well as information about their identity, location, or reproductive status. Echolocation allows animals to see underwater, hunt and characterise prey, locate and avoid obstacles, and move easily through ocean terrain [1].

Shipping contributes to background noise in the ocean. The frequency content of ship noise overlaps significantly with the hearing ranges of marine fauna. Although the propagation of ship noise is lower in shallow coastal waters, the higher concentration of ships often increases noise levels in coastal regions significantly above ambient noise levels [6].

Man-made ocean sounds include seismic surveys, which produce high-energy, low-frequency sounds of short duration to detect oil and gas deposits on the seafloor, and multibeam echosounders and side-scan sonars, which generally produce high-frequency sounds to map the seafloor and detect organisms and particles in the water column.Scientific surveying uses similar instruments to map the seabed and identify geological features. Fishermen use fish finders for fishing, while the navies use active sonars over a range of frequencies to detect submarines and other targets. In addition, there are the by-products of different human acttivities regarding coastal development and resource extraction, traffic on bridges and aircraft flying at low altitudes over the sea, pile driving during the construction of offshore wind farms, operating noise from turbines, dynamic positioning systems used to maintain the position of offshore structures, dredging of the seafloor, mineral extraction, trawling, dynamite fishing still practised in some parts of the world, controlled detonation of bombs, explosion of mines, missiles and bombs during naval warfare or military exercises, and fireworks, which also constitute a source of destructive sound [6,7].

In addition, various construction activities on land, such as dock building, can cause marine noise, although their effects depend on how well the land and sea media are coupled, which has not yet been adequately researched [1].

Areal drones and coastal recreational activities contribute anthrophony to marine soundscapes, see also [8]. Recreational vessels contribute the most to a shallow water soundscape as corroborated by a study of noise pollution from recreational boats compared to other vessels [9]. The authors showed that in shallow coastal areas, noise in the one-third octave bands at 0.125, 2, and 16 kHz is mainly caused by motorised recreational boats, without AIS. Additional source of noise from recreational boating are jet skis, small motorised watercraft propelled by water jets, which are usually present near shore. This can be a problem because these areas are often heavily inhabited by organisms [1]. Nautical tourism in the Mediterranean as a tourist hotspot remains a growing concern [10]. During the summer season, a significant increase in noise levels can be observed in the Adriatic Sea. The measuring site, which is quiet and peaceful outside the tourist season, is polluted by the large number of recreational boats, which peaks in the period of July-August [11].

In addition to fish finders and echo sounders, the fishing and aquaculture industry also uses acoustic deterrent devices that generate noise to keep marine mammals away from fishing gear and aquaculture cages [1].

To monitor changes in ocean temperature, low-frequency sonars, i.e., acoustic thermometry, are used [1]. One of the most important effects of climate change is the increase in ocean temperature and, consequently, sound, which travels faster in a warmer ocean. Ocean acidification, i.e., lowering pH, also alters sound propagation by reducing sound absorption for frequencies below 10 kHz [6].

High number of noise-producing human activities is located in the Adriatic [12]. Besides shipping, tourism and other noise-generating sectors and despite the climate change targets agreed in Paris Agreement, there is still a large industrial demand for energy from fossil fuels. In the last decade, the extent of seismic investigations has increased, especially in the Adriatic Sea area [10].

Covid-19 control strategies have also led to an unusual expansion of marine mammal and shark movements in formerly busy and noisy waters such as harbours and urban coastal areas where they are not regularly seen. On the other hand, there is an increasing focus on ocean-based economy which includes industries that may be major sources of underwater noise. However, the High Level Panel for a Sustainable Ocean Economy has not considered anthropogenic noise in addressing the actions required to achieve Sustainable Development Goal (SDG) 14: Life Below Water [6].

There are no long-term (more than 10 years), systematically collected ocean acoustic data for any frequency band. In addition, there are very few data outside the Northern Hemisphere, no data have been collected in biologically sensitive areas for specific species, and there are few data for frequencies above several kilohertz [1].

4. Effects

Duarte et al [6] synthesised the negative effects of noise pollution on marine animals in the literature. Anthropogenic underwater noise can have detrimental effects on marine biodiversity. Effects include physical damage to auditory organs, injury to other body tissues, death of individual specimens, behavioural changes, chronic/cumulative effects, and stress [3,10,13]. Recent research revealed negative effects of seismic surveys on zooplankton, which, along with phytoplankton, form the basis of the marine food web on which fish and other marine animals depend [10]. The contribution of individual species to the overall health of the ecosystem is fundamental to the concept of the marine food chain. If noise affects the reproduction or viability of one prey species, all species above it in the food chain may be affected, so noise can have a negative impact on the entire ecosystem. Noise could be a source of overall habitat degradation [1]. The full extent of seismic impacts on populations is largely unknown, in part due to the lack of baseline knowledge of species abundance and distribution. Potentially the most serious effect of low-level sound is sound masking (covering up one sound by another).

The health risks that underwater sound poses to marine mammals are similar for divers and swimmers. These effects can range from nonexistent to life-threatening, including temporary and permanent changes in hearing sensitivity (threshold shifts), resonance in air-filled cavities (including lungs, sinuses, and airways), disorientation, and acoustic annoyance [1].

5. Regulation

Although there is no international legal instrument that specifically and exclusively addresses underwater noise, the precautionary principle undoubtedly provides legislators with a framework for action. Regulatory frameworks for underwater noise have mostly been developed in the form of soft law standards, meaning that they are not legally binding and are therefore difficult to enforce. Guidelines and best practices, on the other hand, are easily modifiable and can be adapted to new developments. Updating is often left to the relevant expert bodies rather than international conferences or national legislators, which means it is quicker and less complicated [2].

In the United Nations Convention Convention on the Law of the Sea (UNCLOS), Article 1(1)(4) states that "Pollution of the marine environment means the introduction by man, directly or indirectly, of any substance or energy into the marine environment..." Article 206 contains a provision requiring an assessment of the potential impact of activities that may cause significant pollution. It requires an assessment of planned activities before they begin. It contributes to a comprehensive environmental management system. Article 65 relates directly to marine mammals and requires States to cooperate. All these provisions provide a framework for the development of international regulation of underwater sound.

The IMO has issued the Guidelines for the Reduction of Underwater Noise from commercial shipping to address the negative impacts on marine life [14]. The 2018 submission on IMO's work on anthropogenic underwater noise states that the issue of underwater noise and its impact on marine life is also addressed through the Particularly Sensitive Sea Areas (PSSAs) adopted by IMO. It also notes that the issue of noise has been discussed in the context of the work of the London Convention and the Protocol on the Protection of the Marine Environment from Pollution by Dumping of Wastes and Other Matter, noting that dredging, which is the main source of waste discharged into the sea under these treaties, is also a source of anthropogenic noise [15].

Two other conventions could also serve as forums where protection from underwater noise arises from their general obligations, namely the Convention on Migratory Species (CMS) and the Convention on Biological Diversity (CBD).

The EU has made a unique effort to protect against underwater noise with the publication of Marine Strategy Framework Directive (MSFD), which develops a common approach among Member States to address underwater noise pollution, see also [16]. To determine good environmental status, 11 qualitative descriptors were defined, with descriptor 11 focusing on energy discharges, including underwater noise. Underwater noise has been formally defined as a pollutant in Article 3(8) of the Directive. Member States are required to cooperate at European and regional level to ensure coherent implementation of the Directive. The criteria and methodological standards were set out in the subsequent Commission Decisions of 2010 and 2017. In the Commission Decision of 2017, two criteria are defined for descriptor 11: The first criterion (D11C1) concerns anthropogenic impulsive sound in water, which is described as follows: The spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect population of marine animals; the second criterion (D11C2) concerns anthropogenic low-frequency continuous sound in water, which is described as follows: The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound sources do not exceed levels that adversely affect the population of marine animals [17].

Several projects and initiatives are addressing the implementation of descriptor 11, and one of the ongoing initiatives entitled Soundscapes in the North Adriatic Sea is funded by EU-INTERREG V-A, Italy-Croatia with lead organization being the Institute of Oceanography and Fisheries, to be completed in 2021. In the Baltic Sea and North-East Atlantic Ocean regions, there is now a joint register for impulsive sound. Efforts are also underway in the Mediterranean Sea and Black Seas to establish a register for impulsive sounds.

In addition to the MSFD, the Habitats Directive, the EIA Directive and the SEA Directive are the main parts of the EU acquis communaitaire dealing with nature conservation and anthropogenic underwater noise. A Maritime Spatial Planning (MSP) Directive also aims at a balanced use of already competitive marine areas.

6. Measures

Compared to other stressors that persist in the environment, anthropogenic noise is typically a point pollutant whose effects diminish rapidly once the sources are removed. When considering ocean noise, all sources of noise must be considered, both random and continuous.

Since shipping is a major contributor to anthropogenic noise pollution of the acoustic environment, priority should be given to finding regulations and technical solutions for this industry. Currently, most ships lack equipment to monitor their acoustic condition. At comparatively low cost, such systems could be integrated into the hull of new ships when they are built, allowing crews to monitor and control their acoustic state [3]. Technological improvements, such as the use of diesel-electric systems, have had a major impact on reducing noise from ships. Also, larger ships have a greater draft, so there is less cavitation from the propellers [1]. A recent study compared sound level measurements of container ships before and after modifications to improve energy efficiency. The modifications included replacing the bulbous bow, lowering the main engines for slow steaming and installing new propellers with boss caps fins to reduce cavitation. The estimated underwater source sound pressure levels of the five vessels were lower by a median of 6 dB in the 8-100 Hz frequency band and a median of 8 dB in the 10-1000 Hz frequency band for the retrofitted vessels [18]. Four-stroke engines have resulted in significantly quieter vessels. Regarding recreational boating, if we compare newer engines with those which are built in a past few years, newer engines for leisure boats are reportedly nearly 70 percent quieter. Noise reduction could be achieved by using new noise suppressing materials, redesigning the intake/exhaust system, and isolation of the engine drive train. In fact, it is not yet known how much underwater noise is actually reduced since some of the noise reduction is achieved by moving the exhaust system from above the waterline to below the waterline. In addition, noise reduction technology for vessels registered under flags of convenience is costly and may be difficult to implement. Additional cost of reducing noise emissions would hit flag states with large merchant fleets, such as Panama or Liberia, hard. To date, the shipping industry has generally paid little attention to the problem of noise pollution at sea [1].

Other applicable measures include regulating speeds and routes, targeting 15% of ships that generate half of the total noise emitted by the shipping fleet, noise-dampening technology for ship structures, and alternative technologies for seismic air guns (vibroseis) [6].

A promising approach to prevent noise pollution is the determination of environmental capacity. In addition, an important ex-ante tool is environmental impact assessment [19], which provides a basis for decision-making, offers a comprehensive information and opinion platform, takes into account externalities and alternatives to proposed projects when properly conducted, and involves the public.

In matters of underwater noise, it is important to apply the best available technology (BAT), at least the best practicable technology (BPT), which takes into account technology costs, or preferably the best practicable environmental option (BPEO), which implies that among equally effective techniques, the one that causes the least environmental damage should be used [1].

If spatial components of threats can be defined, marine protected areas (MPAs) are a useful conservation measure. However, their designation is in itself no guarantee that their objectives will be achieved, the world being littered with paper parks, see also [20]. The successful implementation of an MPA depends on biological, ecological, economic, and social factors. Due to conflicts of use, the establishment of protected areas will be increasingly contentious, difficult, and dependent on compromise. For example, regulating tourism and fisheries within MPAs has proven difficult. There is also the problem of protecting a moving target. Buffer zones around MPAs should provide an additional level of security [1].

Zoning is an important component of MPA management plans. In the context of acoustic habitat description and marine spatial planning [21], increasing attention is being paid to mapping soundscapes at national and regional levels. It is important to consider acoustic habitats when determining the sustainable level of industrial use in any area [22].

The framework for risk assessment of problems related to the impact of anthropogenic sound on underwater fauna should be developed in several steps: Hazard identification, dose-response assessment, exposure assessment, risk characterization, and finally risk management, which depends on whether the risk of harm exceeds thresholds set by legislation, societal views, or the biological significance of the impact [7].

7. Conclusion

Underwater noise as a form of pollution is beginning to receive adequate public attention, but still not in the form of globally binding legislation. Addressing underwater noise should focus on habitats rather than on the effects of individual sound sources on individual species. Such an approach requires overcoming sectoral divisions and approaches, i.e. integration and interdisciplinary work, as well as the involvement of various stakeholders such as the fishing industry, oil companies, the military, environmentalists and scientists.

The potential of the blue economy in the seas and oceans poses a particular challenge to marine soundscapes. The timely implementation and further development of the European MSFD and its provisions related to underwater noise is of exceptional importance for the Adriatic Sea, which is facing increasing pressure from various industries generating underwater noise.

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