Impact of underwater noise pollution from maritime traffic on marine mammal communication patterns

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Abstract

This paper focuses on the effect of noise pollution on the communication of marine mammals. Animals such as whales, dolphins, and seals use sound for navigation, socializing, and reproduction, making them Oceano zoological. Their survival, ecological interaction, and social structure rely heavily on marine acoustics. Human activities like shipping traffic, military sonar or offshore drilling, and seismic surveying cause noise pollution that interferes with marine life communication. The masking of signals severely impacts marine mammals' communication and the behaviors necessary to feed, mate, and socialize. Furthermore, high-intensity sonar noise and underwater detonations can inflict direct and severe damage, such as hearing loss. These disturbances have been shown to affect a marine mammal's behavior, increase stress, cause displacement from their natural habitat, and alter population demographics in the long term. The increasing volume of human activity worldwide requires marine mammals to receive careful attention from an interdisciplinary approach, along with the development of noise reduction technology. This study stresses the importance of actively working to protect the communication capabilities of marine mammals to ensure their continued existence in an ever-evolving ocean.

Keywords: Noise pollution, Ocean, Mammal communications, Sound for navigation, and Impacts

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Introduction

Once regarded as vast and largely silent domains, the world's oceans are increasingly inundated with anthropogenic noise primarily from maritime activities. Among the various sources of oceanic noise pollution, commercial shipping has emerged as a dominant contributor to the persistent acoustic disturbances that pervade marine environments today (Clark *et al.,* 2009; Imo, 2014). The rapid expansion of global maritime trade has led to a significant increase in the density and frequency of vessel traffic, elevating ambient underwater noise levels by as much as 3 dB per decade in some regions (Fadaei *et al.,* 2024; Hildebrand, 2009).

Marine mammals such as whales, dolphins, and porpoises depend on sound for critical functions such as communication, navigation, foraging, and avoiding predators (Nandini, 2024). They use sound frequencies with significant overlap to those produced by ships and have highly specialized auditory systems tailored to the acoustic characteristics of the ocean (McDonald, Hildebrand and Wiggins, 2006; Merchant *et al.,* 2014). The increase of maritime traffic is, therefore, more than a disruption; it can alter these animals' fundamental aspects of life by causing behavioral changes, shrinking ranges in communication, and adding stress (Petrova and Kowalski, 2025; Erbe, 2013).

The most direct consequence of ship noise on communication for marine mammals is the masking of biologically relevant signals. Masking is when noise or other stimuli prevent a person from hearing or interpreting an acoustic cue; because of this, the effective distance individuals can communicate over is shortened (Desai and Joshi, 2023; Simmons, 2016). For some animals, like humpback whales (Megaptera novaeangliae), studies have shown they alter their vocalization patterns to ambient noise, which often leads to greater vocalization (the Lombard Effect) and longer calls (Southall *et al.,* 2008; Yadav *et al.,* 2024). Masking has also been observed to have these same consequences on bottlenose dolphins (Tursiops truncatus) who have altered their whistles to combat the increased background noise (Hatch *et al.,* 2012).

Exposure to elevated noise levels for significant periods may result in chronic stress responses in marine mammals, which impact reproductive success, immune systems, and overall fitness (Krishnan and Patel, 2023). In addition, persistent noise pollution may cause displacement of ecosystems, resulting in marine mammals vacating essential feeding or breeding locations (Slabbekoorn *et al.,* 2010; Rolland *et al.,* 2012). Such disruptions are especially damaging for particular species with limited geographic distributions or highly specialized habitat requirements due to the cascading ecological effects that those disruptions can have (Noad *et al.,* 2000; Lammers *et al.,* 2003).

Despite an increase in the focus of concern towards this issue, gaps remain regarding the cumulative and synergistic impacts of noise pollution on the population of marine mammals (Nandy and Dubey, 2024). The intricacy of ocean sounds, the number of marine mammal species, and the different levels of

sensitivity to marine sounds all present challenges concerning impact assessment and mitigation (Kao *et al.,* 2019).

However, new technologies aimed at monitoring marine sounds and policy changes, such as the regulations from the International Maritime Organization, intend to limit ship noise and provide hope for reducing the adverse effects of underwater sound pollution (Wiley and Asmutis, 1995; Garland, Merchant and Thompson, 2012)

This paper analyzes the consequences of ships crossing navigational borders on marine mammals' communication, drawing from scientific literature, case studies, and active and passive mitigation measures (Nair and Sengupta, 2023). By integrating empirical evidence and theoretical frameworks, this research aims to enhance understanding and elicit action regarding this dire environmental issue alongside other adopted strategies for marine conservation (You, 2010).

Objective of the Study

This study seeks to examine the impact of noise pollution on marine mammals' communication while highlighting the need to safeguard the acoustic environment, which is fundamental for ecological functionality.

Research Methodology

The conclusions for this study were drawn from secondary sources, which included articles, books, documents, credible internet publications, and scholarly publications. These resources are particularly helpful for researching marine mammals' communication, ship noise pollution, and other related ecological impacts.

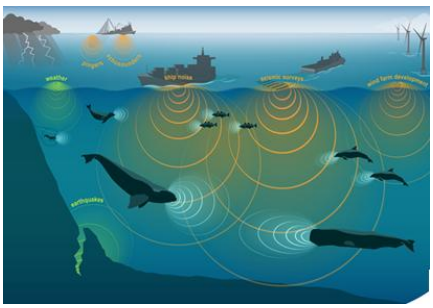

Figure 1: Noise Pollution on Marine Mammal Communication

Impact of Noise Pollution on Marine Mammal Communication

Masking of Communication Signals

Like other species, marine mammals like whales, dolphins, and seals communicate by vocalizing sounds below the water's surface. Compared to land, the sound medium in water is much more effective. This enables the animals to produce and receive signals over much longer distances. Their vocal variety is immense and includes clicks, whistles, and songs for echolocation, mating, social interactions, and many other purposes.

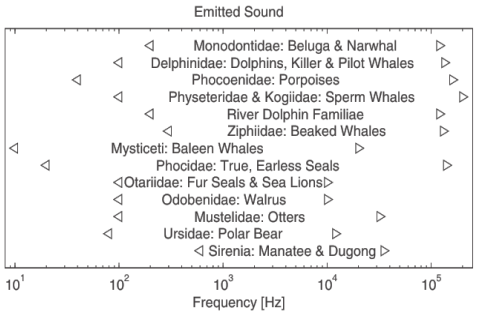

Figure 2: The bandwidth of sounds released by marine mammals

Explosive anthropogenic noise pollution from commercial shipping, military sonar, offshore construction, and seismic surveys for oil and gas services poses rising threats to interactions based upon sound. Such human-generated sounds, spanning low, mild, and high frequencies, tend to blend with the bands used by marine mammals. Together,

these signals produce an effect known as the “masking effect", whereby noise pollution from human activity obstructs the natural sounds made by marine animals.

The direct consequences of masking effects include:

- Obscured Acoustic Signals: Sewage and industrial pollution hinder marine mammals from detecting essential sounds such as mating or group member distress calls. Consequently, individuals may fail to respond accurately to vital behavioral signals, hindering social integration and reproductive attainment.
- Reduced Communication Range: Clear acoustic pathways enable marine mammals to communicate effectively over long distances. The increase in human-made noise in the environment reduces the distance within which these animals can effectively transmit and receive signals. This dramatically reduces their communication abilities across vast regions of their habitat and impedes coordinated activities such as hunting, social interaction, and even migrating.
- Behavioral Modifications: Marine mammals may try to employ other strategies to enhance their communication potential due to the masking effect. For example, they may raise the intensity or frequency of their calls so that background noise does not mask them. Although this change might enable some form of communication, it is doubtful that excessive noise pollution will have significant impacts. This adjustment in vocalization can disrupt social order and group coordination, which are vital during the migratory, feeding, and mating seasons.

Disruption of Natural Behavior

Marine mammals' natural behaviors, including feeding, mating, socializing, and navigating through the ocean, have evolved millions of years and are finely adapted to their acoustic milieu. Anthropogenic noise is a form of pollution that seriously disrupts the environment, impairing an ecosystem's natural habits and heuristic processes at the physiological and population levels.

Echolocation Disruption: A distinguishing feature of many marine mammals is their use of echolocation to find food. Echolocation is the biological sonar (i.e., the use of sound waves for distance ranging) where an animal emits sound and listens to the sound coming back (reverberation or echo) to check if something is present. Hawkins (2018) explains that understanding underwater noise in ecology is critical for sustaining marine life. Due to anthropogenic noise, the close and distant ranges become inaccessible due to being unused, leading to fragmentation, isolation, and increased mortality rates of fauna. This disrupts ordinary life and the rate at which the world changes, sending fauna into a state of fragmentation.

Extreme versions of range fragmentation, leading to interference in sociocultural behaviors, lead to diversions due to the increased stored energy that sea animals undergo in their environment. Ethological economic disruption leads to underestimating the need of organisms reliant on echolocation to ensure their survival or determine their habitat range while using sonar waves to

navigate through their surroundings and locate structures.

Breeding and Social Interactions: Most marine mammals create distinct sounds during the breeding season to attract mates and mark territories. Such bred noises might uniquely differ from average anthropogenic underwater sounds, thus classifying them as noise pollution. Furthermore, failing to hear calls due to noise interference can limit reproductive opportunities and success. In addition, noise pollution can affect social interactions within groups for social species like dolphins and orcas, who rely heavily on verbal communication to keep the group intact. Impairment of group interaction can disintegrate social units or lead to heightened anxiety and tension, which may disturb the breeding rhythm and population health in the long term.

Stress and Hormonal Responses: Marine mammals will likely encounter physiological stress when exposed to persistent or significant noise levels. Stress reaction often translates into increased cortisol concentration, which impacts an individual's immune system, hormone imbalance, and general health. Chronic stress can harm one's health but can also lower an individual's reproductive rate, lifespan, and raise risks for several illnesses. Moreover, the unwelcome stress that comes with noise pollution can force the subject to alter their patterns and result in evasion of odious regions, social withdrawal, and greater exhaustion – all of which do not provide long-term benefits for one's fitness and survival.

Impacts of Noise Pollution on Physical Health

Military sonar, underwater explosions, and seismic work-related exploration noises are violent enough to damage marine mammals beyond their physiological endurance limits. These anthropogenic sounds, also known as impulsive sounds, tend to inflict immediate and catastrophic damage as they disrupt communication.

- Sonic Wounding: By nature, marine mammals use sound to communicate, so they need their acute hearing to detect potential prey, fellow group members, and even navigate their surroundings. That said, marine mammals face the threat of permanent or even temporary scoliosis due to high-intensity sonic bombardment from military sonar and underwater explosions. Damage to the hearing faculties usually results in loss and almost complete hearing damage, affecting the primary frequencies utilized in echolocation, coding signals to navigate the surroundings. Thus, seals suffer the incapacitating possibility of catastrophic loss and impairment to communication, navigation, hunting, and survival.

Figure 3: Marine mammal mitigation during innovative sonic treatment

- Stress and Physical Damage: About marine mammals, high-intensity noise often comes hand in hand with hearing

damage. However, other forms of physical trauma, such as internal organ or tissue damage, due to the violent pressure shifts within water, may also be inflicted. Some behavioral responses resulting from these sounds include leaving the area, diving further down, or breathing to escape the noise. Such trauma may result in death, long-term injury, or exacerbated damage that the population suffers from.

- Displacement and Avoidance: With the aid of current technology, it has become easier for us to track marine mammals and study their behavior. As a result, we have gathered information suggesting that a marine mammal's interaction with noise pollution often involves avoidance of the source at hand. Though this may provide short-term respite from harmful noise exposure, it almost always increases the frequency of silence on an animal's breeding or feeding grounds. Population fragmentation results in animals being forced into unknown regions, greatly limiting the chances of survival and reproduction.

Migration and Navigation Disruptions

Marine mammals undertake migrations for vital biological purposes such as feeding, breeding, and evading predators. Alaskan whales, for example, are known to migrate thousands of kilometers across the ocean. In addition to their remarkable journeys, marine mammals are also known to have a great sense of navigation, which relies on ocean sounds and geomorphological features of the sea floor.

Unfortunately, sounds generated by the ocean, such as waves, currents, and marine life, create mental sound maps that underwater traffic, naval sonar, and global warming distort. Failure to regulate torpedoes creates ‘acoustic images’ that can disrupt ocean sound systems. These ‘ocean sounds’ are essential for proper alignment.

Disorientation and Stranding Events

Disrupting navigation systems often leads to disorientation, which could result in the mass stranding phenomenon. When marine mammals can no longer detect or interpret critical natural sounds, they might abandon their critical migratory pathways and find themselves stranded in shallow waters or coastal regions perilous, unfamiliar, or often choked full of dangerous substrates. Whales like beaked whales are particularly susceptible to this operational hazard. These deep-diving cetaceans depend extensively on echolocation for both navigation and hunting. Numerous studies suggest that naval sonar operations have been directly associated with mass strandings of beaked whales. With such exposures, intense mid-frequency sonar has been shown to elicit panic-induced flight responses in animals to the extent that they ascend too rapidly, resulting in gas embolism or beaching themselves out of distress. Based on these accounts, the high-frequency anthropogenic noise associated with sonar is a marker of profound physiological and behavioral pace disturbance.

Long-term Population Effects

Aside from immediate dangers like stranding, navigation disruptions from noise give rise to marine mammal population threats. One of the most

critical issues is the compounded decrease in population size. First, enduring exposure to sonic disturbances might cause animals to lose migratory corridors, reducing access to feeding or breeding grounds. Second, prolonged displacement from essential habitats can lower reproductive success and therefore, the viability of births. Additionally, increased mortality might result from stress, habitat degradation, and high energy costs associated with detouring around critical areas. An additional cause for concern is the subdivision of populations into smaller and more isolated groups. Isolation can reduce resilience against environmental threats, disease, and even climate change, worsening the climate and decreasing genetic variability. These factors may result in a downward spiral, increasingly complicating population recovery.

In summary, the impact of human-induced underwater noise pollution on marine mammals' ability to multitask their navigation capabilities has short-term and multi-accumulative effects. The range of effects goes from the tragic mass stranding phenomenon to more subtle impacts, including population fragmentation and decline, which derive from the natural suspects the implementation that impede migratory orientation. This underscores the immediate need for subaqueous sound mitigation techniques. To overcome these challenges, there is a need for sound policy at the crossroads of regulation, innovation, and improved observance of marine ecosystems and their species.

Conclusion

In conclusion, the impact of an anthropocene world on marine mammals' communication remains one of the untouchable, unsolved puzzles of the contemporary world, needing acute attention along with practical management methods and techniques. Whether navigating, foraging, reproducing, or socializing, marine mammals perform sound-centric activities. The problem society faces, where people are the root cause of the problem, is that the level of noise pollution is worsening at an unprecedented rate. This highlights marine noise pollution as a veritable communication disruptor through the lethal damage of essential physical structures, to fundamental archaeological "building-blocks" of communications, which, for angering, have emerged as mutually shared vital and critical "acoustic-silence" geophysical spaces. A constant, unmitigated assault of countless critical inputs quite literally bludgeons marine mammals in their efforts to forage, reproduce, socially maneuver, sustain, and defend equilibrium socio-ecological systems, population health, and physiological resilience. Active solutions must first focus on technological regulations crafted towards noise emission reduction on marine ecosystems, setting emission limits, and mobilizing public action into awareness efforts that help inform the public on the consequences of noise pollution on marine mammals. The declines in population of marine mammals due to noise pollution will be contained through the introduction of 'quieter' shipping policymaking and voluntary noise-reducing technologies off-waters and protected areas of silence reserved within marine zones where rid of detrimental high sound levels. Additionally, targeted

research into the effects of various sources and types of noise on marine mammal species needs to be intensified to develop effective containment measures. Sustainable measures that limit marine mammal and ocean health can be achieved through strengthened collaboration and the integration of noise subjects into maritime spatial governance effected on the part of sustainably advanced marine mammals. Maintaining the ocean's soundscape is crucial for conserving these species and other key wildlife.

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