International Journal of Life Science Research Archive

ISSN: 0799-6640 (Online)

Journal homepage: https://sciresjournals.com/ijlsra/

(REVIEW ARTICLE)

The impact of anthropogenic sound on marine mammals: A review

Lakhnarayan Kumar Bhagarathi [1, 2, *], Phillip N. B. DaSilva [2], Gyanpriya Maharaj [3], Rahaman Balkarran [4] and Aarif Baksh [2]

[1] *Faculty of Natural Sciences, University of Guyana, Turkeyen Campus, Greater Georgetown, Guyana.*
[2] *Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana.*
[3] *Centre for the Study of Biodiversity, Faculty of Natural Sciences, University of Guyana, Turkeyen Campus, Turkeyen, East Coast Demerara, Guyana.*
[4] *Queensborough Community College, New York, United States of America.*

International Journal of Life Science Research Archive, 2024, 07(02), 009–033

Publication history: Received on 30 August 2024; revised on 10 October 2024; accepted on 12 October 2024

Article DOI: https://doi.org/10.53771/ijlsra.2024.7.2.0070

Abstract

This paper aims to review and evaluate published literature on the impact of anthropogenic sound on marine mammals. A systematic method was utilized to access research works of literature on "Impact of Anthropogenic Sound on Marine Mammals". A total of seventy-seven (77) research papers published between the years 1959 to 2022 were accumulated and used for this review. A subjective approach was used to select the topics: impact of anthropogenic sound and marine mammals. In this paper, six (6) detrimental impacts of anthropogenic sound on marine mammals were evaluated and presented. Anthropogenic sounds originate from a variety of sources such as explosions, commercial shipping, seismic exploration, sonar, research sound source, acoustic deterrent devices and pingers, polar icebreakers, industrial activities, offshore drilling, construction, small ships, boats, and personal watercraft. Among the main impacts identified were that anthropogenic sounds affect marine mammals by causing hearing loss, masking, change in behavior, habituation shift and mass stranding. A mini checklist of several species of marine mammals and different types of anthropogenic noise that affect them are presented. Marine mammals are capable of self-generating their own sounds and they are also affected by anthropogenic sounds that are not native to their natural environments. The published literature that was reviewed established that the global marine mammal population dynamics, abundance, distribution, navigation, ecology and behavior are all affected by anthropogenic sounds. This review highlights the fact that more extensive studies on the impact of anthropogenic sound on marine mammals should be done in neotropical countries since there are gaps of such information on research and published data in these biodiversity-rich regions.

Keywords: Impact; Marine Mammals; Anthropogenic Sound; Sources

1 Introduction

1.1 Anthropogenic sound

Oceanic background noise currently includes a significant amount of human activity in the maritime environment. Anthropogenic sounds in the marine environment are a major problem in and one that has been identified as being responsible for a range of negative effects on marine ecosystems and taxa [66] [162].

The following are some general categories into which anthropogenic sound sources can be divided:

- explosions

---

[*] Corresponding author: Lakhnarayan Kumar Bhagarathi

- large commercial ships
- air guns and other seismic exploration devices
- military sonars
- navigation and depth-finding sonars
- research sound sources
- acoustic harassment devices (AHDs) and pingers
- polar icebreakers
- offshore drilling and other industrial activity; and
- small ships, boats, and personal watercraft [66].

1.1.1 Explosions

Nuclear and chemical explosions are two types of man-made explosions that produce loud noises in the ocean. Tests of nuclear devices have been conducted on oceanic islands, in the atmosphere above the ocean, and underwater. All nuclear-armed governments agreed to cease testing their bombs underwater when they signed the Limited Test Ban Treaty in 1963. In 1996, the major nuclear countries signed the Comprehensive Test Ban Treaty, which committed them to ending all nuclear testing. The most recent maritime experiments were carried out in the South Pacific at the islands of Fangataufa and Mururoa by France between 1995 and 1996. While the likelihood of nuclear device testing in the water is now minimal, geopolitical developments in the upcoming years or decades could cause this to alter [66].

One of the most potent sources of underwater sound is nuclear explosions. With fission devices producing the equivalent of tens to hundreds of kilotons and fusion devices producing the equivalent of tens of megatons, their source levels are stated as an equivalent weight of chemical explosives. Although there are no data on marine mammal monitoring or stranding, previous testing most certainly had a significant effect on marine mammals nearby the test locations. A worldwide monitoring system, comprising a number of sea hydrophones and terrestrial (island) seismic sensors to detect high-intensity sounds, is being implemented to verify compliance with the Comprehensive Test Ban Treaty [66]. The International Data Center receives this data in real time, and analysts there search for any signs of potential nuclear explosions. Because of the physical characteristics of the oceans, the noises of these explosions can travel over very great distances with minimal energy loss. A limited number of stations are used to monitor a huge portion of the world's oceans. There are currently eleven stations in the network intended for ocean monitoring, most of which are situated in the Southern Hemisphere [66].

Chemical explosions are more transportable and simpler to execute in an oceanic environment; they have been employed in construction, military testing, and oceanic research. Underwater explosions were recorded in the North Pacific in the 1960s at a startlingly high rate (between 300 and 4,000 a month) [66] [132]. Airgun arrays, which offer a more dependable source signature, have supplanted chemical explosions as a popular method for marine seismic investigation. Undersea constructions are still being built and taken down using chemical explosions, mostly by the oil sector, though it is likely that fewer explosions have occurred in recent years [66].

To ascertain their capacity to tolerate explosions, new classes of military vessels are put through testing known as shipshock trials [26] [66]. In a ship-shock trial, hull stress is measured in the vicinity of the vessel's hull after a sizable chemical explosion (10,000 kg, for example) is set off. Other Navy operations involving underwater explosions include the "Sinkex" operation, which uses chemical explosives or torpedoes to sink retired ships; testing of weaponry in development; and testing of operating stocks to ensure they are combat ready. In the course of the most recent conflict in Iraq, twelve 500-pound sea mines that had been captured from the Iraqi navy were destroyed by Navy SEALS. The explosions occurred simultaneously in the Persian Gulf, producing a sound that could be heard in Kuwait from 50 miles away [34] [66].

1.1.2 Commercial shipping

The main cause of low frequency (5–500 Hz) background noise in the world's oceans is commercial shipping [66] [67]. Large geographic areas are affected by ship noise, and in distant vessel traffic, individual vessel noises are frequently indistinguishable in both space and time. Because the marine sound channel—the zone of greatest effective sound propagation—reaches the surface in high latitudes, vessel traffic noise travels exceptionally well across great distances [66] [133] [162].

Propulsion machinery, hydraulic flow over the hull, and propeller activity are the main sources of noise aboard ships. Cavitation [66] [124] [125] [133] [162] is the formation of voids from zones of pressure lower than the ambient water pressure, and it is linked to propeller noise. Sound is produced as these apertures collapse. Due to its ability to be manipulated by blade-passage frequencies and their harmonics—referred to as the blade lines in a spectrum—

cavitation produces both broadband and tonal sounds. Eighty to eighty-five percent of the noise emitted by ships comes from the wideband and tonal components created by cavitation [66] [124] [133] [162]. Unsteady propeller blade-passage forces can also produce propeller noise, and ship propulsion machinery can produce extra noise [66] [133] [162].

Specific vessels have distinct sound signatures that can be identified by their frequency bands and source levels. These acoustic signatures frequently exhibit sharp tone peaks caused by spinning and reciprocating machinery, such as pumps, fans, blowers, diesel engines, diesel generators, hydraulic power plants, and other auxiliaries. Particularly at higher ship speeds, hydrodynamic flow over the hull and hull appendages is a significant process for producing wideband sound. The ghostly features of individual ships are visible at comparatively close ranges and in remote locations. Many ships add to the background noise at remote ranges in the open ocean, and the combined effect of numerous distant sources results in large spectral peaks of noise in the 5-500 Hz band [66] [133] [162].

The U.S. Navy has created models for representative sound spectra for several ship types. The broadband (5–500 Hz) spectrum level for different classes of vessels is determined by the research ambient noise directionality (RANDI) model [18] [66] [129] [133] [148] [162] using ship length, speed, and an empirically established power law. Peak spectral densities for individual commercial ships vary from 140 dB re µPa2/Hz at 1 m for small fishing vessels to 195 dB re µPa2/Hz at 1 m for supertankers cruising at 20 knots or faster. For the majority of the world's big commerce fleet, source-level models have also been built for the propeller tonal blade lines, which occur at 6–10 Hz, and their harmonics [62] [66] [133] [162].

The distribution of shipping vessel traffic is not constant. In order to reduce journey time, the main commercial shipping channels adhere to coasts or great circle routes. The bulk of traffic is handled by dozens of large ports, or "mega ports," although smaller amounts of traffic are handled by hundreds of tiny harbors and ports. In its catalog of commercial and transportation marine traffic, the U.S. Navy identifies 3,762 traffic lanes and 521 ports [40] [66] [133] [162]. Fishing vessels, military ships, scientific research ships, and leisure craft are among the vessels that are located in places outside of major maritime channels; the latter are usually found nearshore [66] [133] [162].

The Lloyd's Register of the World's Commercial Fleet for the year 2001 included 92,817 vessels recorded in the world's ocean [66] [109] [110]. The main categories (with their respective numbers in parenthesis) are offshore supply (3,139), fishing (23,841), towing/ dredging (13,835), bulk dry transport (6,357), oil tankers (10,941), and cargo/passenger transport (34,704). However, gross tonnage might be a more significant indicator of sound production than vessel counts. Accordingly, less than 19% of all vessels are vessels, whereas oil tankers and bulk dry transport vessels account for approximately 50% of total tonnage [66].

According to Mazzuca (2001), vessel operation statistics show a consistent increase in vessel traffic over the previous few decades. Both the quantity of cargo shipped and the number of vessels has increased. For instance, over the previous 20 years, the number of products shipped by the U.S. Maritime Transportation has increased by 30% (both in terms of volume and ownership) [66] [146]. Large amounts of commodities and resources are transported throughout the world effectively via oceanic transportation. Long-distance transportation is becoming more and more necessary for the transportation of finished goods and raw materials due to the globalization of the economy. There are significant financial benefits to maritime shipping, and there is now no practical substitute for moving heavy loads of goods long distances [66].

Few ports handle the majority of the waterborne trade in the United States. According to U.S. Maritime Administration (2003), for example, the combined California ports of Los Angeles and Long Beach handle 37 percent of the world's trade in 20-foot-equivalent containers. This focuses shipping noise into the areas around these ports and their approaches within the U.S. Exclusive Economic Zone. There are also notable hubs for shipping traffic in New York (13%) and the Puget Sound region of Washington (8%) [66].

Commercial waterborne transportation that does not cross an ocean is known as short sea shipping. This alternate mode of transportation for goods moves cargo from large domestic ports to its final destination via inland and coastal waterways. The growth of short sea shipping is being actively supported by the European Commission and the U.S. Maritime Administration in an effort to relieve freight congestion on national rail and highway systems. Compared to 44% by road and 8% by rail, short sea shipping already makes up 41% of the entire European goods transport sector [47] [66]. Because short sea commerce occurs near coasts, it is especially problematic for marine mammals and shipping noise [66].

1.1.3 Seismic Exploration

High-intensity sound is used in seismic regression profiling to create images of the Earth's crust. It is widely employed by the fossil fuel extraction industry as the main method for locating and tracking reserves of natural gas and oil. Researchers from universities and the government also utilize it to collect data for their studies on the tectonic history and origins of the Earth [66]. The sound-producing components in seismic reconstruction profiling are arrays of air guns [36] [37] [66]. By releasing a certain amount of air under high pressure, air guns produce a sound pressure wave. This is caused by the air bubble expanding and contracting. A coherent pulse of sound is produced by firing many air guns at precisely the same time in order to achieve high intensities. Oil industry air gun arrays usually consist of twelve to forty-eight individual guns that are dispersed across an area of twenty-by-twenty meters and are trailed around 200 meters behind a vessel. The guns operate at pressures of 2,000 psi [66].

An air gun array's pressure output is a function of its operating pressure, the quantity of air guns it has, and the cube root of the total gun volume. Air gun-array source levels are back-calculated to an analogous source concentrated into a 1-m-radius volume in order to maintain consistency with the underwater acoustic literature. This results in source levels as high as 259 dB peak re 1 μPa at 1 m output pressure [63] [66]. Although the highest-pressure levels in the near field are restricted to 220–230 dB peak re 1 μPa, the effective source level forecasts pressures in the array's far field. An air gun array's far-field pressure is concentrated vertically, with a vertical strength that is roughly 6 dB more than that of a normal array's horizontal direction. Industry arrays have peak pressure values between 5 and 300 Hz [66]. Air guns are usually fired every ten seconds and are towed at a pace of approximately five knots. A seagoing seismic-reconnaissance operation involves six to ten seismic receiving streamers (hydrophone arrays) and many parallel sweeps through a region by a vessel towing an air gun array. Repeated seismic reconstruction surveys, or "4-D" surveys, are being used more and more for "timelapse" monitoring of oil fields that are producing. Worldwide, there are more than 90 seismic vessels accessible [66] [128] and roughly 20% of them are working in the field at any given moment [66] [141].

Activities related to offshore oil and gas exploration and development take place near continental borders. The United States and Mexican Gulf of Mexico, Venezuela, Brazil, West Africa, South Africa, North Sea, Middle East, northwestern Australia, New Zealand, southern China, Vietnam, Malaysia, Indonesia, and the Sea of Okhotsk are among the regions where activity is currently taking place. Deep water West Africa and the U.S. Gulf of Mexico are two new exploration hot spots that have experienced an increase in activity over the last five to ten years [66]. Air gun activity around the continental margins may propagate into the deep ocean and contribute significantly to low-frequency noise, according to a recent study of ambient noise in the North Atlantic [66] [111]. Throughout the summer, air gun sounds were captured nearly nonstop at places more than 3,000 kilometers away from the hydrophones that recorded them [66].

1.1.4 Sonar

In order to explore the water, sonar systems deliberately produce sonic energy. They look for details about items in the sediment, at the bottom of the sea, or in the water column. High-intensity acoustic energy is emitted by active sonar, which then receives reflected and/or scattered energy. There are several different types of sonar systems in use for both military and civilian purposes. Sonar systems can be divided into three categories for discussion: low-frequency (<1 kHz), mid-frequency (1–20 kHz), and high-frequency (>20 kHz) [66].

Target detection, localization, and classification are done with military sonars. They are used in both war and training operations, and they typically have larger source levels and a wider frequency range than civilian sonars. Military sonar may be employed primarily in training exercises because training takes place over a considerably longer period of time than battle. Wide-ranging monitoring is possible using low-frequency active (LFA) sonars, which can follow submarines over distances of several hundred to thousands of kilometers. LFA sonars, which are made up of arrays of source elements suspended vertically below the ship, are deployed by specialized support ships. An array of eighteen projectors operating in the frequency range of 100 to 500 Hz, with a 215 dB re 1 μPa at 1 m source level for each projector, is used in the U.S. Navy's surveillance towed array sensor system (SURTASS) LFA sonar [66] [74]. The effective source level of an LFA array, when seen horizontally, can be 235 dB re 1 μPa at 1 m or higher. These systems are made to project energy beams in a horizontal direction. With a bandwidth of roughly 30 Hz, the signal consists of both frequency-modulated (FM) and constant-frequency (CF) components. A ping sequence can have a duration of 6 to 100 s, with a typical duty cycle of 10-15% and intervals of 6 to 15 minutes. For days or weeks at a time, structured sequences of signal transmissions are released [66].

Tactical antisubmarine warfare (ASW) sonars operating at mid-frequency are intended to identify submarines across distances of several tens of kilometers. Surface combatants that hunt submarines, such destroyers, cruisers, and frigates, have them integrated into their hulls. Currently in use, 117 of these sonars are aboard U.S. Navy ships, and comparable systems in other navies—such as the British, Canadian, and French—bring the total number of these sonars in use globally to roughly 300 [66] [159]. The U.S. Navy's most sophisticated surface ship ASW sonar, the AN/SQS-53C, produces FM pulses in the 1- to 5-kHz band with a period of 1-2 s and source levels of 235 dB re 1 μPa at a height of 1 m or more [48] [66]. This sonar is pointed 3° down from the horizontal and has a nominal 40° vertical beam width (depending on frequency). The purpose of the AN/SQS-53C is to carry out direct-path ASW search, detection, localization, and tracking using a hull mounted transducer array consisting of 576 units housed in a bulbous dome beneath the ship's bow waterline. Both surface and subsurface vessels can be tracked by these systems, which can frequently identify surface ships farther away than conventional radar systems [66].

The Navy uses additional mid-frequency sonars for device activation, platform-to-platform communication, and depth sounding. Mine countermeasures and antitorpedo devices are examples of weapon countermeasures that use high-frequency sonars. Weapons include mines and torpedoes. Their intended operating range is between a few hundred meters to a few kilometers. For mine detection, mine-hunting sonars operate at tens of kilohertz, and for mine localization, above 100 kHz. These sonars use pulsed waves and are very directed. Side-scan sonar, which is typically used at frequencies close to 100 kHz for imaging the bottom, is another type of high-frequency military sonar [66]. The U.S. Navy has been emphasizing training missions in coastal and shallow-water environments for the last ten years. Shallow-water training ranges are now being planned for the East and West coasts of the United States [66].

Commercial sonars are intended for sub-bottom profiling, depth sounding, and fish finding. They usually produce sound between 3 and 200 kHz, with each sonar system producing a very specific restricted frequency range. At 1 m, source levels vary between 150 and 235 dB re 1 μPa. The majority of commercial flush finders and depth sounders are made to concentrate sound into a downward beam. The purpose of depth sounders and sub-bottom profilers is to identify the sea floor and explore beneath it, respectively. They are mostly used in shallow, nearshore areas. Both shallow and deep waters require the usage of fish finders [66].

Since small-scale commercial sonars are restricted by a number of important physical qualities, it is doubtful that their acoustic characteristics would change much in the future. They are constrained by the transducers' physical dimensions at low frequencies (about 3 kHz). They are restricted by considerable sound attenuation at the high frequency end (200 kHz). Similarly, cavitation limits the maximum power level (200 dB re 1 μPa at 1 m) that a single transducer can emit at shallow operating depths. More power levels can be attained by mounting sensor arrays on the ship's hull [66]. For accurate depth sounding, multibeam echo-sounding devices (like SeaBEAM or Hydrosweep) produce narrow, directed beams of sound (1° beam width, for instance). These systems, which use hullmounted arrays of transducers, may attain 235 dB re 1 μPa at 1 m source levels; in deep water, they are usually operated at frequencies between 12 and 15 kHz, and in shallow water, at higher frequencies up to 100 kHz. They might ensonify a few tens of kilometers along the ship's path [66]. Sonar is a very effective tool for depth sounding and sub-bottom profiling. Commercial sonar is present in almost all of the 80,000 commercial ships in the world's fleet as well as many of the 17 million small boats owned in the US. New applications could cause these systems to become even more widely used. It's probable that the limited range of these systems will partially counterbalance the impact of their widespread use [66].

1.1.5 Research Sound Sources

Sound is frequently used in research related to acoustical oceanography and underwater acoustic propagation. The Office of Naval Research funds nearly every program in the US, and the data gathered is useful for enhancing military sonar technology. The sound sources utilized in these investigations are either transducers that are readily available on the market or systems that are especially made to satisfy certain study needs. During these initiatives, a large range of signals, bandwidths, source levels, and duty cycles are conveyed. Most experiments have a spatial scope of tens of kilometers, but there have also been basin-scale initiatives like the Acoustic Thermometry of Ocean Climate (ATOC) program [66].

Fearing that its sound source might have an adverse effect on marine mammals, regulatory bodies, the public, and the scientific community paid close attention to the ATOC (later renamed the North Pacific Acoustic Laboratory [NPAL]) project, which was started in the early 1990s to investigate ocean warming [7] [66]. Both of the National Research Council's (NRC) 1994 and 2000a reports included in-depth discussions of this program. At 939 meters, close to the deep sound channel's axis, the ATOC source is installed and has a 195 dB re 1 μPa at 1 m level [66] [70]. With the noises being picked up by the U.S. Navy's fixed hydrophone arrays, it is intended to explore the whole North Pacific basin. With a bandwidth of 37.5 Hz, the transmitted signal is centered at 75 Hz. With a 5-minute "ramp-up" period and a 20-minute full-power signal length, it broadcasts every 4 hours. One of the main factors raising concerns about this experiment's possible effects on marine mammals was how long it was run [66] [118].

Another study using sonar at the basin size makes use of drifting sources, known as SOFAR floats [66] [126]. These devices drift at depth and periodically emit a continuous signal at 185–310 Hz for 120 s or longer, or a high-intensity tone (195 dB re 1 μPa at 1 m) that is frequency swept at 200–300 Hz. The sounds serve as a stand-in for deep currents since distant listeners may detect them and use their timing to infer the location of the float and, consequently, its drift [66].

1.1.6 Acoustic Deterrent Devices and Pingers

Sound is used by acoustic deterrent devices (ADD) to try and keep marine mammals away from fishing operations. These gadgets are designed to deter animals by producing a nearby audio disturbance or warning signal. In certain fisheries, pingers are utilized to warn marine mammals about the existence of nets or other entangling objects and to eject them from the area. ADDs of this type are usually low-power, with source levels between 130 and 150 dB re 1 μPa at 1 m. The use of acoustic harassment devices (AHDs) lessens the number of fish that are depredated by marine mammals that are trapped or raised. With source levels of 185–195 dB re 1 μPa at 1 m, these are powerful devices. Pingers and AHDs produce pulses that last between two and two thousand milliseconds, and their frequencies fall between five and 160 kHz. A single device may transmit with multiple wave shapes and time intervals to lessen habituation [66].

According to studies conducted by Kraus *et al*. (1997), Culik *et al*. (2001) and Bordino *et al*. (2002), pingers have been demonstrated to be successful in minimizing bycatch, at least for certain species of marine mammals. A study conducted in 2003 by Barlow & Cameron examined the effectiveness of pinger utilization in the drift gillnet shark and swordfish fishery in California. The results indicated that the entanglement rate for both sharks and cetaceans in nets equipped with pingers was reduced to a third compared to nets without devices. Further, according to Larsen (1997) and Vinther (1999), pinger trials conducted on a broad scale in Danish gillnet fisheries resulted in a decrease in harbor porpoise bycatch [66].

According to Morton & Symonds (2002) and Oleskiuk *et al*. (2002), there is a concern that the use of AHDs in aquaculture facilities may cause marine mammals, such as killer whales and harbor porpoises, to be unintentionally relocated near salmon farms in British Columbia. In a similar vein, there are worries that the extensive usage of AHDs would force porpoises out of crucial feeding areas [77]. Marine mammals that come into close contact with AHDs may suffer hearing impairments because to their high source levels [66].

1.1.7 Polar Icebreakers

In the arctic regions, noise pollution originates from ice-breaking ships [42] [66]. Propeller cavitation noise and bubbler system noise have been identified as the two types of noise associated with ice breaking. Certain ice-breaking vessels are outfitted with a bubbler mechanism, which propels air at high pressure into the surrounding water to dislodge floating ice. The noise has a broadband spectrum below 5 kHz and is constant while the bubbler system is in use. For bubbler system noise, a source level of 192 dB re 1 μPa at 1 m in one-twelfth-octave bands has been reported. The sound of the icebreaker propeller cavitating is caused when the ship rams the ice while its propeller is spinning quickly. Propeller cavitation noise has a source level of 197 dB re 1 μPa at 1 m and a broadband spectrum up to at least 20 kHz [66].

1.1.8 Industrial Activities, Offshore Drilling, and Construction

Underwater noise can be caused by building and industrial activity both in the ocean and near the coast. Coastal power plants, pile driving, dredging, tunnel boring, wind mills that produce electricity, and canal lock operations are a few examples [63] [66] [133]. It is not well understood how these sounds are coupled into the marine environment; however, it is generally more effective at lower frequencies. In order to extract seabed resources, reclaim land, and deepen channels and harbors, marine dredging is frequently carried out in coastal seas. For one third-octave bands with peak intensities between 50 and 500 Hz, reported source levels for dredging operations range from 160 to 180 dB re 1 μPa at 1 m [63] [66] [133].

Drilling, the installation and removal of offshore structures, and related transportation are among the oil and gas production activities that produce noise in the maritime environment. Drilling is connected with the highest sound pressure levels, with a maximum broadband (10 Hz–10 kHz) energy of roughly 190 dB re 1 μPa at 1 m. Both the drilling equipment and the propellers and thrusters employed for station maintaining produce drill-ship noise. Platform drill rigs are the next most popular type of offshore drilling equipment, after jack-up rigs. Ancillary noise is produced during drilling by the motion of support aircraft and supply boats. Large, heavy structures are transported from the point of manufacturing to the location of emplacement by means of strong support boats, which causes temporary localized noise [66] [133]. This could be a few-week long event that happens eight to ten times a year globally. The following activities related to oil production provide additional noise: drilling, grouting, perforating, pumping, installing pipes, driving piles, and providing ship and helicopter support. Source levels as high as 195 dB re 1 µPa at 1 m with peak frequencies at 40–100 Hz are suggested by Greene & Moore (1995) who state that production operations can produce received levels as high as 135 dB re 1 µPa at 1 km from the source [66] [133].

Production of oil and gas is shifting from shallow water environments to depths of up to 3,000 meters. Because drill ships and floating production facilities are used in deep water drilling and production, noise levels associated with these activities may be higher than in shallow-water production. Furthermore, for long-range propagation, noise produced in deep water may be easier to couple into the deep sound channel. Although the number of offshore mobile drill rigs in use varies globally based on business conditions, the number of drill rigs on the market has increased by about 10% over the last five years [66] [133].

1.1.9 Small Ships, Boats, and Personal Watercraft

Small boats may be substantial local sound generators, especially in coastal environments, but they do not make a large contribution to the global ocean sound environment. Whale-watching boats can have sound levels as high as 115–127 dB re 1 µPa at 1 m for one-third-octave bands [2] [66] and as high as 145–169 dB re 1 µPa at 1 m for one-twelfth-octave bands [42] [66]. Peak spectral levels in the 350–1200 Hz region is estimated to be 145–150 dB re 1 µPa2/Hz at 1 m, according to a recent study on noise levels from small powerboats [11]. In the United States, there are approximately 17 million small boats owned, although the exact number of recreational vessels in use is not well documented [66] [108]. Outboard (8.4 million), inboard (1.7 million), stern drive (1.8 million), sailboats (1.6 million), personal watercraft (1.4 million), and miscellaneous (2.5 million) are the different vessel classifications. According to the U.S. Fish & Wildlife Service (2001), there are around a million recreational boaters registered in Florida's inshore waters. Seasonally, an influx of boats from out of state increases the total number of boats in use [66].

1.2 Comparison of Anthropogenic Sound Sources

The individual source elements for sources made up of arrays of elements (such military sonars and air guns) can be widely dispersed. To standardize the calculation, the source level in this instance is provided for a range of 1 m; however, in actuality, the levels encountered close to the source are never as high as those shown. Rather, at longer ranges—where the distance to the source is significantly more than the source dimensions—these levels are employed to precisely calculate what the source level is. In actuality, another crucial factor to take into account is how sensitive marine mammals are to different types of sound [66].

The highest overall sound pressure levels are produced by underwater nuclear testing and ship-shock experiments; however, as these are uncommon occurrences, it is reasonable to conclude that their total influence is minimal. High SPLs are found in both military SURTASS-LFA sonars and large-volume air gun arrays. LFA sonars have higher total energy levels because to their lengthy ping durations and high duty cycles; the SURTASS-LFA and air gun arrays have higher energy at low frequencies, which is where long-range propagation is most likely to occur. Mid-frequency military sonars, like the SQS-53C, operate at middle frequencies, which limits their range. They also have shorter ping durations and more moderate duty cycles. Local environments are the focus of concern for these sonars' effects [66].

With over 10,000 vessels in operation worldwide, commercial supertankers are undoubtedly the most nearly ubiquitous producers of high-intensity emissions. The busiest shipping lanes and the areas closest to large ports are the areas where people are most concerned about these noise sources. Despite having a short duty cycle, the ATOC project's moored research sound source has a source level comparable to that of a supertanker. The source levels of AHDs are high, while those of ADDs are comparatively moderate. Although multibeam hull-mounted echo sounders have high source levels, their range and the area they ensonify are limited by their narrow beam widths and middling frequencies. Research acoustic floats (RAFOS) are operated at a very low duty cycle, yet they emit a somewhat high source level. Fishing boats may be at least a local source of acoustic annoyances due to their modest source levels [66]. Figure 1. compares the spatial extent and duration of different sound sources.

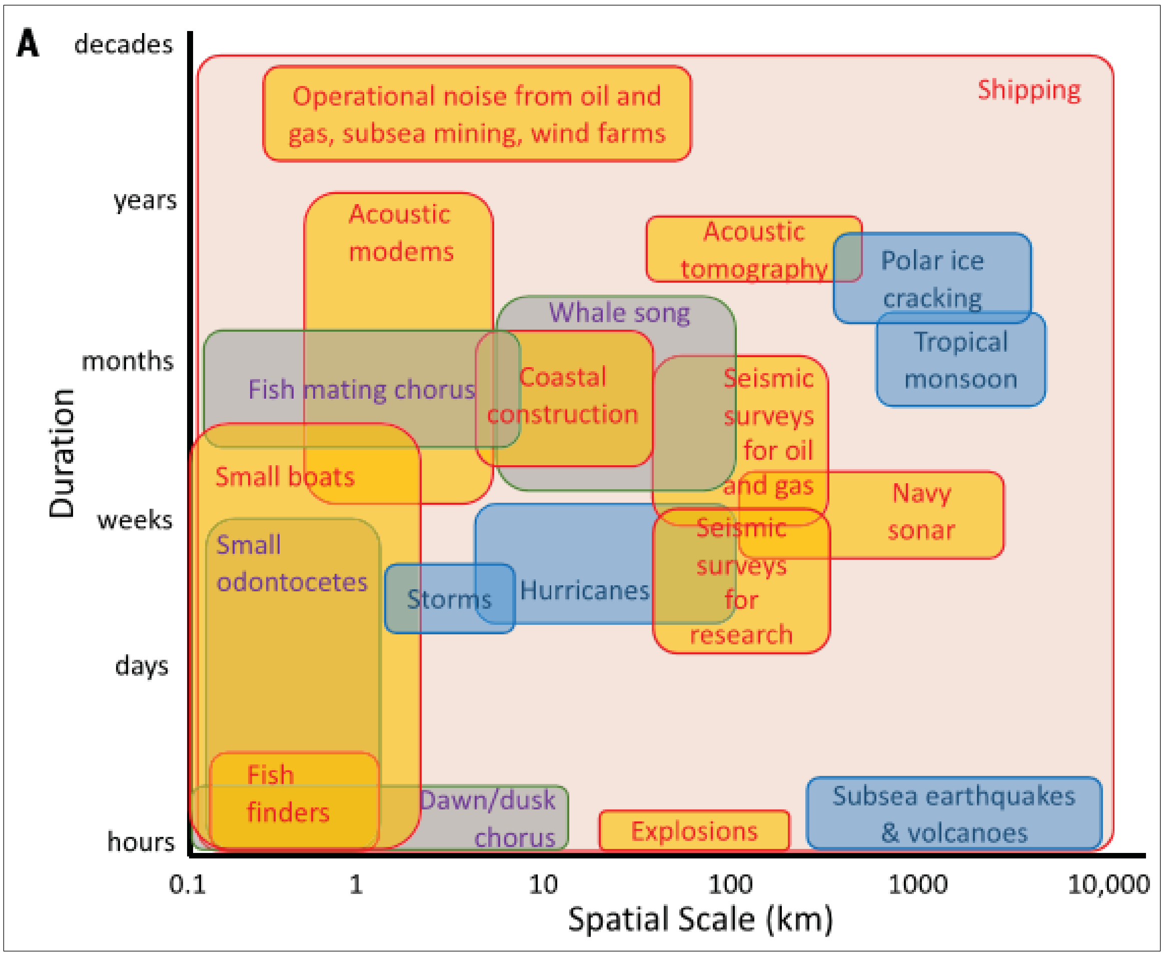

Figure 1 (A) The spatial extent and duration of different sound sources (Harding & Cousins, 2022)

1.3 Long term trends in ocean noise

There are non-anthropogenic and anthropogenic components to the overall trends for the sea level of sound. For example, there is evidence that elevated sea states as a result of global climate change may have increased background noise levels [6] [61] [66]. However, it's possible that anthropogenic noise increases have become more noticeable over the last few decades. The anthropogenic causes most likely to have contributed to increased noise include, in order of significance, offshore drilling and oil and gas exploration, commercial shipping, and navy and other sonar applications [66].

The waters surrounding Australia are isolated from the majority of commercial shipping, making it possible to distinguish between the effects of man-made and natural noise. Australian research indicates that ocean noise levels at low frequencies (100 Hz) could be as low as 50 dB re 1 µPa2 /Hz, which is roughly 30–40 dB lower than values in North American and European seas [24] [66]. These data also imply that, contrary to the deepwater curves established from Northern Hemisphere data [66] [160], wind/wave noise increases at low frequencies. The challenge of distinguishing between wind- and wave-generated noise and shipping noise in North American datasets was highlighted by The National Research Council (2003).

Ocean noise levels may have grown by 10 dB or more between 1950 and 1975, according to trends in background noise and anthropogenic activity levels [66] [124] [125]. Increases in commercial shipping are thought to be the cause of these changes, which are most noticeable in the eastern Pacific and eastern and western Atlantic. Three to five decibels can be explained by doubling the number of ships, and an extra six decibels could be explained by higher average ship speeds, engine power, and propeller tip speeds [66].

The comparison of contemporary recordings made along North America's west coast with historical U.S. Navy acoustic array data [66] [161] provides additional information on long-term noise trends [1] [66]. At a location off the coast of central California, a 33-year rise in low-frequency noise was detected by 10 dB. The growth in both the number of ships and the gross tonnage of commercial shipping accounts for the noise increase observed in this band. Global ship numbers climbed from roughly 57,000 to 87,000 between 1972 and 1999, while total gross tonnage rose from 268 to 543 million gross tons [66].

In order to determine that low-frequency noise increased by an average of 16 dB between 1950 and 2000, Mazzuca (2001) examined the findings of Wenz (1969), Ross (1987), and Andrew *et al*. (2002). For the previous 50 years, this translates to a doubling of noise power (3 dB) every ten years, or a 7% yearly increase in noise. Within this time frame, the global fleet grew by three times (from 30,000 to 87,000 ships) and by 6.5 times (from 85 to 550 million gross tons) [100] [109] [110].

2 Material and methods

The topic of "impact of climate change on marine mammals" was the subject of a systematic review using "Google Scholar," a web-based search engine which provides a quick and easy way to search and access published literature from articles, journals and books. Thematic search terms such as impact, sources, anthropogenic sound and marine mammals were used in the search.

The subjects evaluated in this research were chosen using an approach that involved assessing at the related works of literature. Publications between the years 1959 to 2022 were acquired for this review. However, not all of the articles that were reviewed, were used in this study because the major objective was to assemble data from recent research (past 10 to 20 years) on impact of anthropogenic sound on marine mammals. However, papers that contained relevant literature from as far back as the 1900's and the 2000's were also utilized for this review. One hundred twenty-seven (127) research articles were retrieved and included in this review and literature from seventy-seven (77) papers published between the years 1959-2022 were presented in this paper.

The search yielded different results: Some articles had all the thematic keywords and some were obtained that were specific to legislation measures and management approaches to protect marine mammals against anthropogenic sound, while others were specific to anthropogenic sound affecting fishes, marine mammals threatened with oil spills and marine mammals' responses to environmental stressors.

3 Results

When searching "Google Scholar" for information on the impact of anthropogenic sound on marine mammals, a total of 99,400 was retrieved. Among the results obtained from the search, a total of 21,900 were published within the years 2000-2023, 22,800 were published between the years 2010-2023 and 21,500 were published within the years 2015-2023. 21,200 publications between 2010 and 2023 reviewed the impact of anthropogenic sound on marine mammals.

However, not all the results retrieved for this research focused on the impact of anthropogenic sound on marine mammals. Some focused solely on anthropogenic sound on marine mammals, others examined legislation measures and management approaches to protect marine mammals from the impact of anthropogenic sound and some were specific to anthropogenic sound affecting fishes, marine mammals threatened with oil spills and marine mammals' responses to environmental stressors. Further, some papers focused on checklists sources of various anthropogenic sounds affecting specific species of marine mammals.

4 Discussion

4.1 How sound affects marine mammals

Numerous factors influence how marine mammals react to sound, such as (a) the sound pressure level and other characteristics like frequency, duration, novelty, and habituation; (b) the animals' physical and behavioral conditions; and (c) the surrounding acoustic and ecological aspects of the environment. The responses of marine mammals to various sound sources were reviewed by Richardson *et al*. (1995). However, the current knowledge of marine mammals' sound responses is insufficient to make accurate predictions of their behavioral reactions to either prolonged increases in ambient background noise or loud noises [66].

Human perception of sound intensity is influenced by a variety of psychological and physiological elements in addition to hearing sensitivity [14] 66]. A loudness-level scale, known as the phon (in dB), was created through extensive testing in which a human subject evaluated the relative loudness of two sounds. For example, the phon compares the loudness level of tones with different frequencies to a reference tone at one kHz. In actuality, a sound's degree of discomfort is determined by a variety of variables other than its volume, such as how often it occurs; sporadic sounds are more bothersome than continuous ones. There are significant differences in the role of sound in sensing the marine and terrestrial environments, and the ambient and biologically significant sounds, like those of predators, differ in each setting. It is therefore uncertain to what extent research on humans and terrestrial animals can be reliably extrapolated to marine mammals [66].

4.2 Marine mammal sound production

The range of noises that marine mammals find significant either coincides with or surpasses the frequency band in which they generate sounds (Figure 2). According to Watkins & Wartzok (1985), the frequency of calls made by marine mammals is often inversely correlated with body size, with Mysticetes having larger bodies and lower call frequencies than Odontocetes [66].

The low frequency range of 10–2,000 Hz is where Mysticetes produce the majority of their sound [66] (Edds-Walton, 1997). Mysticete sounds are produced either as isolated calls or integrated into patterned sequences or songs. They can be broadly classified as (a) tonal calls, (b) FM sweeps, (c) pulsed tonals, and (d) broadband gruntlike sounds. The mid-frequency and high-frequency range of 1–200 kHz is where Odontocetes produce the majority of their sound [66] [97]. Odontocetes produce three types of sounds: (a) burst-pulse click trains; (b) broadband clicks with peak energies ranging from 5 to 150 kHz, depending on the species; and (c) FM or tonal whistles with a frequency range of 1 to 25 kHz. Breeding pinnipeds on land have a narrow range of barks and clicks, from less than 1-4 kHz. During the breeding season, those animals that mate in the water create intricate vocalizations. Sound is used by all pinnipeds, sea otters and manatees to form and preserve the mother-young link, particularly during post-separation reunions [65] [66] [127].

Richardson *et al*. (1995) have documented that at least thirteen Odontocete species possess the ability to employ self-generated noises, sometimes known as echolocation, to gather information about objects and aspects of their surroundings. Echolocation clicks have been seen in every known species of Odontocete, and none has been demonstrated to be incapable of doing so. By acting as acoustic lenses, certain fats in the forehead (melon) emit these echolocation sounds in beams that are directed forward. Certain Odontocetes species have peak spectra above 100 kHz and little to no whistles or very high frequency clicks. The Amazon River dolphin (*Inia geoffrensis*) [66] [112] and the harbor porpoise (*Phocoena phocoena*) are two such species [66] [79].

Other Odontocetes routinely use whistles and generate clicks with peak spectra below 80 kHz. The pantropical spotted dolphin (*Stenella attenuata*), which frequently inhabits offshore seas, and the coastal bottlenose dolphin (*Tursiops spp.*) are two examples. Only clicks have been reported from deep-diving odontocetes, including beaked whales (Ziphiidae) and sperm whales (*Physeter macrocephalus*) [66] [68] [76] [104]. According to Caldwell & Caldwell (1965), certain odontocete whistles are considered to be "signature" cries that serve as personal identification. The patterned "coda" clicks sequences emitted by sperm whales exhibit geographic variation [66] [119], and killer whale sounds are known to be group specific [56] [66] [143].

According to reports, the source levels of odontocete clicks can reach up to 228 dB re 1 μPa at 1 m for bottlenose dolphins echolocating in noisy environments [4] and false killer whales (*Pseudorca crassidens*) [66] [137]. For male sperm whales, the source levels can reach up to 232 dB re 1 μPa at 1 m [104]. These echolocation clicks have a short duration (50-200 μs), which indicates that even if their source levels are high, their overall energy is low (197 dB re 1 μPa2-s). Less than 110 dB re 1 μPa at 1 m for the spinner dolphin (*Stenella longirostris*) [66] [153] to 169 dB re 1 μPa at 1 m for bottlenose dolphins [66] [72] are the lower source levels of odontocete whistles than their clicks. Odontocete whistles and clicks have a detection range of roughly 5 km, while reports have also indicated larger detection ranges [10] [60] [66] [87].

Long distances can be used to identify Mysticete calls [66] [116]. For example, low-frequency (10–100 Hz) sounds from blue whales (*Balaenoptera musculus*) have estimated source levels of 185 dB re 1 μPa at 1 m [66] [101]. Depending on the acoustic propagation, these calls can be detected at distances of up to 100 km. According to Richardson *et al*. (1995), the majority of big Mysticetes, including gray, blue, fin, bowhead, right, humpback, Bryde's and minke whales, are known to vocalize at frequencies lower than 1 kHz, with source levels reported to reach as high as 185 dB re 1 μPa at 1 m. Estimates of source levels and frequencies have been made for the underwater calls of various pinniped species. Examples are the Ross seal (*Ommatophoca rossii*), which generates calls at 1-4 kHz [66] [152], and the Weddell-seal (*Leptonychotes weddellii*), which produces calls from 148 to 193 dB re 1 μPa at 1 m at frequencies of 0.2–12.8 kHz [66] [137]. Both in the open ocean and beneath ice, these cries can be heard at several-kilometer distances [66] [155].

4.3 Marine mammal hearing

Underwater sound travels quickly, and marine mammals' ability to detect sounds is demonstrated by the fact that they have evolved hearing ranges that are wider than those of terrestrial mammals. Of the approximately 127 marine mammal species, audiograms have been developed for eleven Odontocetes species and nine pinniped species [66] [106] [150]. All of the hearing data are from small species to be kept in captivity. For species that are not easily examined using standard audiometric techniques, direct hearing data are not available. In the case of the latter, audiograms have to be calculated using mathematical models derived from ear anatomy or deduced from field-exposure tests and the sounds they make [66] [150].

The functional hearing range of Delphinids is believed to be 200 Hz to 100 kHz, with some smaller species having the ability to hear sounds up to 200 kHz. Thus far measured delphinid audiograms exhibit modest sensitivity at 1-2 kHz and peak sensitivity between 20 and 80 kHz. When odontocetes hear and echolocate at high frequencies, they may be able to escape low-frequency background noise because ambient noise reduces at these frequencies. The ambient sound of inshore and riverine settings is another feature that benefits certain odontocetes at high frequencies. Although they have a shorter propagation distance, higher frequencies also offer superior spatial resolution [66].

Hypothetically, Mysticete hearing falls between 20 Hz and 20–30 kHz, based on modeling but lacking measured audiograms. Infrasonic (down to about 10 Hz) frequencies are suspected to be used for hearing in some bigger species, including fin and blue whales. They have optimal hearing between 1 and 20 kHz, according to pinniped audiogram data. Unlike fur seals and sea lions (otariids), true seals (phocids) have higher-pitched underwater hearing. While some pinnipeds have slightly superior hearing in the air than in the water, others are more suited for underwater hearing. The most marine-adapted hearing, with good sensitivity below 1 kHz, is possessed by elephant seals, while sea lions have the most terrestrially adapted hearing [66] [80].

Although the hearing of marine mammals is suited to an aquatic environment, their anatomy came from terrestrial ancestors. The external ears, which are lacking in the majority of marine mammal species, and the middle ears, which are significantly altered in marine mammals, are where the differences in hearing physiology between terrestrial and marine mammals are most noticeable. Marine animals may have evolved robust defenses against hearing loss because ambient noise levels in the water can vary by many orders of magnitude due to storms and other natural events. Other than in general, the effects of high-intensity noises on marine mammals' hearing cannot be predicted based on current research [66]. Table 1. emphasizes on the impacts of anthropogenic sound on different marine mammal species.

Table 1 Impact of anthropogenic sound on marine mammals

Effects	**Description of impacts**	**Author(s)**
Hearing losses	High-intensity sound exposure can lower hearing thresholds. Temporary threshold shifts (TTS) and permanent threshold shifts (PTS) are two categories for hearing losses. A threshold shift is an increase in the minimum sound level required for human hearing. PTS is assumed to result from repeated TTS. The time of exposure, hearing sensitivity, and sound power spectrum all affect how much hearing is lost. An abrupt, high-intensity blast can cause ear injury to cetaceans. Hearing loss can lead to unpredictable behaviour in migratory, mating, and stranding, as well as a reduction in communication range, interference with feeding ability, and increased vulnerability to predators. Both TTS and PTS should be taken very seriously since cetaceans rely heavily on their sense of hearing. Information about hearing loss in marine mammals is somewhat scarce. According to experiments conducted on captive bottlenose dolphins, TTS are detected at 193-296 dB re 1 μPa when the dolphins are exposed to 1-s tones at 20 kHz. Research utilizing impulsive sources, such as seismic water guns, indicates that beluga whales (Delphinapterus leucas) experience TTS when exposed to sound pressure levels of 217 dB re 1 μPa and total energy fluxes of 186 dB re 1 μPa2-s. According to one theory, animals are most susceptible to TTS at or close to the frequencies where their hearing acuity is highest. This indicates low-frequency sensitivity for baleen whales and mid- and high-frequency sensitivity for smaller cetaceans. As both the tonal and impulsive sounds that marine mammals create can be similar in sound intensity to those reported to induce TTS in the previously mentioned controlled tests, it	(Ketten et al., 1993); (Ridgway et al., 1997); (Finneran et al., 2002); (National Research Council, 2003); (Hildebrand, 2005); (Standoff, 2013); (Peng et al., 2015); (Erbe et al., 2018); (Harding & Cousins, 2022)

	also begs the question of why, it seems, they do not cause hearing impairment through their own sound production. It is believed that an animal may be shielded from its own vocalizations by internal systems.	
Masking	Acoustic signals are distinguished from background noise in the environment. An animal's capacity to recognize significant sound may be diminished by increasing background noise; this phenomenon is known as masking. When noise is present in the crucial band (CB) of frequencies surrounding the target signal, it can effectively hide the signal. The critical ratio (CR) is the degree to which a pure tone must surpass the noise spectral level in order to be perceived. The bandwidth (CB) within which background noise impairs an animal's hearing is related to the CR. Odontocetes and pinnipeds kept in captivity are used to estimate the CBs and CRs of marine mammals. The CB stated as a percentage is narrower at medium and high frequencies (1-3 kHz) and broader at low frequencies (25–75% at 100 Hz) for all species. This implies that low frequencies are better covered by band-limited noise than by middle and high frequencies. By distinguishing between the various directions in which the signal and the noise propagate, an animal's directional hearing talents may aid it in avoiding masking. For bottlenose dolphins, a directivity index of up to 20 dB has been measured. Pinnipeds have less acute directional hearing. Erbe and colleagues in the years 1998 and 2000 have built software to simulate the masking of beluga whale sounds by icebreaker noise in their study. Masking was achieved at noise-to-signal ratios of 15–29 dB by icebreaker noise from ramming, ice cracking, and bubbler systems. Forty kilometers was the expected masking zone for beluga sounds from ramming noise. When beluga whales are relocated to areas with increased background noise, their vocal output varies. An animal may be trying to avoid or overcome masking when it hears low-frequency sounds by increasing the sound pressure level and vocalization frequency. In response to boat noise, beluga whales have also been seen to raise their call frequencies and increase their call rates. Similarly, it has been hypothesized that when whale-watching boats are nearby, killer whales adjust the frequencies at which they call.	(Au & Moore, 1984); (Au et al., 1985); (Richardson et al., 1995); (Erbe & Farmer, 1998); (Erbe et al., 1999); (Lesage et al., 1999); (Erbe & Farmer, 2000); (National Research Council, 2003); (Foote et al., 2004); (Hildebrand, 2005); (Peng et al., 2015); (Erbe et al., 2018); (Harding & Cousins, 2022)
Nonauditory sound impacts	The way that sound interacts with the physiology of marine mammals is known as nonauditory effects. In addition to the previously stated impacts on hearing, sound has been shown to have both direct and indirect physiological effects on mammals. These physiological impacts can cause minor disruptions, stress, injuries, and even death. Marine mammals have a physiology that is especially suited to living underwater. Deep-diving species, for instance, possess unique pulmonary and cardiovascular systems that enable breath holding and pressure adaptation. Marine mammals may be more susceptible to sound exposure due to the same physiology that enables them to dive deep and stay underwater for extended periods of time. Their physiological reactions to this exposure may also be different from those of humans and other terrestrial mammals. Studies conducted on captive marine mammals, laboratory-bred terrestrial species, and human divers indicate that exposure to submerged sound can have physiological effects that are not auditory. Numerous potential effects could arise, such as physiological stress, neurosensory effects, vestibular response effects, acoustic resonance-induced tissue damage, gas bubble formation and/or development in tissues and blood, and blast-trauma injuries. Physiological alterations in the immunological and neuroendocrine systems that happen after being exposed to a stressor are referred to as stress. Although physiological stress responses remain incompletely understood, marine mammals have shown signs of noise-induced stress. For example, when exposed to sound, dolphins' heart rates fluctuate. A beluga whale that was exposed to more sound had higher levels of the stress hormones dopamine, adrenaline, and norepinephrine. Long-term noise-induced stress has been shown to cause debilitation in certain fish and invertebrates, including diminished growth, pathological alterations in the reproductive and digestive systems, and sterility. There have been reports of neurologic disturbances in human divers exposed to high underwater sound levels (160–180 dB re 1 μPa for 15 minutes). During exposure, symptoms	(Banner & Hyatt, 1973), (Fletcher et al., 1976); (Erlich & Lawson, 1980); (Lagardere, 1982); (ter Harr et al., 1982); (Ketten et al., 1993); (Greene & Moore, 1995); (Clark et al., 1996); (Crum & Mao, 1996), (Bauman et al., 1997); (Jackson & Kopke, 1998); (Cudahy & Ellison, n.d.); (Cudahy et al., 1999), (Steevens et al., 1999); (Martin et al., 2000); (Houser et al., 2001); (Miksis et al., 2001); (Laurer et al., 2002); (Finneran,

	included dizziness, headaches, sleepiness, and difficulty focusing. Days to weeks following exposure, these divers experienced repeated symptoms, which included, in one instance, a partial seizure 16 months following the first exposure. Marine mammal effects of this kind have not yet been investigated. Humans exposed to sound may have a vestibular reaction or dizziness at thresholds as low as 101–136 dB re 1 μPa, a condition known as the Tullio phenomenon. Transient effects were noted as soon as the human diver's vestibular function was evaluated both before and after being exposed to underwater sound—160 dB re 1 μPa for 15 minutes. Similar to this, rats exposed to 180 dB re 1 μPa for 5 min showed a slight, temporary impairment in vestibule motor function, and guinea pigs subjected to 160 dB re 1 μPa for 5 min underwater sound exposure showed vestibular effects. Mammalian air cavities can experience an increase in pressure in reaction to sound due to acoustic resonance. Since the vibration amplitude is highest at resonance at any given amount of excitation, lung and other air cavity resonance is crucial for determining injury thresholds. A damage threshold of 180–190 dB re 1 μPa is supported by in vivo and theoretical investigations on tissue injury. Based on extrapolation from in-air data and underwater observations of terrestrial mammals, including humans, these studies also establish a link between resonance and body mass. According to Finneran's (2003) direct measurements, the resonance frequencies of the lungs of bottlenose dolphins and beluga whales are at low frequencies (30 and 36 Hz, respectively). The resonance's tuning or amplification impact is a crucial consideration for resonance effects. The degree of tuning (defined as Q, where a higher Q denotes a sharper tuning) in the lungs of humans and pigs has been measured in vivo; in the case of beluga whales and bottlenose dolphins, the corresponding values are 2.5 and 3.1. This implies that resonance frequencies experience a moderate level of amplification (a factor of three). In mammalian tissues, sound can enhance the existence of gas bubbles, particularly in cases where dissolved gasses are plentiful due to frequent dives. While deep-diving marine mammals have evolved a way to prevent decompression sickness during their regular diving activity, human divers are required to decompress carefully after dives in order to prevent bubble formation. Strong sound causes bubbles to form (in vivo cavitation) and encourages bubble expansion (rectified diffusion). The likelihood of clogged arteries rises with the expansion of bubbles. Air-filled cavities, like the lungs, sinuses, ears, and intestines, can sustain harm from high pressures originating from sources like explosions. An abrupt reduction in pressure, like that caused by blast waves, can lead to the rupture of air-filled organs. The mechanical effect of a brief pressure pulse (positive acoustic impulse), according to studies on blast damage in animals, appears to be most closely associated with organ damage. In rats, air-filled intestines are perforated and haemorrhaged at peak pressures of 222 dB re 1 μPa. In sheep, arterial gas embolisms, bleeding, pulmonary contusions, and barotraumas are caused at lethal peak pressures of 237 dB re 1 μPa. After a 5,000-kg explosion nearby, two deceased humpback whales were discovered, and analysis of the temporal bones in their ears indicated significant blast trauma.	2003); (National Research Council, 2003); (Romano et al., 2004); (Hildebrand, 2005); (Standoff, 2013); (Peng et al., 2015); (Erbe et al., 2018); (Harding & Cousins, 2022)
Impact of noise on marine mammal behaviour	It is unclear how marine mammals respond to noise in terms of behaviour. The presence of offspring, age, sex, behavioural condition, habituation or desensitization, exposure location, and proximity to a shoreline are some of the factors that may influence a response. They can take many different forms, from mild adjustments to surfacing and breathing patterns to vocalization cessation to active avoidance or flight from the area with the highest sound levels. For example, research indicates that bowhead whales exposed to anthropogenic noise, even at moderate received levels (114 dB re 1 μPa), exhibit a pattern of shorter surfacing, shorter dives, fewer blows per surfacing, and longer intervals between blows. Reduced or stopped vocalization is another common response pattern. Examples of this include right whales reacting to boat noise, bowheads to industrial sounds played back, sperm whales responding to acoustic pinger	(Loughrey, 1959); (Fish & Vania, 1971); (Watkins & Schevill, 1975); (Watkins, 1977); (Calkins, 1979); (Stewart et al., 1982); (Bryant et al., 1984); (Fay et al., 1984); (Malme et al., 1984); (Au

	pulses and military sonar, and sperm and pilot whales (*Globicephala spp.*) responding to an acoustic source for oceanographic research. In addition, humpback whales prefer to stop vocalizing when they approach boats, lengthen their song cycles when exposed to the LFA source, and avoid mid-frequency sonar. In the midst of increased background noise, beluga whales modify the frequencies and source levels of their echolocation clicks. Air gun noise elicited an avoidance reaction in gray whales (*Eschrichtius robustus*), and the response was stronger when the source intensity went from 164 to 180 dB re 1 μPa. Additionally, they avoided LFA transmissions that were directed landward. There have been reports of marine mammals responding either minimally or not at all to certain anthropogenic sounds. For instance, when sperm whales came across echosounders or were subjected to sound levels of 180 dB per 1μPa from a detonation, they kept phoning. There was the sound of a container ship, but the fin whale (Balaenoptera physalus) did not alter its calling in terms of frequency, volume, or rate. The two main determinants of noise sensitivity are age and gender. For example, young and pregnant Steller sea lions (*Eumetopias jubatus*) are more prone than territory-holding males and females with young to flee a haul-out site in reaction to aircraft overflights. When exposed to sounds from aircraft or vessels, walruses (*Odobenus rosmarus*) may momentarily abandon their calves or undergo a stampede that results in their crushing. Cow-calf pairs in gray whales are thought to be more susceptible to disturbance from whale-watching boats than other age or sex classes, and humpback groups with one or more calf appear to be more susceptible to vessel traffic than groups without calf. The context of the exposure, such as the source's location in relation to the animal, its mobility, and the source's initiation and repetition (random versus periodic and predictable), appears to have an impact on marine mammal reactions as well. Fin whales can tolerate a stationary source better than a moving one. When a source comes in slowly, humpback whales are more likely to respond than when it comes in suddenly. When dragged out of a ship, California sea lions (*Zalophus californianus*) and harbour seals (*Phoca vitulina*) react at a greater distance; the same is true for walruses. When in shallow water, bowheads react more quickly to aircraft overflights. When slow-moving boats are around in the St. Lawrence River, beluga whales are less likely to alter their swimming and diving habits than when fast-moving boats are there. In Alaska, noise from small boats can cause beluga whales feeding on river salmon to halt and move downstream; noise from fishing boats generally has little effect on them. In Bristol Bay, beluga whales may withstand intentional disturbance in order to maintain their feeding behaviour even while encircled by fishing vessels. When tiny boats approached bottlenose dolphins in Sarasota Bay, their pauses between breaths were longer. As the number of boats in Kings Bay, Florida, increased, so did the manatees' utilization of boat-free sanctuaries. Few research has documented the long-term responses of marine mammals to human sound, suggesting in certain cases habitat desertion. Gray whales may have left Guerrero Negro Lagoon in Baja California throughout the majority of the 1960s due to shipping and dredging related to a salt works. Following the cessation of these actions, the lagoon was once again inhabited, initially by lone whales and then by pairs of cow-calf. Between 1993 and 1999, the Broughton Archipelago was home to killer whales (*Orcinus orca*) in the British Columbia region. During this time, acoustic harassment devices were being used on salmon farms.	et al., 1985); (Malme et al., 1985); (Tilt, 1985); (Watkins et al., 1985); (Watkins, 1986); (Edds, 1988); (Wartzok et al., 1989); (Bauer et al., 1993); (Maybaum, 1993); (Richardson & Malme, 1993); (Blane & Jaakson, 1994); (Bowles et al., 1994); (Richardson et al., 1995); (Tyack & Clark, 1998); (Buckingham et al., 1999); (Madsen & Mohl 2000); (Miller et al., 2000); (Nowacek et al., 2001); (Morton & Symonds, 2002); (National Research Council, 2003); (Hildebrand, 2005); (Standoff, 2013); (Peng et al., 2015); (Erbe et al., 2018); (Harding & Cousins, 2022)
Habituation and tolerance of noise	The gradual lack of sensitivity to noise is known as habituation. Over time, the animals may become less receptive because they have grown acclimated to the signal and no longer feel threatened by it. On the other hand, despite the noise's irritating quality, animals could decide to return to the noisy place due to its significance. The greatest proof that marine mammals have become accustomed to loud noises comes from attempts to keep them away from fishing gear and aquaculture facilities by using acoustic harassment devices (AHDs). Evidence suggests that harbour seals, for example, adjust their swimming behaviour to keep their heads out of the water when they are in high-intensity sound fields,	(Jones & Swartz, 1984); (Watkins, 1986); (Mate & Harvey, 1987); (Ketten et al., 1993); (Jefferson & Curry, 1994); (Todd et al., 1996); (Cox et al.,

	which may help them become accustomed to AHDs. It has also been observed that harbour porpoises require ten or eleven days to acclimate to gillnet pingers. Responses to other boats and whale watching have also been observed, which points to some degree of noise acclimatization. The common minke whale (*Balaenoptera acutorostrata*) on Cape Cod shifted from being drawn to boats to appearing largely disinterested; humpback whales went from mixed, but typically strongly negative, to strongly favourable reactions; and fin whales went from flight reactions to disinterest. As the season goes on, gray whales at San Ignacio Lagoon in Baja California are less likely to jump from whale-watching boats. The absence of hearing loss or harm from loud noises does not imply that habituation has occurred. In Newfoundland, humpback whales continued to eat close to the seafloor blasting location. Based on the size of the explosive charges, it was assumed that the source levels were between 295 and 300 dB re 1 μPa at 1 m. The received sound pressure levels at 1 mi from the explosions were typically 145–150 dB re 1 μPa at 240–450 Hz. The behaviour, movement, and residence time of the whales did not exhibit any discernible response to the blasting. However, after the blast exposure, there was a rise in unintentional trapping in nets. Furthermore, following a 5,000-kg explosion, two whales were discovered dead, and an analysis of the temporal bones in their inner ears indicated severe blast injuries. This event emphasizes how challenging it is to track the impact of noise or high-intensity sound on marine mammals via overt behavioural reactions.	2002); (National Research Council, 2003); (Hildebrand, 2005); (Standoff, 2013); (Peng et al., 2015); (Williams et al., 2015); (Erbe et al., 2018); (Harding & Cousins, 2022)
Incidence of mass stranding associated with high-intensity sound	The use of air guns during seismic reconstruction profiling and high-intensity sonar during naval operations have been linked to multiple-animal strandings, or "mass strandings." These instances are notable for primarily involving beaked whales, namely Cuvier's beaked whales (*Ziphius cavirostris*). It was not believed that the Cuvier's beaked whale was the most prevalent cetacean species in many of the locations where these incidents took place. It is known that odontocetes mass strand, or arrive at the shore in groups consisting of two or more animals. However, beaked whale mass strandings are not common. A global catalogue of Cuvier's beaked whale strandings involving two or more animals has been compiled by the National Museum of Natural History, Smithsonian Institution (J. Mead pers. comm.). There are no reports of multiple-animal strandings until 1963, with the exception of a solitary incident involving two individuals in 1914. Three to ten mass strandings of Cuvier's beaked whales were documented every decade between 1963 and 2004, while the rising number of mass stranding incidents observed in recent decades may be explained by improved reporting. Simmonds & Lopez-Jurado (1991) made the first documented correlation between beaked whale strandings and naval activities. They reported three multi animal strandings in the Canary Islands in 1985, 1988, and 1989 that were linked to naval operations. They also reported two more mass strandings of beaked whales in the Canary Islands in 1986 and 1987. These authors linked the large strandings of beaked whales to the presence of nearby naval operations rather than to the use of ASW sonar. The introduction of midfrequency ASW sonar has been linked to an increase in the number of multi animal beaked whale stranding incidents. First tested in 1957, hull-mounted ASW sonar prototypes (such as SQS-23 and 26) were installed on a variety of US and foreign navy vessels, including destroyers, cruisers, and frigates, starting in the early 1960s. This time aligns with an upsurge in reports of Cuvier's beaked whale mass strandings. Of the thirty-two known mass strandings of these whales, eleven have been linked to ongoing naval operations. The past few decades have seen a global increase in the effort to record marine mammal strandings; hence, increased reporting efficiency could contribute to the higher numbers that have been reported. It might be possible to clarify the connection between the occurrence of high-intensity sound and these mass strandings by looking into the circumstances around them. Thorough investigative reports have been produced on two of these strandings: the May 1996 incident in the Greek island of Kyparissiakos Gulf and the March 2000 incident in the Bahamas. Analyzing further beaked whale	(Gerken, 1986); (Simmonds & Lopez-Jurado, 1991); (D'Amico & Verboom 1998); (Evans & England, 2001); (Walsh et al., 2001); (National Research Council, 2003); (Hildebrand, 2005); (Peng et al., 2015); (Erbe et al., 2018); (Harding & Cousins, 2022)

	mass strandings offers more insight into the variety of sound sources, surroundings, and circumstances connected to these occurrences.	

The effects of anthropogenic noise on marine life have emerged as one of the most significant research areas as a result of humans' increasing use and exploration of the ocean. Table 2. And Figure 3. provides an overview of how the effects of anthropogenic noise on marine organisms vary depending on the species under investigation and the amount of both stationary and impulsive noise.

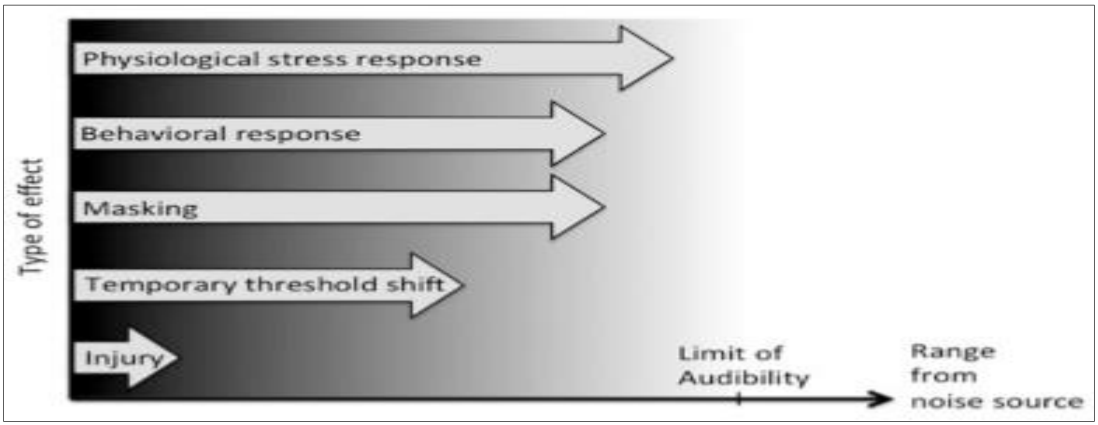

Figure 3 Range of noise source and the type of effect (Erbe *et al.*, 2018)

Table 2 Mini Checklist on Effects of different types of anthropogenic noise on some marine mammal species

Scientific name	**Common name**	**Type of anthropogenic noise**	**Effects**	**References**
Acoustic communication and physiological hearing system				
Mirounga angustirostris	Northern elephant seal	Increased ambient noise	Constrains acoustic communication	(Southall *et al.*, 2003); (Peng *et al.*, 2015)
Phocoena phocoena	Harbor porpoise	Seismic air-gun shooting	Shifts the hearing threshold	(Lucke *et al.*, 2009); (Peng *et al.*, 2015)
Tursiops truncatus	Common bottlenose dolphin/ Atlantic bottlenose dolphin	Experimental noise emanating device	Shifts the hearing threshold	(Nachtigall *et al.*, 2004); (Peng *et al.*, 2015)
Individual behaviour				
Megaptera novaeangliae	Humpback whale	ATOC (Acoustic Thermometry of Ocean Climate) sound Sonar	Increases distance and time intervals between successive surfacing Modifies courtship calls	(Frankel & Clark, 2000); (Miller, 2000); (Peng *et al.*, 2015)
Tursiops truncatus	Common bottlenose dolphin/ Atlantic bottlenose dolphin	Pile driving noise	Modifies sound producing	(David, 2006); (Peng *et al.*, 2015)
Eubalaena glacialis	North Atlantic right whale	Vessels' noise	Modifies calling behaviour	(Parks *et al.*, 2007); (Peng *et al.*, 2015)
Eubalaena australis	Southern Right Whale	Vessels' noise	Modifies calling behaviour	(Parks *et al.*, 2007); (Peng *et al.*, 2015)

Mesoplodon densirostris	Blainville's beaked whale	Mid-frequency sonar	Disrupts foraging and induces avoidance behaviour	(Tyack *et al*., 2011); (Peng *et al*., 2015)
Population distribution and abundance				
Ziphius cavirostris	Cuvier's beaked whale/ Goose-beaked whale	Naval sonar	Causes mass strandings	(Frantzis, 1998); (Jepson *et al*., 2003); (Fernández *et al*., 2005); (Cox *et al*., 2006); (Peng *et al*., 2015)
Orcinus orca	Orca/ Killer whale	High-amplitude acoustic harassment devices	Induces emigration	(Morton, 2002); (Peng *et al*., 2015)
Phocoena phocoena	Harbor porpoise	Pile driving noise Wind farm noise	Induces emigration Alters vertical distribution	(Carstensen *et al*., 2006); (Thompson *et al*., 2010); (Peng *et al*., 2015)
Tursiops truncatus	Common bottlenose dolphin/ Atlantic bottlenose dolphin	Pile driving noise Underwater explosives	Induces emigration Mass strandings	(Klima *et al*., 1988); (Thompson *et al*., 2010); (Peng *et al*., 2015)
Mesoplodon densirostris	Blainville's beaked whale	Naval sonar	Mass strandings	(Jepson *et al*., 2003); (Fernández *et al*., 2005); (Cox *et al*., 2006); (Peng *et al*., 2015)
Mesoplodon europaeus	Gervais' beaked whale	Naval sonar	Mass strandings	(Jepson *et al*., 2003); (Fernández *et al*., 2005); (Cox *et al*., 2006); (Peng *et al*., 2015)
Physiological impacts				
Delphinapterus leucas	Beluga whale	Seismic air-gun shooting Experimental noise emanating device	Increases metabolism and decreases immunity Increases heart rate	(Romano *et al*., 2004); (Lyamin *et al*., 2011); (Peng *et al*., 2015)
Tursiops truncatus	Common bottlenose dolphin/ Atlantic bottlenose dolphin	Seismic air-gun shooting	Increases metabolism and decreases immunity	(Romano *et al*., 2004); (Peng *et al*., 2015)

5 Conclusion

Marine mammals contribute to maintaining the health of ecosystems and at the same time act as sentinel species, or an early warning system, for when ecosystem health is declining. Since marine mammals are consumers at different trophic levels, their place in the trophic hierarchy directly influences the dynamics of both predators and prey, which in turn affects marine biodiversity and the cycling of nutrients. Additionally, humans benefit from "ecosystem services" provided by marine mammals. These services include carbon sequestration, greater ocean productivity in some areas, and tourism income. Anthropogenic sounds originate from a variety of sources such as explosions, commercial shipping, seismic exploration, sonar, research sound source, acoustic deterrent devices and pingers, polar icebreakers, industrial activities, offshore drilling, construction, small ships, boats, and personal watercraft. Marine mammals are capable of self-generating sounds and they are also affected by anthropogenic sounds that are not native to their natural environments. The published works of literature established that global marine mammal population dynamics, abundance, distribution, navigation, ecology and behavior are all affected by anthropogenic sounds. Further, anthropogenic sounds affect marine mammals by causing hearing loss, masking, change in behavior, habituation shift, mass stranding and they are also affected by nonauditory sound. Many of the published pieces of literature that were reviewed provided information on countries external to the neotropics. There is a need for more research on the impact anthropogenic sound on marine mammals since there is a paucity of data in this biodiversity-rich region.

Compliance with ethical standards

Acknowledgments

The authors would like to thank the University of Guyana, Berbice Campus, Division of Natural Sciences, Department of Biology for giving this tremendous opportunity and supporting the successful completion of this research. Heartfelt thank you is also extended to Mr. Rahaman Balkarran of Queensborough Community College, New York for his contribution towards this review paper.

Disclosure of conflict of interest

The authors hereby declare that this manuscript does not have any conflict of interest.

Statement of informed consent

All authors declare that informed consent was obtained from all individual participants included in the study.

References

[1] Andrew, R. K.; Howe, B. M.; Mercer, J. A. & Dzieciuch, M. A. (2002). Ocean ambient sound: Comparing the 1960's with the 1990's for a receiver off the California coast. Acoustic Research Letters Online 3(2): 65-70.

[2] Au, W. W. & Green, M. (2000). Acoustic interaction of humpback whales and whalewatching boats. Mar Environ Res 49(5): 469-481.

[3] Au, W. W. L. & Moore, P. W. B. (1984). Receiving beam pattern and directivity indices of the Atlantic bottlenose dolphin. J Acoustic Soc Am 75: 255-262.

[4] Au, W. W. L. (1993). The Sonar of Dolphins. New York, Springer-Verlag.

[5] Au, W. W.; Carder, D. A.; Penner, R. H. & Scronce, B. L. (1985). Demonstration of adaptation in beluga whale echolocation signals. J Acoust Soc Am 77: 726-730.

[6] Bacon, S. & Carter, D. J. T. (1993). A connection between mean wave height and atmospheric pressure gradient in the North Atlantic. International Journal of Climatology 13: 423-436.

[7] Baggeroer, A. B.; Birdsall, T. G.; Clark, C.; Colosi, J. A.; Cornuelle, B. D. Costa, D.; Dushaw, B. D.; Dzieciuch, M.; Forbes, A. M. G.; Hill, C.; Howe, B. M.; Marshall, J.; Menemenlis, D.; Mercer, J. A.; Metzger, K.; Munk, W.; Spindel, R. C.; Stammer, D.; Worcester, P. F. & Wunsch, C. (1998). Ocean climate change - comparison of acoustic tomography, satellite altimetry, and modeling. Science 281(5381): 13271332.

[8] Banner, A. & Hyatt, M. (1973). Effects of Noise on Eggs and Larvae of 2 Estuarine Fish. Transactions of the American Fisheries Society 102(1): 134-136.

[9] Barlow, J. & Cameron, G. A. (2003). Field experiments show that acoustic pingers reduce marine mammal by-catch in the California drift gill net fishery. Mar. Mamm. Sci. 19(2): 265-283.

[10] Barlow, J. & Taylor, B. (1998). Preliminary abundance of sperm whales in the northeastern temperate Pacific estimated from a combined visual and acoustic survey. International Whaling Commission Working Paper SC/50/CAWS20.

[11] Bartlett, M. L. & Wilson, G. R. (2002). Characteristics of small boat signatures. J Acoust Soc Am 112: 2221.

[12] Bauer, G. B.; Mobley, J. R. & Herman, L. M. (1993). Responses of wintering humpback whales to vessel traffic. J Acoust Soc Am 94: 1848.

[13] Bauman, R. A.; Elsayed, N.; Petras, J. M. & Widholm, J. (1997). Exposure to sublethal blast overpressure reduces the food intake and exercise performance of rats. Toxicology 121(1): 65-79.

[14] Beranek, L. L. & Ver, I. L. (1992). Noise and Vibration Control Engineering. New York, Wiley and Sons.

[15] Blane, J. M. & Jaakson, R. (1994). The impact of ecotourism boats on the St. Lawrence beluga whales. Environmental Conservation 21: 267-269.

[16] Bordino, P.; Kraus, S.; Albareda, D.; Fazio, A.; Palmerio, A.; Mendez, M. & Botta, S. (2002). Reducing incidental mortality of Franciscana dolphin Pontoporia blainvillei with acoustic warning devices attached to fishing nets. Marine Mammal Science 18(4): 833-842.

[17] Bowles, A. E.; Smultea, M.; Wursig, B.; DeMaster, D. P. & Palka, D. (1994). Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. J Acoust Soc Am 96(4): 2469-2484.

[18] Breeding, J. E. J. (1993). Description of a noise model for shallow water: RANDI-III. J Acoust Soc Am 94: 1920.

[19] Bryant, P. J.; Lafferty, C. M. & Lafferty, S. K. (1984). Reoccupation of Laguna Guerrero Negro, Baja California, Mexico, by gray whales. Pp 375-386 in The Gray Whale Eschrichtius robustus. M. L. Jones (ed.), Academic Press,Orlando, Fl.

[20] Buckingham, C. A.; Lefebvre, L. W.; Schaefer, J. M. & Kochman, H. I. (1999). Manatee response to boating activity in a thermal refuge. Wildlife Society Bulletin 27(2): 514-522.

[21] Caldwell, M. C. & Caldwell, D. K. (1965). Individual whistle contours in bottlenosed dolphins (Tursiops truncatus). Nature 207: 434-435.

[22] Calkins, D. G. (1979). Marine Mammals of Lower Cook Inlet and the potential for impact from outer continental shlef oil and gas exploration, development, and transport. Pp 171-263 in Environmental Assessment of the Alaskan Continental Shelf: Final Reports of Principal Investigators, Volume 20. NTIS PB85-201226. (ed.), NOAA,Juneau, AK.

[23] Carstensen, J.; Henriksen, O. D. & Teilmann, J. (2006). Impacts of offshore wind farm construction on harbour porpoises: Acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Mar. Ecol. Prog. Ser. 321, 295–308.

[24] Cato, D. H. & McCauley, R. D. (2002). Australian research in ambient sea noise. Acoustic Australia 30: 13-20.

[25] Clark, J. B.; Russell, K. L.; Knafelc, M. E. & Steevens, C. C. (1996). Assessment of vestibular function of divers exposed to high intensity low frequency underwater sound. Undersea & Hyperbaric Medicine 23(Supplement): 33.

[26] Commander Naval Air Warfare Center. (1994). "Marine Mammal Protection/ Mitigation and Results Summary for the Shock Trial of the USS John Paul Jones (DDG 53). Naval Air Warfare Center, Weapons Division, 521 9th St., Point Mugu, CA 93042-5001. Prepared for: The Assistant Administrator for Fisheries, National Oceanic and Atmospheric Administration, US Department of Commerce, 1335 East-West Highway, Silver Spring, MD 20910. 26 + Appendix pp.

[27] Cox, T. M.; Ragen, T. J.; Read, A. J.; Vos, E.; Baird, R. W.; Balcomb, K.; Barlow, J.; Caldwell, J.; Cranford, T.; Crum, L. et al. (2006). Understanding the impacts of anthropogenic sound on beaked whales. J. Cetacean Res. Manag. 7, 177–187.

[28] Cox, T. M.; Reed, A. J.; Solow, A. & Treganza, N. (2002). Will harbour porpoises, Phocoena phocoena, habituate to pingers? Journal of Cetacean Research and Management 3(81-86).

[29] Crum, L. A. & Mao, Y. (1996). Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. J. Acoust. Soc. Am. 99: 2898.

[30] Cudahy, E. & Ellison, W. T. (n.d.). A review of the potential for in vivo tissue damage by exposure to underwater sound. Naval Submarine Medical Research Laboratory, Groton, CT 6 pp.

[31] Cudahy, E.; Hanson, E. & Fothergill, D. (1999). Summary Report on the Bioeffects of Low Frequency Water Bourne Sound. Naval Submarine Medical Research Laboratory, Groton, CT 29 pp.

[32] Culik, B. M.; Koschinski, S.; Treganza, N. & Ellis, G. M. (2001). Reactions of harbor porpoises Phocoena phocoena and herring Clupea harengus to acoustic alarms. Marine Ecology Progress Series 211: 255-260.

[33] D'Amico, A. & Verboom, W. C. (1998). Summary record of the SACLANTCEN Bioacoustics Panel, La Spiezia, 15-17 June 1998. SACLANT Undersea Research Center 72 pp.

[34] Dao, J. (2003). Waterways declared nearly clear of mines NEW YORK TIMES Mar. 28, 2003.

[35] David, J. A. (2006). Likely sensitivity of bottlenose dolphins to pile-driving noise. Water Environ. J. 20, 48–54.

[36] Dragoset, W. (1984). A comprehensive method for evaluating the design of air guns and air gun arrays. Geophysics: The Leading Edge of Exploration 3(10): 52-61.

[37] Dragoset, W. (2000). Introduction to air guns and air-gun arrays. Geophysics: The Leading Edge of Exploration 19: 892-897.

[38] Edds, P. L. (1988). Characteristics of finback Balenoptera physalus vocalizations in the St. Lawrence Estuary Canada. Bioacoustics 1: 131-150.

[39] Edds-Walton, P. L. (1997). Acoustic communication signals of mysticete whales. Bioacoustics 8: 47-60.

[40] Emery, L.; Bradley, M. & Hall, T. (2001). Data Base Description (DBD) for the Historical Temporal Shipping Data Base (HITS), Version 4.0, PSI Tech. Rep. TRS-301. Planning Systems Incorporated, Slidell, LA 35 pp.

[41] Erbe, C. & Farmer, D. M. (1998). Masked hearing thresholds of a beluga whale (Delphinapterus leucas) in icebreaker noise. Deep-Sea Research Part II-Topical Studies in Oceanography 45(7): 1373-1388.

[42] Erbe, C. & Farmer, D. M. (2000). Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. J Acoust Soc Am 108(3): 1332-1340.

[43] Erbe, C. (2002). Underwater noise of whale-watching boats and potential effects on killer whales (Orcinus orca), based on an acoustic impact model. Marine Mammal Science 18(2): 394-418.

[44] Erbe, C.; Dunlop, R. & Dolman, S. (2018). © Springer Science+Business Media, LLC, part of Springer Nature 2018 H. Slabbekoorn et al. (eds.), Effects of Anthropogenic Noise on Animals, Springer Handbook of Auditory Research 66, https://doi.org/10.1007/978-1-4939-8574-6_10.

[45] Erbe, C.; King, A. R.; Yedlin, M. & Farmer, D. M. (1999). Computer models for masked hearing experiments with beluga whales (Delphinapterus leucas). J Acoust Soc Am 105(5): 2967-2978.

[46] Erlich, M. A. & Lawson, W. (1980). The Incidence and Significance of the Tullio Phenomenon in Man. Otolaryngology - Head & Neck Surgery 88(5): 630-636.

[47] European Commission. (2001). European transport policy for 2010: time to decide. Office for Official Publications for the European Communities, Luxemborg 126 pp.

[48] Evans, D. L. & England, G. R. (2001). Joint Interim Report Bahamas Marine Mammal Stranding Event of 14-16 March 2000. Washington, D.C., US Department of Commerce and US Navy, www.nmfs.noaa.gov/prof_res/overview/Interim_Bahamas_Report.pdf.

[49] Fay, F. H.; Kelley, B. P.; Gehnrigh, P. H.; Sease, J. L. & Hoover, A. A. (1984). Modern populations, migrations, demography, tropics, and historical status of the Pacific walrus. Pp 231-376 in Environmental Assessment of the Alaskan Continental Shelf: Final Reports of Principal Investigators, Volume 37. OCS Study MMS 860021. NTIS PB87-107546 (ed.), NOAA,Anchorage, AK.

[50] Fernández, A.; Edwards, J. F.; Rodríguez, F.; Espinosa de los Monteros, A.; Herráez, P.; Castro, P.; Jaber, J. R.; Martín, V. & Arbelo, M. (2005). “Gas and fat embolic syndrome” involving a mass stranding of beaked whales (family Ziphiidae) exposed to anthropogenic sonar signals. Vet. Pathol. 42, 446–457.

[51] Finneran, J. J. (2003). Whole-lung resonance in a bottlenose dolphin (Tursiops truncatus) and white whale (Delphinapterus leucas). Journal of the Acoustical Society of America 114(1): 529-535.

[52] Finneran, J. J.; Schlundt, C. E.; Dear, R.; Carder, D. A. & Ridgway, S. H. (2002). Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. J Acoust Soc Am 111(6): 2929-2940.

[53] Fish, J. F. & Vania, J. S. (1971). Killer whale, Orcinus orca, sounds repel white whales, Delphinapterus leucas. Fishery Bulletin 69: 531-535.

[54] Fletcher, E. R.; Yelverton, J. T. & Richmond, D. R. (1976). The thoraco-abdominal system's response to underwater blast. Final Technical Report for ONR contract N00014-75-C-1079, Arlington, VApp.

[55] Foote, A. D.; Osborne, R. W. & Hoelzel, A. R. (2004). Environment - Whale-call response to masking boat noise. Nature 428(6986): 910.

[56] Ford, J. B. K. (1991). Vocal traditions among resident killer whales (Orcinus orca) in coastal waters of British Columbia. Can. J. Zool. 69: 1454-1483.

[57] Frankel, A. & Clark, C. (2000). Behavioral responses of humpback whales (Megaptera novaeangliae) to full-scale ATOC signals. J. Acoust. Soc. Am. 108, 1930–1937.

[58] Frantzis, A. (1998). Does acoustic testing strand whales? Nature 392, doi:10.1038/32068.

[59] Gerken, L. (1986). ASW versus Submarine Technology Battle. Chula Vista, CA, American Scientific Corp.

[60] Gordon, J. C. D.; Matthews, J. N.; Panigada, S.; Gannier, A.; Borsani, F. J. & Notarbartolo di Sciara, G. (2000). Distribution and relative abundance of striped dolphins in the Ligurian Sea Cetacean Sanctuary: results from an acoustic collaboration. Journal of Cetacean Research and Management 2: 27-36.

[61] Graham, N. E. & Diaz, H. F. (2001). Evidence for intensification of North Pacific winter cyclones since 1948. Bulletin of the American Meteorological Society 82: 18691893.

[62] Gray, L. M. & Greeley, D. S. (1980). Source level model for propeller blade rate radiation for the world's merchant fleet. J Acoust Soc Am 67(2): 516-522.

[63] Greene, C. R. J. & Moore, S. E. (1995). Man-made Noise. Pp 101-158 in Marine Mammals and Noise. D. H. Thomson (ed.), Academic Press, San Deigo.

[64] Harding, S. & Cousins, N. (2022). Review of the Impacts of Anthropogenic Underwater Noise on Marine Biodiversity and Approaches to Manage and Mitigate them. Technical Series No. 99. Secretariat of the Convention on Biological Diversity, Montreal, 145 pages.

[65] Hartman, D. S. (1979). Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. Am. Soc. Mammal., Spec Publ. 5: 153 p.

[66] Hildebrand, J. (2005). Impacts of Anthropogenic Sound. Marine Mammal Research: Conservation beyond crisis, Book. Pg. 101-123. https://escholarship.org/uc/item/8997q8wj.

[67] Hildebrand, J. (2009). Anthropogenic and natural sources of ambient noise in the ocean. MARINE ECOLOGY PROGRESS SERIES. Mar Ecol Prog Ser. Vol. 395: 5–20. doi: 10.3354/meps08353.

[68] Hooker, S. K. & Whitehead, H. (2002). Click characteristics of northern bottlenose whales (Hyperoodon ampullatus). Marine Mammal Science 18(1): 69-80.

[69] Houser, D. S.; Howard, R. & Ridgway, S. (2001). Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? Journal of Theoretical Biology 213(2): 183-195.

[70] Howe, B. M. (1996). Acoustic Thermometry of Ocean Climate (ATOC): Pioneer Seamount Source Installation. Tech Memo Applied Physics Laboratory, University of Washington, Seattle, WA, TM 3-96: pp.

[71] Jackson, R. & Kopke, R. (1998). The effects of underwater high intensity low frequency sound on vestibular function. Naval Submarine Medical Research Laboratory, Groton, CTpp.

[72] Janik, V. M. (2000). Source levels and the estimated active space of bottlenose dolphin (Tursiops truncatus) whistles in the Moray Firth, Scotland. Journal of Comparative Physiology A-Sensory Neural & Behavioral Physiology 186(7-8): 673-680.

[73] Jefferson, T. A. & Curry, B. E. (1994). Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Marine Mammal Research Program, Texas A&M University, for the U.S. Marine Mammal Commission, Washington, D.C., College Station, TX,NTIS PB95100384: pp.

[74] Jepson, P. D.; Arbelo, M.; Deaville, R.; Patterson, I. A. P.; Castro, P.; Baker, J. R.; Degollada, E.; Ross, H. M.; Herráez, P.; Pocknell, A. M. et al. (2003). Gas-bubble lesions in stranded cetaceans: Was sonar responsible for a spate of whale deaths after an Atlantic military exercise? Nature 425, 575–576.

[75] Johnson, J. (2002). Final Overseas Environmental Impact Statement and Environmental Impact Statement for Surveillance towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar, Vols. 1 and 2.pp.

[76] Johnson, M., P. T. M.; Zimmer, W. M. X.; Soto, N. A. D. & Tyack, P. L. (2004). Beaked whales echolocate on prey. Biology Letters DOI: 10.1098/rsbl.2004.0208.

[77] Johnston, D. W. (2002). The effect of acoustic harassment devices on harbour porpoises (Phocoena phocoena) in the Bay of Fundy, Canada. Biological Conservation 108(1): 113-118.

[78] Jones, M. L. & Swartz, S. L. (1984). Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California sur, Mexico. Pp 309-374 in The Gray Whale (Eschrichtius robustus). M. L. e. a. Jones (ed.), Academic Press,Orlando, FL.

[79] Kamminga, C. (1988). Echolocation signal types of odontocetes. Pp 9-22 in Animal Sonar Processes and Performance. P. W. B. Moore (ed.), Plenum Press,New York.

[80] Kastak, D. & Schusterman, R. J. (1998). Low-frequency amphibious hearing in pinnipeds - methods, measurements, noise, and ecology. Journal of the Acoustical Society of America 103(4): 2216-2228.

[81] Ketten, D. R.; Lien, J. & Todd, S. (1993). Blast injury in humpback whale ears: Evidence and implications. J Acoustic Soc Am 94: 1849-1850.

[82] Klima, E. F.; Gitschlag, G. R. & Renaud, M. L. (1988). Impacts of the explosive removal of offshore petroleum on sea turtles and dolphins. Mar. Fish. Rev. 50, 33–42.

[83] Kraus, S.; Read, A. J.; Solow, A.; Baldwin, K.; Spradlin, T.; Anderson, E. & Williamson, J. (1997). Acoustic alarms reduce porpoise mortality. Nature 388: 525.

[84] Lagardere, J. P. (1982). Effects of Noise on Growth and Reproductive of Crangon Crangon in Rearing Tanks. Marine Biology (Berlin) 71(2): 177-186.

[85] Larsen, F. (1997). The effects of acoustic alarms on the by-catch of harbor porpoises in bottom set gill nets. Danish Institute for Fisheries Research Report No 44-97pp.

[86] Laurer, H. L.; Ritting, A. N.; Russ, A. B.; Bareyre, F. M.; Raghupathi, R. & Saatman, K. E. (2002). Effects of underwater sound exposure on neurological function and brain histology. Ultrasound in Medicine & Biology 28(7): 965-973.

[87] Leaper, R., O. C. & Gordon, J. (1992). The development of practical techniques for surveying sperm whale populations acoustically. Report of the International Whaling Commission 42: 549-560.

[88] Lesage, V.; Barrette, C.; Kingsley, M. C. S. & Sjare, B. (1999). The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary. Marine Mammal Science 15: 65-84.

[89] Loughrey, A. G. (1959). Preliminary investigations of the Atlantic walrus, Odobenus rosmarus rosmarus (Linnaeus). Canadian Wildlife Service Wildlife Management Bulletin Series 1, Number 14: 123.

[90] Lucke, K.; Siebert, U.; Lepper, P. A. & Blanchet, M. A. (2009). Temporary shift in masked hearing thresholds in a harbor porpoise (Phocoena phocoena) after exposure to seismic airgun stimuli. J. Acoust. Soc. Am. 125, 4060–4070.

[91] Lyamin, O. I.; Korneva, S. M.; Rozhnov, V. V. & Mukhametov, L. M. (2011). Cardiorespiratory changes in beluga in response to acoustic noise. Dokl. Biol. Sci. 440, 257–258.

[92] Madsen, P. T. & Mohl, B. (2000). Sperm whales (Physeter catodon L. 1758) do not react to sounds from detonators. J Acoust Soc Am 107(1): 668-671.

[93] Malme, C. I.; Miles, P. R.; Clark, C. W.; Tyack, P. & Bird, J. E. (1984). Investigations on the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Phase II: January 1984 migration. BBN Laboratories Inc., Cambridge, MA for U.S. Minerals Management Service, Washington, D. C, BBN Report 5586, NTIS PB86-218377: pp.

[94] Malme, C. I.; Miles, P. R.; Tyack, P.; Clark, C. W. & Bird, J. E. (1985). Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Laboratories Inc., Cambridge, MA for U.S. Minerals Management Service, Anchorage, AK, BBN Report 5851, NTIS PB86218385: pp.

[95] Martin, J. S.; Rogers, P. H.; Cudahy, E. & Hanson, E. (2000). Low frequency response of the submerged human lung. Journal of the Acoustical Society of America 107: 2813.

[96] Mate, B. R. & Harvey, J. T. (1987). Acoustical deterrents in marine mammal conflicts with fisheries. Oregon State University Sea Grant College Program, Corvallis, OR, ORESU-W-86-001: 116 pp.

[97] Matthews, J. N.; Rendell, L. E.; Gordon, J. C. D. & Macdonald, D. W. (1999). A review of frequency and time parameters of cetacean tonal calls. Bioacoustics 10: 47-71.

[98] Maybaum, H. L. (1993). Responses of humpback whales to sonar sounds. J Acoustic Soc Am 94: 1848-1849.

[99] Mazzuca, L. L. (2001). Potential Effects of Low Frequency Sound (LFS) from Commercial Vessels on Large Whales. Master of Marine Affairs, University of Washington: 70 pp.

[100] McCarthy, E. & Miller, J. H. (2002). Is anthropogenic ambient noise in the ocean increasing? J Acoustic Soc Am 112(5): 2262.

[101] McDonald, M. A.; Calambokidis, J.; Teranishi, A. M. & Hildebrand, J. A. (2001). The acoustic calls of blue whales off California with gender data. J Acoust Soc Am 109(4): 1728-1735.

[102] Miksis, J. L.; Grund, M. D.; Nowacek, D. P.; Solow, A. R.; Connor, R. C. & Tyack, P. L. (2001). Cardiac responses to acoustic playback experiments in the captive bottlenose dolphin (Tursiops truncatus). Journal of Comparative Psychology 115(3): 227-232.

[103] Miller, P. J.; Biassoni, N.; Samuels, A. & Tyack, P. L. (2000). Whale songs lengthen in response to sonar. Nature 405(6789): 903.

[104] Mohl, B., M. W., Madsen; P. T.; Miller, L. A. & Surlykke, A. (2000). Sperm whale clicks: directionality and source level revisited. J Acoust Soc Am 107(1): 638-648.

[105] Morton, A. B. & Symonds, H. K. (2002). Displacement of Orcinus orca (L.) by high amplitude sound in British Columbia. ICES Journal of Marine Science 9: 1-9.

[106] Nachtigall, P. E., D. W. L. & Roitblat, H. L. (2000). Psychoacoustic studies of dolphin and whale hearing. Hearing By Whales and Dolphins 12: 330-363.

[107] Nachtigall, P. E.; Supin, A. Y.; Pawloski, J. & Au, W.W. (2004). Temporary threshold shifts after noise exposure in the bottlenose dolphin (Tursiops truncatus) measured using evoked auditory potentials. Mar. Mammal Sci. 20, 673–687.

[108] National Marine Manufacturers Association. (2003). Recreational Boating Statistical Abstract http://www.nmma.org/facts/boatingstats/2003/index.asp.

[109] National Research Council. (2003). Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. ISBN: 0-309-50694-8, 204 pages. http://www.nap.edu/catalog/10564.html.

[110] National Research Council. (2003). Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. National Academy Press, Washington, D. C.pp.

[111] Nieukirk, S. L.; Stafford, K. M.; Mellinger, D. K.; Dziak, R. P. & Fox, C. G. (2004). Low frequency whale and seismic air gun sounds recorded in the mid-Atlantic Ocean. Journal of the Acoustical Society of America. 115(4): 1832-1843.

[112] Norris, K. S.; Harvey, G. W.; Burzell, L. A. & Kartha, D. K. (1972). Sound production in the freshwater porpoise Sotalia cf. fluviatilis Gervais and Deville and Inia geoffrensis Blainville in the Rio Negro Brazil. Investigations on Cetacea 4: 251262.

[113] Nowacek, S. M.; Wells, R. S. & Solow, A. R. (2001). Short-term effects of boat traffic on bottlenose dolphins, Tursiops truncatus, in Sarasota Bay, Florida. Marine Mammal Science 17(4): 673-688.

[114] Olesiuk, P. F.; Nichol, L. M.; Sowden, M. J. & Ford, J. K. B. (2002). Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (Phocoena phocoena) in retreat passage, British Columbia. Marine Mammal Science 18(4): 843-862.

[115] Parks, S. E.; Clark, C. W. & Tyack, P. L. (2007). Short- and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. J. Acoust. Soc. Am. 122, 3725–3731.

[116] Payne, R. & Webb, D. (1971). Orientation by means of long-range acoustic signaling in baleen whales. Ann N Y Acad Sci 188: 110-141.

[117] Peng, C.; Zhao, X. & Liu, G. (2015). Review: Noise in the Sea and Its Impacts on Marine Organisms. Int. J. Environ. Res. Public Health 2015, 12, 12304-12323; doi:10.3390/ijerph121012304.

[118] Potter, J. R. (1994). ATOC: Sound policy or enviro-vandalism? Aspects of a modern mediafueled policy issue. Journal of Environment and Development 3: 47-76.

[119] Rendell, L. E. & Whitehead, H. (2003). Vocal clans in sperm whales (Physeter macrocephalus). Proceedings of the Royal Society of London Series B-Biological Sciences 270(1512): 225-231.

[120] Richardson, W. J. & Malme, C. I. (1993). Man-made noise and behavioral responses. Pp in The Bowhead Whale. J. J. e. a. Burns (ed.), Society for Marine Mammology,Lawrence, KS.

[121] Richardson, W. J.; Greene, C. R. J.; Malme, C. I. & Thomson, D. H. (1995). Marine Mammals and Noise. San Diego, Academic Press.

[122] Ridgway, S.; Carder, D. A.; Smith, R. R.; Kamolnick, T.; Schlundt, C. E. & Elsberry, W. (1997). Behavioral responses and temporary shift in masked hearing threshold of bottlenose dolphins Tursiops truncatus, to 1-second tones of 141 to 201 dB re: 1 mu Pa. NRAD, RDT&RE Div., Naval Command, Control & Ocean Surveillance Center, San Diego, CA,Tech. Rep. 1751: pp.

[123] Romano, T. A.; Keogh, M. J.; Kelly, C.; Feng, P.; Berk, L.; Schlundt, C. E.; Carder, D. A. & Finneran, J. J. (2004). Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. Canadian Journal of Fisheries & Aquatic Sciences 61: 1124-1134.

[124] Ross, D. (1987). Mechanics of Underwater Noise. Los Altos, CA, Peninsula Publishing.

[125] Ross, D. (1993). On ocean underwater ambient noise. Acoustics Bulletin January/February: 5-8.

[126] Rossby, T.; Dorson, D. & Fontaine, J. (1986). The RAFOS system. J. Atmos. Oceanic Tech 3: 672-679.

[127] Sandegren, F. E., E. W. C. & Vandevere, J. E. (1973). Maternal behavior in the California sea otter. J. Mammal. 54(3): 668-679.

[128] Schmidt, V. (2004). Seismic contractors realign equipment for industry's needs. Offshore 64: 36 –44.

[129] Schreiner, H. F. J. (1990). The RANDI-PE noise model. Proc. IEEE Oceans 90, 576-577.

[130] Simmonds, M. P. & Lopez-Jurado, L. F. (1991). Whales and the military. Nature 351: 448.

[131] Southall, B. L.; Schusterman, R. J. & Kastak, D. (2003). Acoustic communication ranges for northern elephant seals (Mirounga angustirostris). Aquat. Mammal. 29, 202–213.

[132] Spiess, F. N.; Northrup, J. & Werner, E. W. (1968). Locations and enumeration of underwater explosions in the North Pacific. J Acoust Soc Am 43(3): 640-641.

[133] Standoff, K. (2013). Anthropogenic Sound and Marine Mammals in the Arctic. Prepared for The Pew Charitable Trusts' U.S. Arctic Program www.oceansnorth.us.

[134] Steevens, C. C.; Russell, K. L.; Knafelc, M. E.; Smith, P. F.; Hopkins, E. W. & Clark, J. B. (1999). Noise-induced neurologic disturbances in divers exposed to intense waterborne sound: Two case reports. Undersea & Hyperbaric Medicine 26(4): 261-265.

[135] Stewart, B. S.; Evans, W. E. & Awbrey, F. T. (1982). Effects of man-made waterborne noise on behavior of belukha whales (Delphinapterus leucas) in Bristol Bay, Alaska. Hubbs/Sea World Research Institute for the U.S. National Oceanic and Atmospheric Administration, Juneau, AK, San Diego, CA, HSWRI Technical Report 82-145: 29 pp.

[136] ter Harr, G.; Daniels, S.; Eastaugh, K. C. & Hill, C. R. (1982). Ultrasonically induced cavitation in vivo. Br. J. Cancer. 45(Suppl. V): 151-155.

[137] Thomas, J. A. & Turl, C. W. (1990). Echolocation characteristics and range detection threshold of a false killer whale Pseudorca crassidens. Pp 321-334 in Sensory Abilities of Cetaceans: Laboratory and Field Evidence. R. A. Kastelein (ed.), Plenum Press,New York.

[138] Thompson, P. M.; Lusseau, D.; Barton, T.; Simmons, D.; Rusin, J. & Bailey, H. (2010). Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. Mar. Pollut. Bull. 60, 1200–1208.

[139] Tilt, W. C. (1985). Whales and whalewatching in North America with special emphasis on the issue of harassment. New Haven, CT, Yale School of Forestry and Environmental Studies.

[140] Todd, S.; Stevick, P.; Lien, J.; Marques, F. & Ketten, D. R. (1996). Behavioral effects of exposure to underwater explosions in humpback whales (Megaptera novaeangliae). Canadian Journal of Zoology 74: 1661-1672.

[141] Tolstoy, M., J. B. D.; Webb, S. C.; Bohnenstiehl, D.; R.; Chapp, E.; Holmes, R. C. & Rawson, M. (2004). Broadband calibration of R//V Ewing seismic sources. GEOPHYSICAL RESEARCH LETTERS 31: L14310.

[142] Tyack, P. L. & Clark, C. W. (1998). Quick-look report: Playback of low-frequency sound to gray whales migrating past the central California coast. Unpublished Report.pp

[143] Tyack, P. L. (2000). Functional aspects of cetacean communication. Pp 270-307 in Cetacean Societies: Field Studies of Dolphins and Whales. J. Mann (ed.), University of Chicago Press,Chicago.

[144] Tyack, P. L. (2008). Implications for marine mammals of large-scale changes in the marine acoustic environment. J. Mammal. 2008, 89, 549–558.

[145] United States Fish and Wildlife Service. (2001). Florida manatee Recovery Plan (Trichechus manatus latirostris) Third revision. Southeast Region, U.S. Fish and Wildlife Service, Atlanta, GApp.

[146] United States Maritime Administration. (2003). http://www.marad.dot.gov/Marad_Statistics/index.html.

[147] Vinther, M. (1999). Bycatches of harbor porpoises (Phocoena phocoena L.) in Danish set-net fisheries. Journal of Cetacean Research & Management. 1(2): 123-135.

[148] Wagstaff, R. A. (1973). RANDI: Research ambient noise directionality model. Naval Undersea Center, Tech. Pub. 349 pp.

[149] Walsh, M. T.; Ewing, R. Y.; O'Dell, D. K. & Bossart, G. D. (2001). Mass stranding of cetaceans. Pp 83-96 in CRC Handbook of Marine Mammal Medicine. F. M. D. Gulland (ed.), CRC.

[150] Wartzok, D. & Ketten, D. R. (1999). Marine mammal sensory systems. Pp 117-175 in Biology of Marine Mammals. J. E. I. Reynolds and S. Rommel (ed.), Smithsonian Institution Press,Washington, D.C.

[151] Wartzok, D.; Watkins, W. A.; Wursig, B. & Malme, C. I. (1989). Movements and behaviors of bowhead whales in response to repeated exposures to noises associated with industrial activities in the Beaufort Sea. Report from Purdue University for Amoco Production Company, Anchorage, AK 228 pp.

[152] Watkins, W. A. & Ray, G. C. (1985). In-air and underwater sounds of the Ross seal, Ossmatophoca rossi. J Acous Soc Am 77(4): 1598-1600.

[153] Watkins, W. A. & Schevill, W. E. (1974). Listening to Hawaiian spinner porpoises (Stenella cf. longirostris) with a three-dimensional hydrophone array. Journal of Mammology 55: 319-328.

[154] Watkins, W. A. & Schevill, W. E. (1975). Sperm whale codas. J Acoustic Soc Am 26: 1485-1490 + phono record.

[155] Watkins, W. A. & Wartzok, D. (1985). Sensory biophysics of marine mammals. Marine Mammal Science 1: 219-260.

[156] Watkins, W. A. (1977). Acoustic behavior of sperm whales. Oceanus 20(2): 50-58.

[157] Watkins, W. A. (1986). Whale reactions to human activities in Cape Cod waters. Marine Mammal Science 2: 251-262.

[158] Watkins, W. A.; Moore, K. E. & Tyack, P. (1985). Sperm whale acoustic behaviors in the southeast Caribbean. Cetology 49: 1-15.

[159] Watts, A. J. (2003). Jane's Underwater Warfare Systems, Fifteenth Edition 2003-2004.

[160] Wenz, G. M. (1962). Acoustic ambient noise in the ocean: spectra and sources. J Acoustic Soc Am 34: 1936-1956.

[161] Wenz, G. M. (1969). Low-frequency deep-water ambient noise along the Pacific Coast of the United States. Journal of Underwater Acoustics 19: 423-444, recently declassified.

[162] Williams, R.; Wright, A. J.; Ashe, E.; Blight, L. K.; Bruintjes, R.; Canessa, R.; Clark, C. W.; Cullis-Suzuki, S.; Dakin, D. T.; Erbe, C.; Hammond, P. S.; Merchant, N. D.; O'Hara, P. D.; Purser, J.; Radford, A. N.; Simpson, S. D.; Thomas, L. & Wale, M. A. (2015). Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. Ocean and Coastal Management, 115, 17-24. https://doi.org/10.1016/j.ocecoaman.2015.05.021.