ISL Institute of Shipping Economics and Logistics

Discussion Paper ‘Underwater Noise‘

Underwater Noise – Causes, Effects and Outlook

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Executive Summary

For more than two decades, a multitude of scientific publications have drawn attention to the varying intensity of effects of underwater noise on underwater fauna. It has been documented over the course of 35 years that underwater noise has doubled every ten years. With the expansion of transport volumes and shipping across alternative routes, such as the Northeast Passage, a further, drastic increase in underwater noise even in traditional “quiet areas” is to be expected. Marine mammals in particular depend on their calls and hearing in order to find sustenance and mates, to orient themselves or to avoid predators and care for their offspring. In this respect, localisation of mates often takes place over great distances. Accordingly, increasing underwater noise has drastic effects. These range from simply leaving the traditional habitat, a reduction of dietary intake or a reduction in reproduction rates due to masking, increased susceptibility to diseases, partly due to the formation of stress hormones, to the death if individual mammals and fish. Nevertheless, no sufficiently binding measures are being taken to limit or even eliminate the causes of underwater noise. Although international bodies emphasise the particular importance of the topic “underwater noise” in general, they only go as far as to mention the problem without specification of actions to be undertaken.

Neither in the area of maritime shipping, nor inland waterway transport are their adequate legal norms that define sufficient regional, national or even international obligations to reduce the damaging effects of anthropogenic underwater noise to protect the fauna living in the seas and other bodies of water. Partial exceptions here include individual regulations for mammals, e.g. when erecting offshore structures.

A binding, uniform standard for the measurement of anthropogenic underwater noise and a uniform determination of noise limit values for underwater noise by classification societies are lacking.

Currently, no “award” system actively considers underwater noise reduction. The first signs can be seen with the ESI, which is intended to reward measures against surface noise by reducing port fees for participating ports. However, the number of participating parts that grant bonuses for this aspect of ESI is currently marginal.

Existing maritime environmental awards (“award” systems) such as Environmental Ship Index (ESI), Blue Angel, Green Award, Clean Shipping Index (CSI) etc. should reward measures to reduce underwater noise and anchor them in their statutes for conferring award levels.

Based on the current state of research, a colourful potpourri of techniques and measures to reduce underwater noise is already available, but some measures are cost-intensive. There is therefore a need for further research into the extent of the species affected, possible alternatives for avoiding or reducing underwater noise, and for cost-effective developments not only in the construction of new ships, but also for the retrofitting of existing fleets.

When using seismic technologies, research into alternatives is required in order to be able to avoid or significantly reduce the currently enormously high sound pressure levels. The same applies to underwater blasting (insofar as same is absolutely necessary), to the research and development of efficient repellent means and techniques (e.g. for temporary dispersing of animals), inexpensive soundproofing techniques and salvage equipment for moving ammunition findings. dispersing animals

1 Introduction to the Problem of Underwater Noise

Anthropogenic underwater noise is now regarded as one of the main stresses on marine fauna. Because of water's higher density, sounds are transmitted around 4.5 times faster here than in air. As a result, the emitted sound waves are also transported further, which is why noise pollution in water has more far-reaching effects than on land. According to current knowledge, marine mammals, which use sound to communicate, orient themselves and locate their prey, are particularly susceptible to underwater noise. In marine mammals, underwater noise can cause stress and physical injury, permanent or temporary shifts in auditory thresholds or behavioural changes (e.g. flight, avoidance behaviour, interruption of feeding) as well as impairment of the animals' communication in the form of masking. This means that the resulting inability to recognize a signal in the background noise can cause problems when locating or finding a partner, which often takes place over great distances.

1.1 Causes of Underwater Noise

Noise emissions caused by sea-going vessels and installations stationed at sea can have an impairing and therefore adverse effect on the environment. The main sources of noise that can be addressed are: main engines, especially diesel engines, propeller shaft dynamics, pressure and bearing forces emanating from the propeller (fixed propeller vs. controllable pitch propeller), manoeuvring devices (transverse thrusters), air conditioning systems, winches, vortex shedding, air inlets and outlets , wave impacts. *(Charlton et al., 2005)* The following should also be mentioned: ship sonar (fishing, channel sounding, high-intensity active sonar systems in fleet exercises, seismic exploration), dredging activities, underwater detonation of ammunition findings and shipwrecks, testing of defence technology.

In 2020, the BSH detected the lowest underwater noise since measurements began in 2013 via measuring stations of the marine environment network MARNET as a result of the decline in shipping traffic in the Baltic Sea during the COVID-19 pandemic. According to the BSH, this confirms the relationship between shipping and underwater noise. *(BSH, 2021; Basan, 2021)*

1.2 Types and Effect of Underwater Noise

There is a wide range of motorized vessels in terms of their underwater noise intensity. Large and powerful watercraft such as ferries, container ships and icebreakers have source levels of up to and above 200 dB *(Simard , et al., 2016; Gassmann et al., 2017; Erbe et al., 2000)*, which are emitted as continuous noise. However, the source levels vary by 20 to 40 dB due to varying designs, maintenance and operating parameters (such as speed). *(Erbe et al., 2019 wfr)* The strongest source of underwater noise emitted by ships typically comes from the propeller with its cavitation. Propeller cavitation is the most well-known source of underwater noise – air bubbles that form around the rotating propeller as a result of pressure differences that suddenly collapse. The propeller noise is broadband and covers the entire frequency range, although lower frequencies are predominant. Furthermore, it could be shown that the noise caused by cavitation increases with speed, ship size and carrying capacity *(Ross, 1976)*. Underwater noise generated by shipping is thus an increasing, ever-present "acoustic fog" that extends over long distances and masks natural sounds and calls. Although the tonnage of the global merchant fleet has increased by a factor of 2.6 from 2000 to 2020, from 0.76 billion dwt to 1.97 billion dwt, underwater noise has doubled every decade over the past 35 years.

In addition to the continuous noise generated by shipping, there are other actors who endanger marine fauna through underwater impulse noise, sometimes with a direct fatal outcome. In the extensive search for fossil resources in the sea, so-called pulsers (sound cannons) are used. Here, the seismic probing ship pulls the pulsers in the survey area behind it. At intervals of 10 to 15 seconds, the pulsers discharge compressed air towards the seafloor. Compressed air discharged three to six meters under water creates an oscillating bubble and sound waves that penetrate kilometres deep into the geological strata of the Earth. The echoes reflected from there are recorded in a measuring cable up to 4,000 m long with a large number of hydrophones installed in it, which is towed behind the survey ship, and analytically transferred to a three-dimensional map of the seabed based on the sound pattern. These maps provide information about the geological condition of the probed seabed as well as information on any oil deposits it may contain. The seismic surveys sometimes last several months, with the pulsers sending signals 24 hours a day at intervals of 10 to 15 seconds. The surveying of an area of 100 km² takes about three weeks. *(Ehrhardt, oJ)* Typical pulser volumes used by the exploration industry vary from 0.3 to 13.1 litres and are widely used in an " airgun array" consisting of three to six sub-arrays (strings), with each "string" containing six to eight individual sound cannons (pulsers), so that in the standard case between 18 and 48 sound cannons are used, but in some cases up to 100. Small pulsers emit higher frequencies, and larger pulsers, lower frequencies, which means that geophysicists have a wide frequency band at their disposal. Most "gun pressure" used by the seismic industry is 2,000 psi (138 bar). *(n.p., 2020-1)* Research suggests that sonic cannons cause injury, hearing loss, behavioural changes, and masking in fish, marine mammals, and possibly even many invertebrates. Current scientific knowledge uses peak pressure and cumulative sound exposure levels to assess the potential impact of underwater noise from pulsers. The sound cannons used achieve a volume of up to 260 dB. The pain threshold of human hearing varies in relevant literature. The discomfort threshold is reached by values above 100 dB(A) and the pain threshold at around 120 dB(A). *(n.p., 2020-1)* However, since the measurement of sound in dB is based on a logarithmic scale, doubling the values not only means doubling the strength, but a multiple of it. Already in September 2002, the deaths of several beaked whales and a dolphin off the coast of the Gulf of California near the island of San Jose were associated with the testing a sonar rated at 220 dB on the seismic research vessel "R/V Maurice Erwing". *(Gentry, 2002)*

An investigation of three fish species: sea chub *(Couesius plumbeus)*, adult pike and the broad whitefish showed that none of the sensory epithelia in any of the otolithic end organs (which enable the gravity sense (perception) and hearing) were damaged by the use of pulsers. In particular, the saccular sensory epithelium, the otolithic end organs of fish, thought to be most involved in hearing, was not damaged. The examined tissue analyses showed no differences to tissue samples from control groups. *(Popper et al., 2003-1)* However, both adult pike and sea chub showed transient hearing shifts and hearing loss. *(Popper et al., 2005)* It should be noted that the fish in the tests, however, were only exposed to five to 20 sound pulses *(Popper et al., 2005)* , which is not consistent with long-term seismic exploration.

Naval vessels use military sonar to locate submarines and torpedoes. The sonar systems used are mid-frequency active sonar (MFAS) low-frequency active sonar (LFAS) technology. MFAS operate with frequency-modulated tones from approx. 2 to 8 kHz and achieve a nominal sound level of 235 dB. Such high noise levels can be fatal to marine mammals (bleeding, acoustic trauma). By resolution of July 15, 2002, the NMFS (US National Marine Fisheries Service) exempted the use of LFAS for the US Navy from the requirements of the 1972 adopted “Marine Mammal Protection Act”. *(Dyke, 2003)* Ten weeks later, at the end of September 2002, 15 beaked whales stranded on the Canary Islands on the beach of Matas Blancas on Fuerteventura and Lanzarote, of which 13 whales died. *(Kahl, 2002)* At the time the whales beached, the US destroyer "Mahan" (DDG-72) was manoeuvring in the area with a total of 50 ships as well as six submarines from nine other NATO members as part of the naval manoeuvre "NEOTAPON 2002", with MFAS in use. The first stranding of beaked whales occurred just four hours after the sonar devices were deployed. *(Fernández et al., 2005)* With documented diving depths of a good 2,990 m and diving times of up to four hours, beaked whales are the record holders in deep and long-term diving of all mammals. *(Quick, 2020)* Use of military sonars leads to panic flight responses in beaked whales. Because of the rapid ascent from the depths, nitrogen bubbles are released from the bloodstream via gas and fat embolisms with fatal consequences for the whales. *(Fernández et al., 2005)* This is a phenomenon also known to professional divers, which is why decompression is deliberately slowed down when surfacing from great depths. The necropsies carried out on the dead whales at the Faculty of Veterinary Medicine of Las Palmas University revealed bleeding in the ear canals as well as brain damage consistent with an 'acoustic impact' (acoustic trauma). *(Kahl, 2002; Férnandez, et. al. 2005)* This event was repeated two years later in the same region on the beach of Fuerteventura in Sept. 2004 with the beaching of 27 whales, 14 of which died. The grounding happened just four hours after the start of the NATO naval exercise "Majestic Eagle 04", in which 30 ships (including four aircraft carriers and one submarine, 350 aircraft, including helicopters for submarine hunting) *(Globalsecurity, 2004-1)* from ten nations were involved, and different types of MFAS were used. *(EU Parliament, 2004-1)*

As early as 1996, the stranding of 12 dead beaked whales on the shores of the Gulf of Kyparissiakos in Greece was linked to the testing of MFAS by the CACLAT centre just an hour earlier in the region. *(Francis, 1998, Alexander, 2006)* A comprehensive study of a similar stranding of six beaked whales and one nippet dolphin *(Stenella frontalis)* in the Bahamas in mid-March 2000 shows that after intensive testing of tactical MFAS (with 3.5 kHz and 235 dB) by a military ship formation (in which three submarines and seven escort ships were involved) sensitive tissues in the animals' inner ears and brains ruptured, causing bleeding, disorientation and the death of seven of the stranded animals. *(Weiss, 2002; Balcom , 2001)* Furthermore, a fatal stranding of 16 beaked whales *(Ziphius cavirostris , Mesoplodon densirostris* - and *Mesoplodon europaeus)* in mid-March 2001 in the Bahamas was attributed to simultaneous submarine hunting manoeuvres by the US Navy between Great Babaco and Eleuthera with the use of sonar (in a frequency range of 3 to 7 kHz with a volume of 230 dB). *(Broeg , 2003)* In a similar case in 2008, the UK Ministry of Defence admitted that the Royal Navy was conducting training exercises with a submarine and the military research vessel HMS Enterprise (H88) with HF hydrographic sonar near the Cornish coast when, at the same time, 26 dolphins were fatally beached a short distance away in the Percuil River near Falmouth - after it was originally denied that ships had been in the area. *(BBC, 2008)* The autopsy of the animals showed that they were in a sound nutritional condition with no evidence of infectious diseases or acute physical injury *(Acevedo- Whitehouse , 2009)* , which is why a connection with the sonar exercises is assumed.

The recognition that beaked whales are highly sensitive to the use of sonar devices, even to the point of death, led to a temporary sonar ban in select coastal areas by a 2003 ruling by San Francisco District Court Judge Elizabeth Laporte and the injunction by Federal Judge David A. Ezra in Hawaii requiring the Navy to take safety measures when using sonar as same violated the “Marine Mammal Protection Act” (a law protecting marine mammals) *(USDC 2003; USDC 2008)* . However, by order of US President GW Bush (according to US Code Title 16 Chap. 33 § 1456 C 1 B), in January 2008, the Navy was released from previously imposed environmental regulations (including the sonar restriction) *(Kaufman, 2008)*. A lawsuit brought by the US environmentalists (NRDC) and whale protectors (Jean-Michel Cousteau's Ocean Futures Society) against the presidential order failed with a narrow 5 to 4 decision in the US Supreme Court. *(US Supreme Court 07-1239, 2008)* Only Spain, following a recommendation by the European Parliament in 2004 *(EU Parliament, 2004-2)* imposed a ban on naval manoeuvres using sonar devices for the sea area around the Canary Islands, since then no mass strandings of beaked whales have been observed in this area. *(Fernández et al., 2013)*

In addition to the use of seismic equipment, underwater blasting during military exercises, the targeted removal of ammunition residues or the disposal of wrecks also cause significant damage to fauna through underwater noise. According to estimates by the Alfred Wegner Institute, there are 1.6 million tonnes of conventional weapons and 300,000 tonnes of chemical weapons containing nerve toxins such as mustard gas, tabun, phosgene, arsenic and sarin in the German North Sea and Baltic Sea alone *(BT printed matter, 2019; UBA, 2021)* , which represent an increasing problem due to corrosion. In addition to detonations for clearing munitions, underwater detonations with torpedoes and mines are also carried out to test defence technology in naval manoeuvres and to collect data for new naval construction programs - with corresponding collateral damage to the underwater flora and fauna. *(n.p., 2020-2)* At the end of 2019, for example, 42 sea mines were blown up over three days in the Fehmarn Belt nature reserve by a NATO fleet with the participation of the German Navy, which led to the death of eight autopsied porpoises as a result of explosion trauma according to an investigation report by the BfN. The investigation revealed peak values for the modelled "minimum SEL" of 171 dB at a distance of more than 5.6 km from the explosion site. The BfN investigation also notes that this is a conservative estimate "and the sound energies that actually occurred exceeded with a high degree of certainty the "...for the investigation..."modelled sound energies". *(Wolfing et al., 2020)* However, a temporary suspension of underwater blasting to strengthen nature conservation, announced by the political leadership of the Ministry of Defence at the end of September 2020, has been sharply criticized by leading military officials in the German Navy. *(Gebauer, 2012)*

Intensive offshore activities, such as the establishment of sustainably-produced energy for wind turbines or the construction of oil and gas production platforms, the foundations of which are firmly connected to the seabed by ramming of pilings (monopoles, etc.), represent another source of underwater noise. The resulting underwater noise is reduced by means of "base curtains", "hydro-sound dampers " or by steel cylinders filled with air, which are placed over the foundation pile during ramming ("cofferdam") in accordance with a noise protection concept developed by the BMU to prevent injuries and fatalities of porpoises. These levels were reduced to 160 dB (at 750 m from sound source) for individual results and 190 dB for peak sound pressure. *(BfN , 2021, Bellmann et al., 2020).*

As a result of the continuous noise, studies of Atlantic herring *(Clupea harengus)* and the European sprat *(Sprattus sprattus)* show an avoidance of shipping lanes *(Misund et al., 1992)*, while more Alaska pollock *(Gadus chalcogrammus)* were documented around "quiet ships" compared to "louder" ship *(De Robertis et al, 2010)* and some bluefin tuna *(Thunnus thynnus)* show changes in swarming behaviour, school structure and possibly also migrations in the presence of noisy vessels *(Sará et al., 2007)* . Underwater noise has been shown to damage the hearing ability of fish *(Popper 2003-2, McCauley, 2002)* and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as well as redfish *(Sebastes norvegicus)*, herring *(Clupea harengus)*, blue whiting *(Micromesistius poutassou)* and sandals *(Ammodytidae)* were reduced by 40 - 80%. Furthermore, reduced quantities of fish were recorded in the vicinity of seismic surveys *(Engås, 1996; Oceancare , 2016) .* With regard to sticklebacks *(Gasterosteus aculeatus)*, underwater noise was found to adversely affect their food selection *(Puser , 2011*), and in zebrafish it could be shown that higher noise levels led to a significantly increased mortality of the larvae *(Lara et al., 2021)* . In the common mussel *(Mytilus edulis*), DNA damage, reduced filtration and oxidative stress could be detected. *(Wale et al., 2016)*

However, not only the group of particularly well-studied harbour porpoises are affected by the increasing underwater noise, but also other marine mammals *(CSA, 2021)* such as humpback whales (*Megaptera novaeangliae*), which are severely hampered by underwater noise with regard to their foraging activities *(Blair, et. al., 2016)*, and beluga whales (*Delphinapterus leucas*) *(Castellote et al., 2018)* and North Atlantic Right Whales (*Eubalaena glacialis*) show increased stress hormones as a result of underwater noise *(Roland et al., 2021)* . In four species of cephalopods (*Loligo vulgaris , Sepia officinalis, Octopus vulgaris and Illex coindetii*) and squids *(Architeuthis dux),* it was documented that increased underwater noise caused trauma. *(André, 2011; Sole, 2013)* Studies also show that crustaceans, brittle stars *(Ophiuroidea)* and the carpet mussel *(Philippinarum)* have changed their behaviour, which, in part, threatens the species as a whole. *(Solan et al., 2016; n.p., 2016)* In addition, reptiles, such as the loggerhead turtle (*Caretta caretta),* sea turtles (*Chelonioidea*) *(CSA, 2021)* and shore crabs (*Carcinus maenas*) *(Wale et al., 2013)* showed significant impairments in habitats with strong underwater noise. However, the available data for seals and seabirds such as penguins is incomplete to date. *(n.p., 2021-1, Sørensen , 2021)*

In summary, varying intensity of underwater noise effects on underwater fauna has been known for more than two decades as a result of a multitude of scientific publications. Underwater noise has been shown to have doubled every ten years for the past 35 years. With the expansion of transport volumes and the use of alternative routes such as the Northeast Passage, there is a further drastic increase in underwater noise, even in the traditional "quiet areas". Marine mammals in particular rely on their calls to find food and mates to navigate, or to avoid the calls of predators and to care for their young.

Partners are often found through long-distance communication. However, increasing underwater noise has drastic effects, from simply abandoning their accustomed habitat, reduced feeding or reproductive rates due to masking, increased susceptibility to disease partly through the production of stress hormones, and to the death of individual mammals and fish.

2 Legal Framework

As a regulation for the containment of underwater noise, international maritime and marine environmental law forms the framework for legislation. However, there is currently no international treaty that exclusively addresses anthropogenic underwater noise. Relevant conventions contain general provisions for the protection of the marine environment, for the protection of various species, for the protection of biodiversity or for protection against pollution through material discharges. Relevant conventions related to underwater noise include

in the narrow sense:

- UNCLOS (United Nations Convention on the Law of the Sea) Part XII, Section 1, Art. 194 Par. 1 and 3
- CBD (Convention on Biological Diversity)
- Helsinki Convention (with legal validity in the nine countries bordering the Baltic Sea (DK, DE, EST, FI, LET, LIT, POL, RU, SW) and the EU)
- ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas)

in a broader sense:

- Fish Stock Agreement
- CMS (Bonn Convention - Convention on the Conservation of Migratory Species of Wild Animals)

In Dec. 2018, the UN General Assembly in resolution A/RES/73/124 (“Ocean and the Law of the Sea”) stated “…that ocean noise has significant adverse impacts on living marine resources”, “…also [noted] the discussions…” on the “…concern over the potential social, economic and environmental impacts of anthropogenic underwater noise, …” emphasized that “…further research and international cooperation…” are urgently needed “…to assess and address the potential impacts of anthropogenic underwater noise in all ocean areas..." and "...[called] upon States to consider appropriate cost-effective measures and approaches...taking into account the precautionary approach and ecosystem approaches and the best available scientific information, as appropriate". *(UN, 2018)*

Within the jurisdiction of the EU, the MSFD (Directive 2008/56/EG), the Habitats Directive (Directive 92/43/EEC) and the EIA Directive (Directive 2011/92/EU) represent an applicable legal code through which the discharge of underwater noise can be taken into account.

In Germany's national law, the federal states are responsible for the legal framework in coastal waters up to 12 nm. The federal government, represented by the BMU and the BfN, is responsible for the implementation of federal laws in the territory of the EEZ and the continental shelf beyond the 12 nautical mile limit.

Through the Federal Nature Conservation Act (§ 3 BNatSchG), the federal and state governments fulfil the obligations arising from the EU Habitats Directive (Article 3 of the Habitats Directive) to set up and protect the continuous European ecological network "Natura 2000". Chap. 6 §§ 56-58 of the Federal Nature Conservation Act regulate marine nature conservation. § 57 makes provisions for protected marine areas in the area of the German EEZ and the continental shelf. In the case of anthropogenic impulse noise induced by the construction of offshore wind farms, § 57 Para. 3 No. 5 of the act stipulates that the requirements for the protection of maritime Natura 2000 areas may not go beyond the minimum protection standardised in § 34 BNatSchG (§ 57 Para. 3 No. 5 Pt. a), which excludes general bans on the construction of wind turbines. The "Concept for the Protection of Harbour Porpoises from Sound Exposures during the Construction of Offshore Wind Farms in the German North Sea" developed by the BMU (authorized via § 3 BNatSchG) is intended to address and clarify the nature conservation requirements for the construction of offshore wind farms in the EEZ. With regard to anthropogenic continuous noise and according to Section 57 (3) No. 1, 1st half sentence BNatSchG, restrictions on shipping are generally prohibited. At the same time, § 57 Paragraph 3 No. 1, 2nd half sentence BNatSchG (as lex specialis derogat legitimate generali) stipulates that Art. 211 Para. 6 UNCLOS and other international regulations relating to shipping remain unaffected. According to Article 211 Para. 6 Pt. a UNCLOS, a coastal state can therefore, under certain conditions, enact laws and other regulations for an area to prevent, reduce and control pollution from ships. However, the coastal state is bound by the specifications of the IMO. The regulations of the IMO therefore determine the extent to which further measures to protect against underwater noise can be applied in a legally binding manner.

In order to protect the crew from ship noise, the IMOC issued what were then provisional guidelines for the maximum acceptable noise level for listening posts on ships as early as 1975. *(IMO, 1975)* Six years later, in 1981, a noise protection code for personnel on board ships was adopted by the IMOC (Res. A.468 XII), which was revised in 2001, 2009 and 2012 (by MSC/Circ.1014 *(IMO, 2001)* , and MSC.337(91) *(IMO, 2012)*) in more detail and was incorporated in Chap. II-1 of the SOLAS Convention as regulations "3 to 12". This created a legal code for the reduction of noise from machinery to protect the crew for ships of 1,600 GT and above, but not yet for the protection of underwater fauna.

Already by 1991, the IMO adopted guideline A.720(17) for designating special areas and marking particularly sensitive sea areas (PSSA), in which it was explicitly stated (Chap. 1, No. 1.2, Table 1) *(IMO, 1991)* that the noise generated by ship operations was listed as an environmental hazard. In total, the IMO has designated 15 sea areas worldwide (and two extensions in Australia) under PSSA on the basis of this guideline . *(IMO, 2021)*

In the MEPC Correspondence Group, several attempts were made by Australia (MEPC 58/INF.19) and by the USA (MEPC 57/INF.4; MEPC 58/19, MEPC 59/19 and DE 57/17) in the years 2007 to 2011, to bring the IMO's attention to the effects of underwater noise caused by ships. These activities ultimately led to IMO approval in 2014 of guidelines for the reduction of underwater noise from commercial shipping (MEPC 1/ Circ . 833) *(IMO 2014)* , in which the USA and Australia were supported by the countries Germany, Spain and England.

The guideline recognises that ship noise can have short- and long-term effects on marine life and requires measurements of ship noise according to objective criteria (ISO standards), the development of calculation models to identify effective mitigation measures, guidelines for the design of quieter ships and for reduction the noise of existing ships (with a focus on propeller activities). However, the guideline only represents recommendations as it is not binding for the parties involved.

Similar to the US, Canada has made efforts through several federal agencies (DFO, TC) to tackle the problem of underwater noise. Most of Canada's habitat-related underwater noise policy in recent years has focused on the impact of ship noise on species protected by the Species at Risk Act (SARA) passed in 2002. *(n.p., 2002)*. For example, in 2019 the Canadian government introduced a series of new safeguards (such as no-go zones for ships, speed restrictions and reduced use of sonar) aimed at reducing noise levels in an environment (Juan de Fuca Strait, Swiftsure Bank, Gulf Islands and Canadian Pacific waters) home to Southern Resident killer whales (*Orcinus orca* of the dolphin family). However, some of the measures are not mandatory, but rather voluntary. *(n.p., 2021-2)*

With regard to inland navigation, construction-related specifications are set by European standards, which, however, only regulate surface noise. According to the European standard for technical requirements for inland navigation vessels (ES-TRIN), the sound pressure level of the engine noise of an inland vessel at a distance of 25 m from the ship's side must not exceed 75 dB(A) (according to Art. 8.10 No. 2). In the case of "stationary" ships, 65 dB(A) (according to Art. 8.10 No. 3) must not be exceeded at the same distance. *(CESNI, 2021)* From January 1, 2022, the ES-TRIN noise limits will be reduced by 5 dB(A) for new ships. On the initiative of the Netherlands, Article 32.02 applies and reduces limit levels for inland vessels whose keel was laid before April 1, 1976 and which are approved for navigating the Rhine *(Garrelmann , 2017)*.

Neither in the area of maritime shipping, nor in the area of inland waterway transport are there adequate legal norms that formulate sufficient regional, national or even international obligations to effectively reduce the damaging effect of anthropogenic underwater noise to protect the fauna living in the oceans and other bodies of water.

3 Standardised Measuring Systems

According to MSFD (Descriptor 11) *(BMU, 2012)* , energy introduction into the sea, especially underwater noise, must be managed in such a way that no damage occurs to the marine environment. Contributions from ship noise are increasingly coming into focus with regard to possible effects on marine fauna. In order to validly check compliance with the planned regulations to limit noise emissions, the strength of the emissions must be determined. In order to ensure a uniform method of measurement, corresponding standards for the measurement of underwater noise considering the free water surface were developed in the USA (ANSI/ASA S12.64-2009/Part 1) *(ANSI, 2014)* as well as by the International Organization for Standardization (ISO 17208-1:2018; ISO 17208-2:2020-11) *(DIN ISO, 2018)* . In addition to these standards, ship classification societies (ABS, BV, CCS, DNV, LR, RINA) have developed measurement methods used in the certification process. *(ABS, 2021-1; BV, 2018; CCS, 2018; DNV, 2010; LR, 2017; RINA 2019)* Furthermore, the ITTC, as an expert committee, developed a guideline including recommended procedures in 2017 for the assessment of the hydrodynamic performance of ships *(ITTC, 2017)* . Last but not least, in two projects funded by the EU as part of the "Oceans of Tomorrow" ("SONIC" and "AQUO") with the collaboration of the classification societies DNV and BV, a guideline for the regulation of underwater noise from merchant shipping was developed ("AQUO 2014"). *(Baudin et al., 2015)*

Consequently, a large number of standardized methods exist for measuring underwater noise. The state of research on the methods is also being continuously expanded (including for the Arctic (*Arctic Council Secretariat (Ed.), 2021 with additional references .)*). For example, a sufficiently deep body of water is required for the measuring methods, which is not the case on most coasts. During the measurements, however, the entire sound including reflections is always measured. This requires the development of appropriate calculation tools with which the reflection for shallow water can also be taken into account in measurement results *. (Göttsche, 2020)*

Publications of underwater noise measurements *(e.g. Simard et al, 2016; Veirs et al, 2016; Jansen & de Jong, 2017)* do not follow the same standard, so a comparison of the published values is not always possible. The same applies to the limit values for ship noise published by the ship classification societies. *(de Jong, 2020)*

Both a binding, uniform standard for measuring anthropogenic underwater noise as well as a uniform determination of noise limit values for underwater noise by the classification societies are lacking.

4 Technological Measures and Developments

Technical options for reducing noise emissions from merchant ships have been increasingly discussed since 2008 in a Correspondence Group (CG) of the IMO's Marine Environment Protection Committee (MEPC).

Possible measures to reduce underwater noise in seagoing vessels include, among others, propeller design and maintenance, the installation of special propeller nozzles, reducing the vibration of ship engines, speed reduction and alternative propulsion types.

There is a wide range of choices in propeller design (such as increasing skew, "enlarging the propeller", "forward -skew" propellers, "CLT" propellers, twisted propellers, "Kepler" propellers, waterjets, compound propellers, variable pitch propellers, revolution per knot reduction, "Voith-Schneider" propeller etc. *(ABS, 2021-2)*), which, however, must be adapted to the individual case depending on the type of ship, size class and service speed. As a result, reductions in the sound pressure level from 2 to a maximum of 20 dB are possible. However, the installation of an "air bubble curtain" on both the hull and the propeller is still in the research stage. This is expected to reduce the absorbed continuous noise by 3 to 6 dB for a cargo ship traveling at a speed of 14 knots . However, the air bubble curtain creates additional drag and reduces the overall efficiency of the ship's propulsion by approximately 2 to 3%, but this can be offset by installing additional techniques for improved follow-up steering. A large number of developments are also available for follow-up steering, which improve the inflow to the propeller (e.g. "Schneekluth- Duct ", " Mewis Duct ", " Grothues Spoiler", "Stern Flaps") and at the same time partially reduce the energy required for the ship's propulsion. *(ABS, 2021-2)*

Another significant source of underwater noise is engine-related noise, which is mainly generated by mechanical vibration. The natural vibrations of the ship's engines are first transmitted to the foundations and then spread to the hull structures, which leads to the emission of underwater noise. Reducing this vibration and isolating the source of vibration from the ship's hull are effective ways to reduce underwater engine noise. A wide variety of measures are used here, such as two-stage insulation for smaller engines and generators (here the machine is cushioned by elastic brackets on a heavy intermediate plate, which in turn is connected to the foundation on a second level, also buffered by elastic brackets), soundproof housing for absorption of engine airborne noise and the generation of active counter-vibrations (to cancel out the original vibration). Thanks to the two-stage insulation, mechanical vibrations noise can be reduced in the range from 20 to 40 dB. In addition, studies show that a decoupled hull coating with rubber foam or viscoelastic tiles can reduce the underwater noise radiated from the ship's hull by 20 dB at high frequencies. However, these methods are expensive. *(ABS, 2021-2)*

In the area of operative measures, propeller polishing to reduce surface roughness and the associated reduction in cavitation should be mentioned. *(ABS, 2021-2)* Another operational measure to reduce underwater noise is a reduction in speed. A study by IFAW scientists concludes that a 10 percent slower merchant fleet could reduce underwater noise by 40 percent. *(Leaper , et al 2014)* . An example is the expedition ship "Le Jacques-Cartier", which was certified by the classification society Bureau Veritas (BV) according to Rule Note "NR614" for "Underwater Radiated Noise" (URN) and whose speed was throttled to 10 knots to reduce the impact on underwater fauna.*(Oldenburg, 2021)*

With regard to the anchoring of offshore structures, there currently exist state of the art bubble curtains *(Schmidtke, 2010; Dietrich, 2014)* (with a reduction potential of up to 18 dB *(Vennemann, 2018)*) and the use of noise protection shells (ramming monopiles (Weyres , 2012) and (Koschinski , 2013; Stahlmann, 2015) , which can achieve a reduction of 45 dB). As the pile diameter increases with the size of the offshore structures, so too does the sound pressure when anchoring with conventional piling techniques, and, thus, the need for corresponding stronger requirements for future noise reduction measures. *(WBGU, 2014)* With the use of seismic devices (airguns), "marine vibroseis systems" generate significantly lower peak noise levels and represent alternatives to current airguns . *(Bastolla et al., 2019)*

Based on the current state of research, a colourful potpourri of techniques and measures to reduce underwater noise is already available, but some measures are cost-intensive. There is therefore a need for further research into the extent of the underwater fauna affected, possible alternatives for avoid-

ing or reducing underwater noise, and for cost-effective developments/technologies/products not only in the construction of new ships, but also for the retrofitting of existing fleets.

When using seismic technologies, research into alternatives is required in order to be able to avoid or significantly reduce the currently enormously high sound pressure levels. The same applies to underwater blasting (insofar as same is absolutely necessary), to the research and development of efficient repellent means and techniques , inexpensive soundproofing techniques and salvage equipment for moving ammunition findings.

5 Financial Incentives and Bonus Systems

An example of port-based initiatives against underwater noise is the "ECHO program" at the Canadian port of Vancouver, which has been in place since 2017. This voluntary program implements reductions in ship speed and clearance distances from sensitive sea areas in order to reduce the effects of noise from shipping activities on endangered whales (such as the killer whale) in the region. Furthermore, beginning in January 2020, there is a port fees credit in the ports of Vancouver and Hamburg if ships operate in a noise-reducing manner. The reduction is based on a rating in the ESI. With 6,874 listed ships (as of the third quarter of 2021), the ESI has the world's largest number of participants listed in a ship-related "Environment Award" and has had "noise" as a criterion in the rating catalogue since the beginning of 2020. Currently (as of the third quarter of 2021) a total of 57 ships are listed under the "Noise" category, of which 16 ships have so far received full points in all three noise categories for the ESI bonus points. The points for the ESI include the groups "Noise in general", "Noise below 160 Hz" and "Reporting on noise reduction", with the points for the second group being doubly weighted. The noise is measured according to the NEPTUNES protocol as a measurement in dB(A) for surface noise. The port fees credit is approved by the ESI and only considers a reduction of surface noise, as underwater noise of the listed ships is not currently measured and the noise-emitting objects often vary from those for underwater noise.

Currently, no “award” system actively considers underwater noise reduction. The first signs can be seen with ESI, which is intended to reward measures against surface noise by reducing port fees for participating ports. However, the number of participating parts that grant bonuses for this aspect of ESI is marginal. Existing maritime environmental awards (“award” systems) such as Environmental Ship Index (ESI), Blue Angel, Green Award, Clean Shipping Index (CSI) etc. should reward measures to reduce underwater noise and anchor them in their statutes for conferring award levels.

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Abbreviations

ABS	American Bureau of Shipping *(classification society)*
AQUO	Achieve QUieter Oceans by shipping noise footprint reduction
Art.	Article
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BfN	Bundesamt für Naturschutz *(Federal Agency for Nature Conservation, Germany)*
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit *(Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany)*
BNatSchG	Bundesnaturschutzgesetz *(Federal Nature Conservation Act, Germany)*
BSH	Bundesamt für Seeschifffahrt und Hydrographie *(Federal Maritime and Hydrographic Agency of Germany)*
BV	Bureau Veritas *(classification society)*
CBD	Convention on Biological Diversity
CCS	China Classification Society *(classification society)*
CENIS	European Committee for drawing up Standards in the field of Inland Navigation
Chap.	Chapter
CG	Correspondence Group
CMS	Convention on the Conservation of Migratory Species of Wild Animals
dB	Decibel
CSI	Clean Shipping Index
DE	Germany
DFO	Department of Fisheries and Oceans *(Canada)*
Diss	Dissertation
DK	Denmark
DNA	Deoxyribonucleic acid
DNV	Det Norske Veritas *(classification society)*
dwt	deadweight tons
Ed.	Editor
EIA	Energy Information Administration
EEZ	German Exclusive Economic Zone *(AWZ; ausschließliche Wirtschaftszone)*
ESI	Environmental Ship Index
EST	Estonia
et al.	Et alia *(Lat.) (and others)*
EU	European Union
ff	following
FI	Finland
GT	Gross tons
HD	Habitats Directive *(Directive 92/43/EEC)*
Hz	hertz
IFAW	International Fund for Animal Welfare
IMO	International Maritime Organization
IMOC	Inter-Governmental Maritime Consultative Organization *(predecessor of IMO)*
kHz	kilohertz
Lat.	Latin
LET	Latvia
LFAS	Low Frequency Active Sonar
lit	Littera
MSC	Maritime Safety Committee
MSFD	MSFD; Marine Strategy Framework Directive (Directive 2008/56/EG) *(MSRL;* Meeresstrategie-Rahmenrichtlinie)
LR	Lloyd's Register *(classification society)*
m	Meter
MEPC	Marine Environment Protection Committee
MFAS	Mid-Frequency Active Sonar
Mio.	Million(s)
n.d.	No date
n.p.	no publisher (given)
nm	nautical mile
No	Number
NRDC	Natural Resources Defense Council
NRW	North Rhine Westphalia
p	Page
Par	paragraph
POL	Poland
PSSA	Particularly Sensitive Sea Areas
RINA	Registro Italiano Navale *(classification society)*
RU	Russia
SDC	Ship Design and Construction
SOLAS	International Convention for the Safety of Life at Sea
SONIC	Suppression Of Underwater Noise Induced by Cavitation
SW	Sweden
TC	Transport Canada *(Ministry of Transport, Canada)*
UK	United Kingdom
UN	United Nations
USDC	United States District Court
wfr	with further evidence

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