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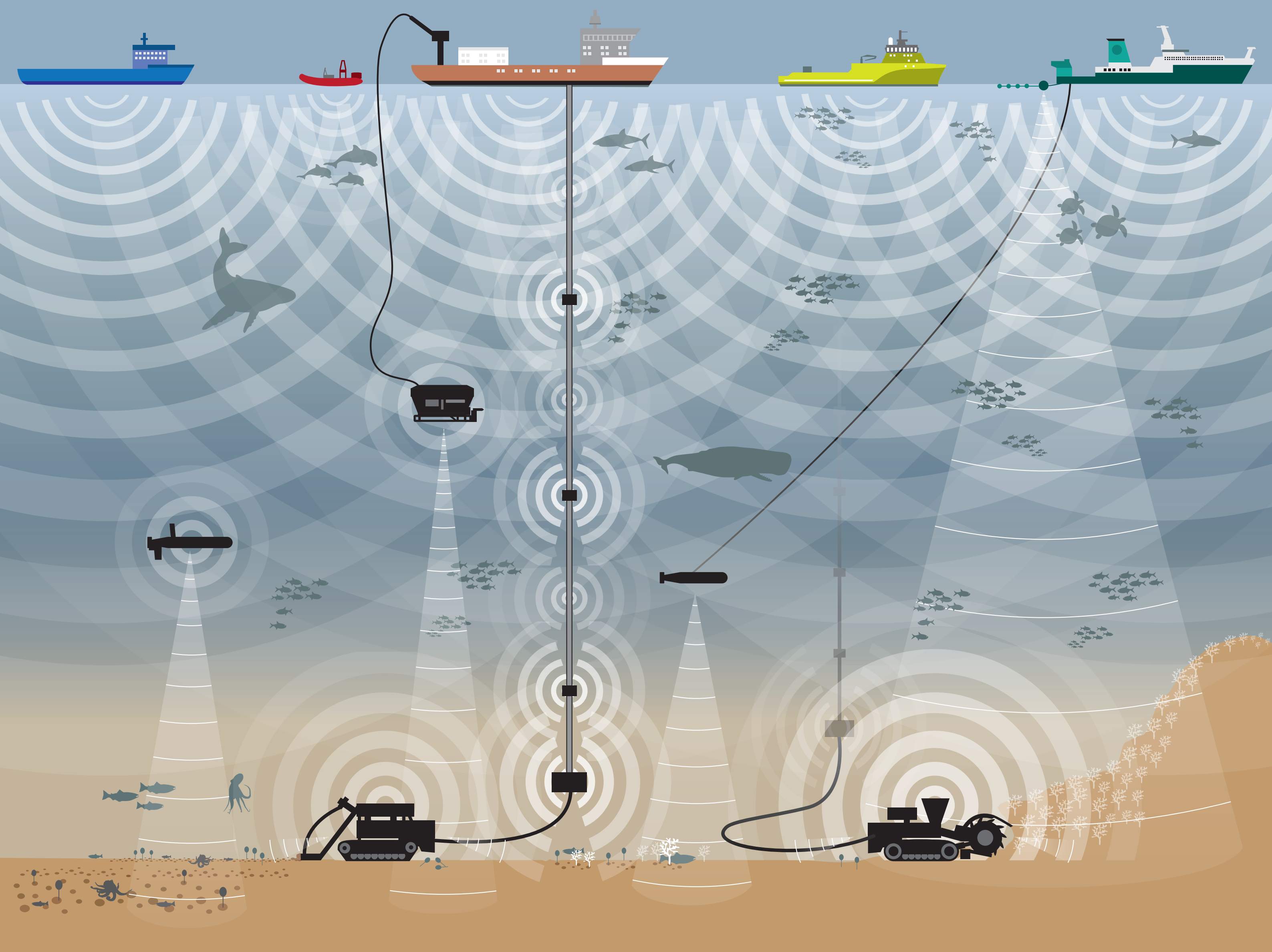
Deep-Sea Mining: A noisy affair

Overview and Recommendations



An OceanCare Underwater Noise and Deep-Sea Mining Report, 2021

Deep-Sea Mining: A noisy affair

Overview and Recommendations

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CONTENTS

LIST OF ABBREVIATIONS

ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
APEI	Area of Particular Environmental Interest
The Area	International seabed and its subsoil according to UNCLOS
Art.	Article
AUV	Autonomous Underwater Vehicle
BACI	Before, After, Control, Impact
BAT	Best Available Technology
BBNJ	International legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction
BEP	Best Environmental Practice
CCZ	Clarion-Clipperton Zone
CBD	Convention on Biological Diversity
CMS	Convention on the Conservation of Migratory Species of Wild Animals
COFI	Committee on Fisheries of the Food and Agriculture Organisation
CW	Continuous Wave
dB	Decibel
DSM	Deep-Sea Mining
EBSA	Ecologically and Biologically Significant Marine Area
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
GFCM	General Fisheries Commission for the Mediterranean
GHG	Greenhouse Gas
HELCOM	Baltic Marine Environment Protection Commission
Hz	Hertz
IGC	Intergovernmental Conference
IMMA	Important Marine Mammal Area
IMO	International Maritime Organization
IRZ	Impact Reference Zone
ISA / ISBA	International Seabed Authority
IWC	International Whaling Commission
Joint NWG	Joint CMS/ASCOBANS/ACCOBAMS Noise Working Group
kHz	Kilohertz
kn	Knots
LTC	Legal and Technical Commission
MAR	Mid-Atlantic Ridge
MEA	Multilateral Environmental Agreement
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
OSPAR Convention	Convention for the Protection of the Marine Environment of the North-East Atlantic
PRZ	Preservation Reference Zone
REMP	Regional Environmental Management Plan
RFMO	Regional Fisheries Management Organization
RMS	Root Mean Square
ROV	Remotely Operated Vehicle

SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessment
SEL	Sound Exposure Level
SOFAR Channel	Deep Sound Channel or Sound Fixing and Ranging Channel
Solwara 1	Polymetallic sulphide site in waters off Papua New Guinea
SPL	Sound Pressure Level
TOB	Third-octave Band
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
VME	Vulnerable Marine Ecosystems
WOA	World Ocean Assessment
µPa	Micropascal
µs	Microseconds

EXECUTIVE SUMMARY

This report gives an overview of the current knowledge on underwater noise emissions from Deep-Sea Mining (DSM) activities and their potential impacts on marine life. The report also summarises existing legal and policy frameworks on underwater noise including their shortcomings with respect to management of DSM activities in the Area. It concludes with recommendations on the necessary steps to fill knowledge gaps and create a solid basis for decision-making regarding noise from DSM activities.

Anthropogenic underwater noise is recognized by science and a wide range of international organizations as a major threat to marine life. There is solid evidence that noise emissions from vessels and active acoustic exploration (e.g. sonar and seismic surveys), which are relevant to DSM activities, have significant harmful effects on marine species. In addition, extraction (dredging, drilling, scraping), mining tool positioning (sonar), pumps (riser system), and submersibles, ROVs and AUVs (e.g. propulsion), can emit loud noise which may result in potentially significant harmful effects on marine species.

Knowledge of underwater noise impacts from DSM based on direct measurements and observations is currently largely missing, but some activities are similar to those in peer industries and in some cases extrapolations are possible. In other cases, information on noise levels and frequencies are lacking. This is the case for electric motors, pumps and riser systems (inter alia material transport sounds, booster stations, dynamic positioning), and machines (seafloor mining tools, on board machinery). However, lack of knowledge does not preclude the potential of these machineries to impact on marine life.

There are substantial knowledge gaps with regard to the ecology of marine species, particularly in deep-ocean habitats, including their sensitivities to noise and vibration. While measurement of full-scale mining activities in the field by independent scientists would be the most effective way to obtain robust noise emission data, full-scale DSM development and testing is not the only way to assess potential impacts of this proposed industry. Instead, studies of already existing noise sources and their impact on known species, let alone the ones still to be discovered, should be the first step to build up a scientifically sound knowledge basis for effective protection of the marine environment from DSM activities in the Area.

In light of the lack of knowledge and the neglect of the issue of underwater noise at ISA, a pause in the drafting of regulations and guidance for DSM in the Area to rectify the obvious lacunae is recommended. Any regulations and guidance drafted before having a solid scientific knowledge basis should strictly adhere to the precautionary principle and be restrictive and only relaxed where there is scientific evidence proving limited harmful effects to the marine environment. If the International Seabed Authority (ISA) nevertheless decides to continue drafting its Mining Code, minimum requirements are necessary to adhere to existing state of the art noise regulations and recommendations, including:

- adoption of a rule explicitly stipulating that introduction of energy, including underwater noise, in mined areas and their vicinity should be at levels that do not adversely affect marine life and the marine environment;
- amendment of existing regulations and guidance to account for the harmful effects of acoustic exploration activities;
- application of existing state-of-the-art noise regulations (e.g. the *Convention on the Conservation of Migratory Species of Wild Animals (CMS) Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities*) and consultation with the most qualified noise experts in order to extrapolate from existing knowledge;
- assessment of expected noise levels based on experience from other industries and verified by independent scientific experts;
- definition of clear requirements concerning noise measurement and mitigation for contractors and DSM technology development companies, including the provision of estimated noise emission levels and frequencies at all relevant depths and distances;
- measurement of background ambient noise levels in contracted areas and their surroundings (including APEIs);
- comprehensive baseline studies including marine mammal, fish and invertebrate surveys.

SECTION 1. POLLUTION FROM DEEP-SEA MINING ACTIVITIES

1.1 Introduction

The deep sea (areas of >200 metres depth) represents the largest global biosphere in terms of habitable volume [1,2,3], of which the vast majority is yet to be explored. From what is known to date, deep-sea habitats include canyons, plains, mountains, trenches, hydrothermal vents, methane seeps, wood falls, whale falls, brine pools, the deep pelagic and much more. These habitats are home to a large variety of species, from microscopic bacteria to deep-diving large marine mammals[4], with their distributions depending on specific habitat characteristics[5]. Approximately two thirds of the species are still to be discovered[6]. Some of these deep-sea creatures have very long lifespans and reproduce very slowly, which makes them particularly vulnerable to disturbance.[7] Our understanding of how the deep ocean functions remains limited, but we know that it is essential to ensuring the habitability of the planet by providing key ecosystem functions and services. These include, for example, carbon sequestration and storage that regulates the climate[8], nutrient cycling, and links to the provision of fisheries[9].

While our knowledge of the deep ocean is poor, growing demands and increasing impacts associated with deep-sea activities[10] have turned our focus to it. Increasing material wealth, developing economies, and trends towards electrification of the transport sector and renewable energy generation, has led to increased interest in the extraction of minerals from the deep seabed. The three main mineral resources being sought after are polymetallic nodules on abyssal plains between 3,000 and 6,000 metres depth, cobalt-rich ferromanganese crusts on seamounts between 800 and 2,500 metres depth, and polymetallic sulphides at hydrothermal vents on mid-ocean ridges and back-arc basins between 1,000 and 4,000 metres depth.[11] Thirty-one exploration licenses have been granted in international waters by the International Seabed Authority (ISA) to date. Yet, little is known about the potential detrimental effects of Deep-Sea Mining (DSM) activities.

1.2 Impacts from DSM Activities

The potential impacts from DSM activities on the deep ocean could be far-reaching and long-lasting.[12,13] Vast areas may be mined[14,15,16] which raises concerns of large scales of effects, especially as these are not limited to the deep seafloor and could affect the water column up to the surface[17]. The following is an introduction to the environmental impacts of DSM activities structured by four main categories: 1) impacts from minerals extraction; 2) impacts from benthic sediment plumes; 3) impacts from the dewatering process; and 4) impacts from the operation of mining equipment.

a) Impacts from minerals extraction

Polymetallic nodules and cobalt-rich ferromanganese crusts form over millions of years and will, once mined, be lost for biota associated with this habitat, resulting in biodiversity and functional loss and maybe even species extinction.[18,19,20,21,22,23,24] In addition, removal of nodules and crusts will cause direct mortality to sessile (non-mobile) organisms[25,26], with compaction and removal of seafloor sediments by mining vehicles being another hazard[27,28,29].

Polymetallic sulphides at hydrothermal vents may re-form much more quickly at active vents (although not at inactive vents) than polymetallic nodules and cobalt-rich ferromanganese crusts[30] but mining would remove substrate and associated biodiversity, alter topography and chemistry, and make these areas unsuitable for recovery and recolonization[31]. The biodiversity and length of recovery will depend on the level of activity of the vent field, as well as their location and type of geological spreading centre.[32,33,34,35,36]

b) Impacts from benthic sediment plumes

Sediment plumes are created from the disturbance of the mining machines on the seafloor. These sediment and particulate plumes (collector plumes) can remain in suspension in the water and travel with currents.[37,38] Benthic mining plumes hence not only impact the mined seafloor but extend the footprint to adjacent areas[39,40,41] as well as the water column[42,43]. These plumes may bury or smother seafloor organisms and habitats, prevent recolonisation[44,45], interfere with feeding[46], respiration, reproduction, and disturb the settlement of juveniles[47,48,49,50,51]. Plumes are also likely to be toxic.[52]

c) Impacts from the dewatering process

Mined ores are transported to the surface support ship or platform where they are separated from the seawater. The wastewater, together with small particles, will be released back into the ocean.[53] Midwater plumes from wastewater returned to the sea (discharge plumes) could, in addition to the abovementioned effects in deeper water and the seabed, have clouding effects causing reduced light penetration, productivity and oxygen levels in the epipelagic zone (0-200 m)[54,55], as well as other changes in water chemistry, even to the point of toxicity in higher water layers, depending on the depth at which the wastewater is injected[56]. This could significantly alter midwater organisms' behaviour.[57] Additional midwater plumes may originate from rewetting and dewatering the ore for ship-to-ship transfer. [58]

d) Impacts from the operation of mining equipment

The mining equipment comprises technology for surveying and exploring for mineral reserves, machines working on and extracting the seafloor, lifting systems to bring the ore to the surface, pipes to return wastewater into the ocean, the production support vessel or platform[59] as well as transporting, supply, research and monitoring vessels. Lights will be required around the clock for operations both on the seafloor (mining machines) and the surface (support vessels/platforms).[60] In the dark deep ocean, anthropogenic light sources may hamper the vision of deep-sea species and interfere with orientation, communication, food-finding, mating and defence against predators.[61] However, visual inspections of the seafloor in the course of mining operations may be less useful than hydroacoustic observations because of their limited reach.[i] Behavioural disruption in birds and near-surface marine life from light emitted from the support ship is another hazard.[62]

Oil spills and leaks from hydraulic equipment, as well as other contaminants from production or transport vessels constitute additional threats to the marine environment. Furthermore, increased ship traffic from mining activities increases the risk of ship strikes on marine mammals and causes air pollution and carbon emissions.[63] Additionally, very small and resilient alien species, such as bacteria, may be transported on mining machinery and pose a potential risk to established communities.[64]

Acoustic survey technology, extraction at the seafloor and associated machinery, riser pipes and pumps, as well as the surface ships and platforms and submersibles will generate noise and vibration, most of which is emitted nearly constantly, with potentially far-reaching effects on marine life. The following sections will provide a short introduction on underwater noise and its impacts on marine animals, followed by a detailed description of the currently available knowledge on noise sources from DSM activities and their potential effects on marine life.

SECTION 2. INTRODUCTION TO ANTHROPOGENIC UNDERWATER NOISE

Sound travels fast and very efficiently underwater, at almost five times the speed of sound in air. Especially low frequencies can sometimes be heard over thousands of kilometres in the ocean. In the deep ocean, sound can go very far, particularly in the Deep Sound or Sound Fixing and Ranging (SOFAR) Channel, where it travels with little loss of energy. This channel is usually located at around 800-1,000 m depth in mid-latitudes, where sound speed is at a minimum, forming a duct which functions similarly to a fibre optic cable.

Sounds of low frequency or pitch travel further in deep water than those of high frequency. Factors other than frequency that affect the propagation or transmission of sound over distance are the intensity or loudness of the sound, the sound speed profile of the water column (related to temperature, salinity and pressure of the water), source and receiver depth, bathymetry or depth profile of the bottom, and properties of the seafloor (hard bottoms

i Personal information by Dr. M. Haeckel, GEOMAR.

reflect sound better than soft ones like mud which absorb sound). Sounds below 500 Hz or 1 kHz are considered low frequency, sounds of 1 to 10 kHz mid-frequency, and above 10 kHz high frequency, though these are rough approximations.

The World Health Organization (2011) notes that human-caused (anthropogenic) noise is recognized as a global pollutant; indeed, for humans, it is one of the most harmful forms, second only to air pollution.[65] Noise is not uncommonly used to study stress in terrestrial research animals, and sonic weapons have been used by military and police to disrupt, confuse, disorientate, demoralize, and even injure opponents. Human-caused noise is pervasive both in terrestrial and aquatic ecosystems. Duarte *et al.* (2021) state that anthropogenic noise is a pollutant in the ocean and that deep-sea mining may be a major source of underwater noise that will likely contribute to increasing impacts on marine species.[66]

BOX 1: HOW SOUNDS ARE CHARACTERIZED

Sounds can be described as being soft or loud, which would be measured by amplitude or intensity/pressure in decibels (dB). Higher amplitude sounds carry more energy. Sounds can also be characterized as being low- or high-pitched, measured by frequency in Hertz (Hz) or kilohertz (kHz). 1,000 Hz is one kHz. Decibel is a relative unit comparing two pressures, so a reference pressure must be included. In underwater acoustics, the reference pressure is 1 micropascal or µPa. In air, the reference pressure is 20 µPa. Therefore, sound intensity in dB in water is not the same as in air. A conversion factor of roughly 26 dB added to sound in air would need to be applied to obtain in-water levels of the same intensity.[67]

The greater difficulty in comparing sound levels in air and in water is that the two media have different densities and marine animals perceive sound underwater differently compared to terrestrial animals in air. The ear may not be the only way sound is perceived in marine animals. Moreover, the pathways to the inner ear are different. In water, the sound couples more easily into a marine animal's body if that body is mainly composed of water, as ours is. Thus, they can more intensively sense or feel the sound through their bodies, similar to how we sense rather than hear the throbbing of low-frequency, loud bass sound, say from a car's bass speaker.

The logarithmic nature of the dB scale means that each increase by 10 dB is a ten-fold increase in acoustic power or intensity. A 20 dB increase is then a 100-fold increase in power, and a 30 dB increase is a 1000-fold increase in power.

Broadband noise is noise covering a broad range of frequencies. One possible band used for frequency analysis is the octave band. This means that the upper frequency limit of the band is approximately twice the lower limit. Each octave band is described by its "centre frequency", which is the geometric mean of the upper and lower frequency limits. If more resolution in frequency is required, then narrower bands can be selected, such as one-third octave bands or TOB (third-octave band). They are about one third the width of an octave band. The power spectral density level is the mean-squared pressure of noise measured within a given frequency bandwidth, divided by the measurement bandwidth change in frequency.[68]

Received sound levels are those at the animal's ear and should not be confused with source levels which characterise the loudness of a sound at its source. Sound levels generally decrease with distance from the source through spherical (sound propagation in all directions) or cylindrical spreading (spreading more laterally, being trapped between sea surface and sea floor). Sounds often initially spread spherically and then gradually shift to cylindrical spreading. Sound propagation through the marine environment can be complex, especially in shallow or ice-covered habitats.[69]

Long-term measurements of low-frequency (<50 Hz) noise from deep-water sensors in the Northeast Pacific found that noise levels, mostly from shipping, doubled every decade, increasing by about 10 dB between the 1960s and mid-1990s.[70,71] It is unclear whether this trend has continued in more recent years. Shipping noise at the surface is also not confined to that area, but penetrates into the deepest oceans. In 2016, hydrophone measurements from nearly 11 kilometres depth in the Mariana Trench recorded not only natural noises such as waves, wind, typhoons and whale vocalisations at the sea surface but also the noise of passing ships.[72] Nieukirk *et al.* (2012) analysed 10 years of recordings from seafloor acoustic sensors from the mid-Atlantic. They found that noise from seismic airguns not only was detected at distances of 4,000 km from the source but that it became the dominant part of the background sound and was ubiquitous, at times drowning out or masking whale calls.[73] In the opposite direction, noise from depth will likely be heard at the surface, though the extent will depend on temperature layers (stratification) in the water column. At times, sound from depth could be refracted downwards away from the surface. The seabed will also reflect sound, depending both on the properties of the seabed and in particular on the frequency (pitch).

Because sound functions so well underwater, marine animals have adapted to using hearing (or sound- or vibration-sensing) as their main sense. Sight does not work very well underwater. Even in very clear water, vision is only useful out to tens of meters at the surface. After the top 200 m, sunlight decreases rapidly with depth, and below 800 m there is no sunlight at all. There are roughly 170,000 known species of non-plankton marine invertebrates and 20,000 species of marine fish, with many species still to be discovered. All fish studied to date are able to hear or feel the particle motion component of sounds[74], and many invertebrates have been found to be able to detect sound and/or vibration and to respond to acoustic cues. Fish and invertebrates make up most marine animals living in the deep sea.[75,76] So, almost all marine animals, especially those in the deep ocean, use sound or vibration to sense their surroundings, communicate with others, find mating partners, find their food, detect predators and other hazards, and find their way. These are all functions that are vital for their survival. Duarte *et al.* (2021) recently reviewed 538 papers reporting on underwater noise impacts on marine species and found that for marine mammals 85-94% of reviewed papers showed significant noise impacts, while 82% and 81% of studies showed significant impacts on fish and invertebrates, respectively.[77] Around 66 species of fish, 36 species of invertebrates[78], and 47 species of marine mammals[79] for a total of around 150 species, have shown documented noise impacts. There is no longer any doubt that underwater noise is a serious pollutant.

Noise impacts[ii] on fish and invertebrates include those on development, namely body malformations, higher egg or immature mortality, developmental delays, and slower growth rates. Noise can also impact animals anatomically by causing massive internal injuries, nerve damage, damage to hearing or sound-sensing structures, causing disorientation or even death, and hearing loss. Stress impacts from noise are common, including higher levels of stress hormones, and a higher metabolic rate, heart rate, and breathing rate. This can result in worse body condition, more parasites, lower growth rates, loss of weight, worse immune response, lower reproductive rates and higher death rates. The DNA can be altered as well as the overall physiology. As to behaviour, animals have shown alarm responses, increased aggression, hiding, flight reactions, decreased anti-predator defense, less courtship calls, less care for nests, lower reproduction, and less feeding. Noise can cause more distraction, resulting in less efficient feeding and greater vulnerability to predators. Schooling can become uncoordinated and unstructured due to noise, affecting migration success. Commercial catch rates can drop drastically from noise exposure. Most importantly, ecological services performed by invertebrates such as water filtration, mixing of sediment layers, and nutrient cycling have been shown to be impacted by noise.[80]

There are some deep divers among the whales, dolphins, pinnipeds, and sea turtles. Pilot whales can dive up to 1,000 m or more, sperm whales to 2,250 m and maybe even 3,000 m, similar to the depths reached by beaked whales. Elephant seals can dive to 1,500 m, though they average at 500 m, and leatherback sea turtles can reach 1,200 m. Noise impacts whales and dolphins by causing them to avoid important habitat, sometimes for days or weeks to even months and years. Noise can also reduce feeding, decrease reproduction, cause masking (obscuring, obliterating of sounds of interest), alter calling rates, potentially affecting mating, and disrupt migration. Noise can elicit strong escape responses, damage hearing damage, and cause stress which impairs the animals' immune response and ability to reproduce. Even death through strandings or deaths at sea can result from noise.[81,82]

ii For an overview of potential noise impacts from DSM activities on marine species in the deep sea see Table 2.

BOX 2: PARTICLE MOTION AND VIBRATION

Sound in water is a travelling wave where the particles of water are alternately forced together and apart. The to-and-fro motion, the so-called particle motion, is accompanied by an oscillatory change in pressure (which looks more like a sound wave) defined as the sound pressure. Sound can be measured as a change in pressure, acting in all directions. Each sound wave is composed of a pressure component (in Pascals) and a particle motion component which is measured by the displacement (metres), the velocity (metres per second) and the acceleration (metres per second squared) of the water in the sound wave. Particle motion contains information about the direction of the propagating wave (i.e., is a vector). Few impact studies of underwater noise have measured the particle motion component of sound. Marine mammals hear by detecting sound pressure, but fish and invertebrates, which make up most marine animal species, mainly sense sound using particle motion. A subset of fish can also detect sound pressure, however.[83,84]

Increasingly, it appears that anthropogenic substrate-borne energy or vibration as produced by construction or pile driving is likely to affect bottom-dwelling invertebrates[85,86,87], even though the impact of seabed vibration on marine animals has been mostly neglected. Activities such as drilling or mining, which involve direct contact with the seabed, produce substrate-borne vibrations and radiating particle motion travelling as various types of waves. Some of these waves can travel large distances from the source, trapped within the surface seabed with little loss of energy, potentially affecting animals at great distance.[88] Particle motion levels in both the sediment and in the water need to be measured to fully quantify vibration exposure levels[89] and need to be considered along with acoustic pressure when assessing the effects of noise on bottom-dwellers.

SECTION 3. UNDERWATER NOISE EMISSIONS FROM DSM ACTIVITIES AND RESPECTIVE STATE OF KNOWLEDGE

The loudest frequencies in ambient or background ocean noise are the very low ones. For frequencies above 30 Hz, ambient noise is under 100 dB re 1 µPa^2/Hz. These measurements are not much different at 10 m depth compared with 650 m depth[90]. Polymetallic sulphide sites at or near active hydrothermal or volcanic sites may have considerable natural background noise (continuous at max 135 dB re 1 µPa @ 1 m)[91] although in rare periods (hours to days) of explosive eruption, this can increase to >250 dB re 1 µPa @ 1 m)[92], while nodule or ferromanganese crust mining sites likely have considerably less natural background noise. This needs to be accounted for when assessing noise emissions and their impacts at different sites, resources, and regions that may be mined. Animals may be somewhat adapted to natural noise, but not human-caused noise.[93] Moreover, absolute levels of noise, rather than just the excess over natural levels, may be more injurious to marine life; animals in naturally noisy sites may have less capacity for additional anthropogenic noise.

The acoustic impact of DSM in the marine environment will likely be significant[94], stressing the surrounding environment and associated marine fauna.[95,96,97] But so far, underwater noise emissions have not been investigated or addressed adequately regarding DSM.[98] Even the acoustic characteristics of DSM noise sources the authors have been able to glean here are mainly based on what could be found in grey literature or supplied by contractors or experts in personal communication. This information needs to be measured and verified in the field by independent experts. Robust environmental impact assessments are not possible with such immense knowledge gaps.[99]

To this end, the authors conducted a literature review combined with a stakeholder survey, including a "Short questionnaire for assessing noise emissions from Deep-Sea Mining (DSM) activities"[iii], directed at the DSM industry, technology developers, engineers, and scientists working on DSM issues, as well as the ISA Secretariat. To the

iii See *Annex 1: Short questionnaire for assessing noise emissions from Deep-Sea Mining (DSM) activities.* The short questionnaire was sent to over 50 DSM stakeholders (ISA, ISA contractors, companies developing DSM technology, mining associations, scientists). The information in the questionnaire could be submitted anonymously (an option chosen by some of the respondents).

knowledge of the authors, only one DSM company has conducted noise modelling based on data derived from full-scale mining equipment for polymetallic sulphide mining tested in tanks and laboratory.[iv] Additionally, three international projects[v,100,101] are currently or in the near future conducting tests of nodule mining equipment, including some limited noise assessments. Limited data on noise from pilot studies with seafloor excavation equipment for polymetallic sulphide and ferromanganese crust mining, as well as lifting systems, have also been collected by two national projects with analysis of the data pending.[vi] In summary, available data on noise emissions from DSM mining equipment is scarce and even the data currently collected comes largely from reduced size-scale prototypes. Moreover, sound transmission via the seabed and in particular particle motion through the water and seabed has, to the authors' knowledge, not been considered by any of these preliminary studies on noise emission from DSM activities.

The following section gives an overview of the available literature and data, including from the authors' own stakeholder survey, grouped by source location. As data on noise emissions from DSM are scarce, extrapolations from related industries are also made to give preliminary estimates for the noise emissions potentially expected from DSM activities. Figure 1 and Table 1 summarize the information on noise sources, source location and noise characteristics.

Surface-level noise emissions from DSM activities

Noise emissions originating from the surface include acoustic exploration methods (sonar and seismic airguns), production vessel/platform propulsion and dynamic positioning (DP), as well as noise from machinery and on-board treatment of ore (including pumps), offtake vessels, supply vessels, monitoring vessels and research vessels. Assessments from the now collapsed project to mine polymetallic sulphides in waters off Papua New Guinea (Solwara 1) indicated that noise generated on the surface would account for a significant portion of underwater noise from DSM activities.[102]

a. Acoustic exploration methods

Side-scanning sonars and multibeam sonars, used commercially and for research, typically have frequency ranges between 12 kHz and 400 kHz, with maximal source levels ranging from 200 to 230 dB re 1 µPa. Multibeam sonars may be configured with many beam widths spanning up to 150° or more, so not just a narrow beam directed downward as with most single-beam echosounders.[103]

Exploration for polymetallic nodules uses vessel-based multibeam and sediment echosounders with the following specifications: source level @ 1m: vessel-based 12 kHz multibeam and 3.5 kHz sediment echosounder; source direction: 12 kHz multibeam: 1° vertical x 150° horizontal; pulse duration: 2/5/8/15 ms CW (continuous wave), 25/100 ms FM chirp.[104] These noise emissions are estimated to have a temporal scale of days up to months.

Surface-based exploration for polymetallic sulphides includes multibeam echosounders with approximately 12 kHz and high-resolution beamforming methods.[105] Moreover, literature mentions seismic surveys to search for inactive vent systems[106] and a system with a series of multichannel vertical cable seismic (VCS) arrays moored to the seafloor with a surface-towed, high-frequency sparker (with a lower frequency air-gun source suggested to map deeper structures) developed by JGI Japan.[107] Noise emissions from seismic surveys for polymetallic sulphides are estimated to have a maximum source level of 259 dB re 1 µPa @ 1 m and a temporal scale of days up to months.[108,109,110] However, a geologist and expert in deep-sea minerals indicated that seismic methods are of very limited use in exploring polymetallic sulphides due to the small scales of vent systems.[vii]

The same geologist explained that acoustic exploration for ferromanganese crusts was still at an early developmental stage and thus far of limited use due to the crusts' very limited vertical structure. [viii] However, other interviewees

iv Nautilus Minerals within its Solwara 1 project in the EEZ of Papua New Guinea.
v Global Sea Mineral Resources (GSR), DeepGreen/The Metals Company, Blue Harvesting
vi Anonymous information by national company.
vii Personal information by Dr. Sven Petersen, GEOMAR.
viii Personal information by Dr. Sven Petersen, GEOMAR.

indicated anonymously that multibeam and backscatter echosounders are being used to explore ferromanganese crusts, which was confirmed by a case study. The same case study states that remote acoustic sensing and ground-truthing are essential to assess the economic potential of ferromanganese crusts. Among others, they used a 3.5 kHz sub-bottom profiler seismic airgun as well as a single-/multi-beam echosounder, side-scanning sonar and shipboard remote sensing techniques to detect ferromanganese crusts.[111]

b. Vessel/platform-based noise

In general, vessel noise will mainly be in the low frequencies except closer to the vessel, where higher frequencies will also be present.[112] Converted oil drill ships are used in nodule mining.[ix] Drill ship noise radiated into the water was indicated by one source to be broadband with frequencies between 100–400 Hz and a RMS source level of 195 dB (rms) re 1µPa @ 1m[113], while another report indicated broadband source levels of 183.6 dB re 1µPa @ 1m for a dynamically-positioned oil floating production, storage and offloading facility vessel[114]. Drill ships can be heard over natural ambient noise up to 38 km away, with most of the energy under 3 kHz.[115] Dredging vessels may offer some additional insight because they involve components similar to those used for DSM (pumps, lifting system, storage, some use dynamic positioning thrusters). Dipole TOB source levels were measured at 155–183 dB re 1 μPa^2 m^2 (depending on the ship) over a frequency range of 40 Hz to 40 kHz. Overall, at higher frequencies (5–40 kHz), there were higher levels of broadband noise than would be predicted from a vessel travelling at 1.5 knots (kn), the typical dredging speed. At lower frequencies (<500 Hz), dredging vessels have comparable source levels to those published for cargo vessels travelling at 8–16 kn.[116]

Vessel dynamic positioning (DP) is mentioned in the literature and was cited by various interviewed experts to be one of the noisiest elements of DSM.[x] It will be used nearly constantly by the production vessel, by the offtake vessels when coming alongside, and by research and monitoring vessels. Large DP vessels emit low frequency broadband sound, with some tonal components ranging from 30 Hz to 3 kHz, and source levels ranging from 180 to 197 dB re 1 µPa @ 1 m with a temporal scale of hours at a time (though presumably nearly constantly active during the whole mining operation), and with the amount of thrust, and thus noise, depending on climatic and tidal conditions. Noise from DP does not vary significantly with speed as a DP system relies on all thrusters working simultaneously regardless of whether the vessel is moving or holding station.[117,118,119,120]

The source level of transiting offtake and supply vessel noise emissions[xi] can be extrapolated from the noise of an average cargo vessel moving at 16 kn, which is 192 dB re 1 µPa re 1 m over 40–100 Hz[121]. Monitoring vessels can also consist of small boats launched from the production vessel with expected source levels of max. 166 dB re 1 µPa at 1 m over 1–5 kHz.[122,123]

Midwater noise emissions from DSM activities

Riser systems, as well as motors of AUVs and ROVs, will likely be the major midwater noise sources according to the literature[124,125,126] and the stakeholder survey.

a. Riser systems

There is currently no information available on the level of noise radiated by a DSM-riser[127], likely because the systems are still under development and have yet to be tested[128]. Air-lift and hydraulic systems will be used to raise the slurry from the bottom to the surface.[xii] Noise is generated by pumps and impellers driving the suction of material through the riser pipes, as well as broadband transport sounds by the movement of sediments and ore through the pipes.[129,130,131,132] Depending on the depth of the mined deposit, additional booster pumps will likely be used along

ix https://www.oedigital.com/news/476155-drillship-to-be-converted-for-subsea-mining

x Depending on the mining cycle, offtake vessels (bulk carriers) will come around ca. every 10 days.

xi Offtake vessel: estimated to arrive every 10 days; supply vessel: estimated to arrive once a month.

xii Hydraulic lifting and air-lifting have advantages compared to mechanical lifting in terms of durability, reliability, and safety (Hong, S., Kim, H.-W., Yeu, T., Choi, J.-S., Lee, T.H., Lee, J.-K. (2019, p.109). Technologies for Safe and Sustainable Mining of Deep-Seabed Minerals. In *Environmental Issues of Deep-Sea Mining: Impacts Consequences and Policy Perspectives*. Sharma (Ed.), pp. 95-143. Springer, Switzerland.), and are likely to be the preferred technology for DSM lifting systems. Hence, only hydraulic and air-lifting will be addressed within this report.

the riser pipe. Vibrations and frictions in the release pipes may also produce broadband sounds emitted in mid-water. DSM riser noise emissions are expected to be far less significant than those of the surface production vessel/platform.[133] However, this noise source is expected to also operate constantly during the mining cycle.[xiii]

With data lacking, some noise level estimates may be derived from modelling-based dredging risers.[134] From dredging, it is known that the aggregate passing through the suction pipe and pump contributes significantly to the high-frequency noise, with coarse gravel being noisier than sand.[135] The expected main noise source from an air-lift system will be the air pump that injects compressed air midway down the riser pipe creating the lift in the pipe which brings the nodules to the surface. The source level for the subsea lift pump (50 m above bottom) was indicated with 165 dB re 1 µPa @ 1 m for the Solwara 1 project.[136]

b. Submersibles, Remotely Operated Vehicles and Autonomous Underwater Vehicles

Submersibles, Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) are used for scientific and monitoring purposes. Their noise emissions can have a maximum source level of 200 dB re 1 µPa @ 1 m at a temporal scale of hours to days.[137] Frequencies were not indicated, and direct requests to manufacturers for more detailed information on noise emissions remained unanswered. Buszman and Mironiuk (2018) measured Sound Pressure Levels of Remotely Operated Vehicles (ROVs) at a maximum of 100 dB re 1 µPa (not indicating the distance to the source).[138]

Seabed or near-seafloor noise emissions from DSM activities

Acoustic exploration, extraction and machinery as well as submersibles, ROVs and AUVs are the known noise sources related to DSM activities on or near the seafloor. Buffer stations as well as subsea lift pumps as the near-seafloor parts of the riser system are other sources of underwater noise.

a. Acoustic exploration close to the seabed

In order to attain a higher resolution, acoustic exploration may be conducted in close proximity to the seabed. Exploration for polymetallic nodules employs deep-towed multibeam echosounders with frequencies of 300 kHz, source levels of 212 dB, source direction of 0.7° vertical x 200° horizontal and pulse duration of 70/200/600 µs CW, 2/6 ms FM, deep-towed sidescan echosounders with 120 kHz, 218 dB, source direction 1.7° horizontal x 50° vertical and pulse duration up to 350 ms, as well as echosounders mounted on ROVs or AUVs.[139]

Estimations for polymetallic sulphide mining indicated that sidescan sonar from ROVs emits 100-500 Hz noise at source levels of 210-230 dB re 1 $\mu Pa^2 m^2$. The duration of the pulse is 0.05 s, with a repetition time of 1 s. The beams are directional with a sweep over horizontal and vertical angles of 60°. Maximum levels are estimated to be 200-210 dB re 1 µPa. Levels 10 times the natural background, estimated to be 75-90 dB re 1 µPa, are reached at 1.9-2.3 km distance, levels five times the background (71-86 dB re 1 µPa) occur at 2-2.4 km distance, with the background noise levels being 65-80 dB re 1 µPa attained at 2.1-2.5 km distance from the source. Seafloor visualization takes place over the mining cycle of 48 hours with a frequency of 45 cycles[xiv].[140]

The thickness of ferromanganese crusts was measured in Japanese and Chinese projects using acoustic probes with 100 kHz narrow beams close to the crust's surface with a high-power acoustic pulse.[xv]

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xiii Duration of sound emissions was estimated for a polymetallic sulphides mining operation to be 48 hours followed by a 24 hour break (*Appendix E: Memo underwater sound emission due to deep-sea mining activities* in Verichev, Stanislav & van Rhee, Cees & Jak, Robbert & Lagerveld, Sander & de Vries, Pepijn & Wit, Lynyrd & Duineveld, Gerard & Lavaleye, M. & Huisman, Maurits & Nijhof, Marten & von Benda-Beckmann, Sander & Steenbrink, Sander & Raalte, Gerard & Boomsma, Wiebe & Ortega, Aleyda & Campman, Mathijs & Haddorp, Regina. (2014). Towards Zero Impact of Deep Sea Offshore Projects. https://www.researchgate.net/publication/296706482_Towards_Zero_Impact_of_Deep_Sea_Offshore_Projects)

xiv "A mining cycle is defined as 48 hours of mining (e.g. excavation and vertical transport) and 24 hours of downtime (e.g. maintenance). 45 production cycles are necessary to complete one mining operation (one mine pit)." (Verichew, S.N., Jak, R.G., van Rhee, C., de Vries, P. et al. (2014). Towards Zero Impact of Deep Sea Offshore Projects. An assessment framework for future environmental studies of deep-sea and offshore mining projects. Final report, April 4th, 2014. https://www.researchgate.net/publication/296706482_Towards_Zero_Impact_of_Deep_Sea_Offshore_Projects)

xv Chinese project: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6806380/; Japanese project: https://ieeexplore.ieee.org/abstract/document/6335440

b. Extraction and machinery

Nodule mining will result in noise emissions as well as vibrations in the seabed[141] from the dredging process and the collector device itself. However, information on these noise sources is not yet available, even though three DSM companies[xvi] have recently been or are in the near future assessing noise emissions from prototype nodule collectors.

Data on noise emissions from the DSM machines themselves (engines, etc.) are very limited. Assumptions from the Nautilus Solwara I project indicate that the production machinery/underwater pump together would have accounted for a level of 125 dB re 1 µPa²/Hz @ 1m up to 200 Hz and a drop of 20 dB per decade from 200 Hz.[142] Extrapolation from dredging suggests that moving the seafloor mining tool (SMT) produces broadband, continuous noise with most of the energy between 10 Hz and 10 kHz. Moving takes 24 hrs every 72 hrs and there are 45 cycles of this.[143]

Data from dredging activities has been previously used to estimate noise emissions from DSM extraction.[144] Noise levels of suction activities may allow preliminary extrapolation to polymetallic nodule mining. McQueen *et al.* (2020) departed from 192 dB re 1 µPa-m as maximum broadband source levels recorded for hopper dredging with 95% of the acoustic energy contained below 2.5 kHz. The same authors noted that "dredging produces predominantly low-frequency (<1000 Hz) sounds".[145] Robinson *et al.* (2011) estimate dipole TOB levels of about 177 dB re 1 $\mu Pa^2 m^2$ "with a relatively flat spectrum from 1 to 20 kHz".[146] Specifically, at 1 kHz and 20 kHz, maximum TOB levels are 150-177 dB re 1μPa^2.[147] Those suction activities will exceed natural background levels over nearly 200 to nearly 600 km distance, at mid-frequencies of 1 kHz.[148] Other sources found maximum broadband source SPL of 189.9 dB re 1 µPa @ 1 m calculated based on third-octave band levels from 31.6 Hz to 39.8 kHz for trailing suction hopper dredgers (TSHDs).[149,150] As this little overview confirms, there are differences in which dredging noise data are collected and reported, making comparison difficult.[151] The duration of noise is expected to last 48 hrs per cycle of 72 hrs.[152]

Mining for polymetallic sulphides and ferromanganese crusts involves drilling, cutting and grinding, but available information on noise is limited. Survey input from one polymetallic sulphide project indicates that seafloor mining activities emit 156 dB re 1 µPa @ 1 m (with an accumulative noise source level of 166 dB re 1 µPa @ 1 together with the subsea lift pump).[xvii] However, other sources imply much louder noise emissions from polymetallic sulphide mining, with one estimation indicating levels of 185 dB re 1 µPa @ 1 m with a temporal scale of weeks for drilling and 195 dB re 1 µPa @ 1 m with a temporal scale of months up to years for scraping.[153] Dredging involving removal or breaking of rocks is likely to emit more noise than soft sediment dredging.[154] Cutter suction dredgers (CSDs) source levels reach a back-calculated level of 175 dB re 1 µPa @ 1 m (3 Hz – 20 kHz) while rock fracturing[155], which allows some extrapolation to both polymetallic sulphide and ferromanganese crust cutting noise[xviii]. Other data on dredging activities involving drilling and cutting suggest source levels of 130–175 dB re 1 µPa and frequencies of 3 Hz – 20 kHz.[156,157,158,159,160,161] Noise from cutting was expected to be continuous noise for 48 hrs per cycle of 72 hrs.[162]

The seafloor mining tool would use side-scanning sonar deployed from a ROV for positioning with estimated source levels of 210–230 dB re 1 µPa @ 1 m with frequencies of 100–500 kHz during the whole mining cycle of 48 hours.[163]

b. Near-seafloor part of riser systems

The subsea lift pump had a source level of 165 dB re 1 µPa @ 1 m in the Solwara 1 project.[164] Noise modelling from a deep-sea phosphate mining project proposed source levels of the operational dredge pump exceeding 175 dB re 1 µPa @ 1 m out to at least 40 kHz.[165,166] As DSM operates in considerably deeper waters than this phosphate mining project (up to over 6,000 m in the case of polymetallic nodule mining), motors used would likely be bigger and emit more noise.

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xvi DEME GSR and The Metals Company (formerly known as DeepGreen) as well as one actor operating in areas within national jurisdiction.

xvii Solwara 1 project. However, available information suggests that these tests were conducted in tanks and laboratory. Measures from tanks and laboratory will not be accurate for measurement of e.g. particle motion, which is affected by the enclosed space.

xviii The source levels in 'Solwara 1 project: Qualitative underwater noise and vibration impact assessment' for the auxiliary cutter were lower because the cutter device was smaller than a cutter dredge.

c. Submersibles, ROVs and AUVs

In addition to the mining noise, but to a much less extent, scientific sampling and monitoring via submersibles, ROVs and AUVs will add to the unnatural soundscape created by deep-sea mining. These noise emissions will likely have a maximum source level of 200 dB re 1 µPa @ 1 m at a temporal scale of hours to days.[167] Buszman and Mironiuk (2018) measured Sound Pressure Levels of ROVs at a maximum of 100 dB re 1 µPa at a frequency of 537 Hz. Above 1 kHz, there was a significant decrease in noise.[168] For the positioning tool of the ROV by sonar, the values are identical to the information given under (a) of this paragraph for seafloor visualization. However, the duration would be the full 135 days for one mining operation.[169]

In addition to the above-mentioned information on noise from specific DSM sources (and extrapolations from peer industries respectively), a report prepared by JASCO Applied Sciences Ltd. for a deep-sea dredging operation (phosphate mining) with three individual sources of noise (dredge under dynamic positioning, on-board mining plant, point source 25 m above the seafloor representing the dredge pump) estimated a fully operational root mean square source level of 195.8 dB re 1 µPa @ 1 m, with 135 dB re 1 µPa @ 5 km and 120 dB received level @ 29 km and an ensonified area of 2,100 km^2.[170]

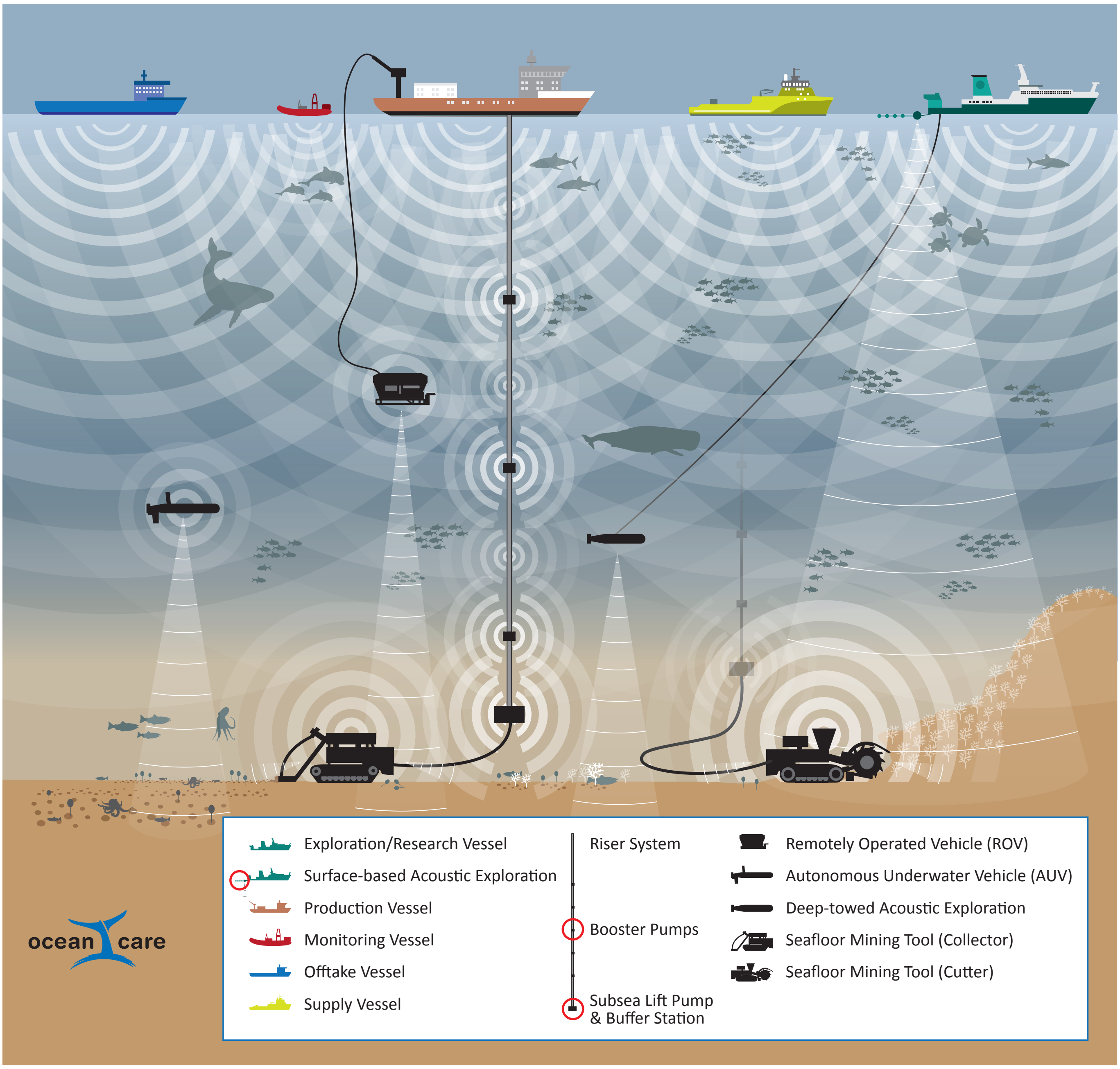

***Figure 1**. Overview of noise sources from DSM activities.*

Table 1. *Noise sources, source location and noise characteristics from DSM activities (partly extrapolated from similar activities). *underwater noise travels far beyond the source location. a) extrapolation form oil drill and dredging vessels. b) extrapolation from dredging.*

Noise source	Source location*			Source Pressure Level (SPL) in dB re 1µPa @ 1 m	Frequency	Temporal Scale	References
	Surface	Mid-water	Near-Seabed and Seabed				
Vessels/platforms							
> production vessel/platform	x			155- 197[a)]	30 Hz- 40 kHz[a)]	nearly constantly	Nedwell & Edwards. (2004)[171]; McPherson *et al.* (2016)[172]; Theobald *et al.* 2019[173]; Lin *et al.* (2019)[174]; Talisman Energy (UK) Ltd (2006)[175]; Wyatt (2008)[176]; Xodus (2014)[177]
> other vessels using DP (offset, research, monitoring)	x			180- 197	30 Hz- 3 kHz	nearly constantly when present (offset vessel ca. once every 10 days)	Talisman Energy (UK) Ltd (2006)[178]; Wyatt (2008)[179]; Xodus (2014)[180]
> other vessels transiting (offset, supply, research, monitoring)	x			192	40 - 100 Hz	Offtake vessels ca. once every 10 days; supply vessel ca. once a month	Hildebrand (2009)[181]
Acoustic exploration							
> surface based sonars	x			200- 230	3.5 kHz- 400 kHz	days up to months	Cholewiak *et al.* (2017)[182]; Rühlemann (2021)[183]; Mitchley *et al.* (2014)[184]
> near seabed sonars			x	212- 218	120- 300 kHz	unknown	Rühlemann (2021)[185]
> Seismic	x		x	max. 259 (p-p)	10 Hz to 10 kHz	days up to months	Greene *et al.* (1995)[186]; Lin *et al.* (2019)[187]; Weilgart (2010)[188]
Submersibles, ROVs, AUVs	x	x	x	100- 200	unknown	hours to days	Lin (2019)[189]; Buszman & Mironiuk (2018)[190]
Riser systems							
> material transport sounds	x	x	x	unknown	unknown	constantly during mining	
> pumps	x	x	x	165- 175	out to at least 40 kHz	constantly during mining	Solwara 1 Project[191]; McPherson *et al.* (2014)[192]
> dynamic positioning			x	unknown	unknown	unknown	

Extraction and Machinery							
extraction (dredging, drilling, scraping)			x	130- 195 b)	3 Hz- 20 kHz b)	48 hrs. per cycle of 72 hrs.	Baron *et al.* (2020)[193]; McQueen *et al.* (2020)[194]; Bassila *et al.* (2019)[195]; Broudic (2014)[196]; Greene (1987)[197]; Nedwell & Howell (2004)[198]; Reine *et al.* (2012b)[199]; Reine *et al.* (2014)[200]; Verichew *et al.* 2014)[201]; Wenger *et al.* (2017)[202]
extraction machine noise			x	125b)	up to 200 Hz b)	48 hrs. per cycle of 72 hrs.	Bassila *et al.* (2019)[203]; Verichew *et al.* (2014)[204]
seafloor visualization (sidescan sonar)			x	210- 230	100- 500 Hz	constantly during mining	Verichew *et al.* (2014)[205]
seafloor mining tool positioning (sidescan sonar)			x	210- 230	100- 500 kHz	constantly during mining	Verichew *et al.* (2014)[206]

Cumulative noise sources

Noise from DSM will add to other sources, such as commercial cargo vessels, fishing vessels, passenger ships, military activities such as applying active low- and mid-frequency sonar systems and generating explosions and detonations, as well as geophysical seismic surveys (either for oil and gas deposits under the seafloor or academic research). Moreover, other DSM activities in nearby areas must be factored in as cumulative noise sources, adding to the overall impacts from noise.

SECTION 4. THE IMPACT OF UNDERWATER NOISE FROM DSM ON MARINE LIFE

There is a great dearth of information on the impacts of underwater noise from DSM operations on most, if not all, deep-sea species. This is because a) little is known about many of these species; b) even less is known about their sound- or vibration-sensing capabilities; and c) little is known about the acoustic characteristics of DSM operations. As a result, analogous or homologous species for which some noise impact studies exist had to be identified, results extrapolated to those species found in the deep-water environment, and noise characteristics of DSM operations estimated from other industrial or shipping noise. An overview on potential impacts of noise from DSM activities on marine species is given in Table 2. While Table 2 is not exhaustive, it nevertheless serves as a guiding overview of the different impacts on some species. It can be expected that cumulative noise impacts will arise from multiple DSM activities overlapping in time and space, which may be particularly important for vicinal areas or for mobile species.

It is important to note that noise from DSM activities will affect life from the sea surface throughout the water column down to the seafloor, given the many sources of noise (Section 3) as well as the ability of sound to travel horizontally and vertically through the ocean. Also, a particular noise source may still be disturbing or harmful even if it doesn't have the same acoustic characteristics as the particular noise that has been shown to cause harmful impacts in scientific studies. We humans, for instance, respond similarly to tornado sirens as we do to fire alarms or even close thunder and lightning strikes. All put us on alarm even if they sound very differently. In the previous section, we described the different noise sources and their location in the water column. Moreover, low- and mid-frequency noise that travels far in the deep ocean will likely have impacts on marine species well beyond the source location.

Despite rising noise levels in many parts of the ocean, most deep-sea species are not usually exposed to anthropogenic noise at close range given the remoteness and the absence of human activities in the deep ocean. Thus, species in the deep sea, especially in remote areas, will most likely not be used to anthropogenic noise[207] and therefore may show more severe behavioural responses to noise. This is highly relevant as natural soundscapes are thought to play a key role in the functioning and connectivity of deep-sea species communities and ecosystems.[208] Benthic (bottom-dwelling) species may use sensitive acoustic sensory systems to detect food falls up to 100 m away[209], for instance. The larvae of hydrothermal vent fauna may locate relatively tiny active vents via their sounds.[210] As such, noise from deep-sea mining, especially if it is nearly constant over weeks, months, years or decades, will appreciably increase noise levels, and could have profound impacts on deep-sea ecosystems and their natural soundscapes.[211,212]

Habitats, where deep-seabed mining may occur, host diverse organisms that support a variety of ecosystem services which are essential to human and ocean health globally. These include links to fisheries, marine genetic resources that can be used in e.g. pharmaceuticals, nutrient and elemental cycling, detoxification, and climate regulation. Additionally, the deep sea has cultural value for many, which includes science and research, education, entertainment, aesthetic value including the arts, spiritual, emotional and historical value.[213,214] Noise has the potential to impact these services which are integral to all life, including humans.

Impacts on surface species

Noise impacts at the surface of the ocean, including from acoustic exploration methods and vessels or platforms, are concerning given the surface layer of the ocean has a relatively high abundance of life. Species in the surface layers include various plankton, squid, jellyfish, fish, dolphin, porpoise, and whale species.[xix] Many of these have direct links to fisheries and the biological pump, which is essential for sequestering carbon via marine snow (biological debris that originates from the top layers of the ocean and drifts to the seafloor, providing a primary source of energy for animals in the deep ocean) from the atmosphere and land into the depths.[215] About 90% of the carbon that gets into the twilight zone remains there, but a small percentage of it sinks down into the deep ocean. Once there, it can remain sequestered and isolated from the atmosphere for hundreds or even thousands of years. Impacts from noise could have grave implications for these processes and the life responsible for them.[216] Two of the habitats where DSM may take place, seamounts and hydrothermal vents, are known to have increased productivity at the sea surface, often leading to plankton blooms and increased biodiversity including commercial fish species.[217,218] Additionally, their use as navigational landmarks often leads to increased megafauna (whales, turtles, etc.) above seamounts.[219]

Audiograms (graphs depicting hearing sensitivity over frequencies) have been measured for at least 18 toothed whale species, with frequency sensitivity ranging from a few kHz to over 130 kHz.[220] Humans can hear from 20 Hz to 20 kHz, though the upper range is more like 15-17 kHz in adults. We hear best between 2-5 kHz.[221] Though not measured for baleen whales, modelled data predict hearing sensitivities in the ranges from tens of Hz to approximately 20 kHz.[222]

Fish mainly hear only low frequency sounds (often to no more than 800–1000 Hz), with a few exceptions, including the *clupeiformes* (herring, shad, anchovies, sardines) that can hear sounds to 3-4 kHz, and American shad and other species in the family *Alosidae* that can detect ultrasonic frequencies to over 180 kHz.[223] Otophysan fish (e.g. carps, minnows, catfish, characins) have enhanced hearing due to connections between the inner ear and swim bladder. Cartilaginous fishes (a class including elasmobranchs, such as sharks and rays) lack a swim bladder and therefore are thought to be only sensitive to the particle motion component of sound.[224] Elasmobranchs have been shown to have acoustic sensitivity thresholds between 20 Hz and 1.5 kHz.[225] Squirrelfishes, some butterflyfishes and Atlantic cod also have good hearing. Oyster toadfish, tuna, or Atlantic salmon have poor hearing.[226,227] However, hearing data exist for only ~100 of the more than 32,000 recorded fish species.[228]

In invertebrates generally, little is known about the specifics of their sound detection. Sound detection organs vary widely between species, indicating that sensitivities may also vary as they do in marine mammals and fishes.[229] Marine

xix However, for many of the areas where deep-seabed mining contract areas exist, there is not comprehensive enough knowledge of the species present to allow for informed management.

invertebrates only detect particle motion, not pressure, via sensory organs and hairs. Some crabs (e.g. male fiddler crabs (*Uca lactea*)) also detect vibrations through the substrate.[230] Vibration caused by human construction activities is hypothesized to interfere with this kind of communication.[xx] Lobsters can detect 20-300 Hz, longfin squid 30-500 Hz, oval squid 400-1,500 Hz, common octopus 400-1,000 Hz, and the common prawn 100-3,000 Hz.[231,232,233]

As the sensitivity to noise varies between species, their response to different noise sources will be specific.

Thus far, a range of impacts on surface-dwelling invertebrate species have been observed, from altered behaviour (including avoidance and distraction) to stress, injury and death. Impacts on fish are known to span from behavioural changes to reduced catch rates, stress and hearing injuries. A range of impacts have been shown for whales and dolphins ranging from altered behaviour (including less vocalisations to changed movement) to death. (Table 2)

Many commercial sonar devices operate well within cetacean hearing ranges. Even systems that are assumed to operate above these hearing ranges generate unintentional signals (i.e. side lobes) at frequencies that are audible to some species.[234] The frequencies of 1-12 kHz, often used by multibeam echosounders, are in the middle of hearing ranges of most whales, dolphins, and porpoises. It was a 12 kHz multibeam echosounder system which most likely caused the deaths through stranding of at least 75 melon-headed whales off Madagascar in 2008 (Table 2).[235] Cholewiak *et al.* (2017) found that significantly fewer (97% less) detections of beaked whales (a deep-diving cetacean taxonomic family) occurred when echosounders, operating simultaneously at the frequencies of 18, 38, 70, 120 and 200 kHz, were active (Table 2). Beaked whales thus change their behaviour in response to commercial echosounders. These echosounders can be detected at 800 m depth out to a distance of at least 1.3 km. In this study, only single-beam echosounders were used, with narrow directivity, therefore likely being less impactful compared to multibeam sonar and omni-directional sonar.[236] Lurton (2016) modelled the sound fields radiated by three different types of multibeam echosounders. For the 12 kHz type, received levels stayed above or equal to 160 dB re 1 µPa up to a range of 4 km. Sound Exposure Level (SEL) measurements (which include signal duration) were over 140 dB re 1 µPa at 2-3 km.[237] Relatively low amplitude source level (135 dB re 1 µPa @ 1m) pingers operating at frequencies from 10 to 12 kHz on gillnets in fisheries in the Pacific Ocean eliminated bycatch of beaked whales[238], indicating that the whales both detected and avoided these sounds (Table 2). Short-finned pilot whales (*Globicephala macrorhynchus*) also changed their movement when exposed to a commercial echosounder from a nearby vessel (Table 2).[239]

A case study by McQueen *et al.* (2020) on impacts of dredging noise reported the transgression of thresholds for temporary hearing threshold shifts in harbour porpoise (*Phocoena phocoena*) at distances >74 m and behavioural avoidance extending beyond 400 m from the noise source.[240] Diederichs *et al.* (2010) showed that harbour porpoises temporarily avoided a trailing suction hopper dredger engaged in sand extraction at distances of 600 m.[241] Pirotta *et al.* (2013) found that bottlenose dolphins clearly avoided dredging activity despite the area being important foraging habitat and experiencing high shipping activity year-round. The effect was consistent across years, with dolphins entirely leaving the harbour for about five weeks when dredging was especially intense. Since the dolphins were used to high levels of disturbance from shipping, the avoidance can be specifically linked to the dredging activity.[242]

The connectivity of the ocean should not be forgotten, not only horizontally but also between the surface and the seafloor. Some species use different depths of the ocean at different times in their lives. For example, larvae of many deep-sea species travel to the surface layers of the ocean to be transported by currents, which means they may be exposed to a range of different stressors during their lives.[243] Although there is no information on the effects of noise on the larvae of deep-sea fauna, some shallower-water larvae are badly impacted (e.g. body malformations and developmental delay[244]), and others are known to use sound as a guide. For example, larval coral reef fish orient towards natural shrimp or fish sounds when returning from the open ocean to find a suitable place to settle and live out their adult lives.[245] Settlement-stage coral larvae[246] and many free-swimming crustacean development stages or species[247] use sound as an orientation cue.

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Impacts on species in the deep-water column

Little is known about the species that inhabit the deep pelagic (from 200 metres depth to the deep seafloor), from the twilight zone through the midnight zone to the abyssal zone. This includes how these communities vary by region. Many of the major taxa groups found in shallower waters are also found in the deeper zones. Therefore, we have generalised for all three habitats where deep-seabed mining may occur (polymetallic nodules, polymetallic sulphides, ferromanganese crusts) by including groups of analogous or homologous taxa in Table 2 and below.

Noise sources from DSM activities in the deep-water column include the riser system, associated motors and pumps and survey equipment such as submersibles, ROVs and AUVs, although noise from impacts at other depths may also have an impact (Section 3). Thomsen *et al.* (2006) concluded that pile driving can be heard by cod and herring at distances possibly up to 80 km away[248], which begs the question of how far similar types of noise will travel in the deep ocean. In addition to other potential stressors that mining activities represent, noise in the twilight zone could impact the world's largest animal migration, namely organisms that move vertically in the water column according to daily rhythms and light levels. This is comprised of zooplankton which are known to be impacted by noise, as are fish, larger crustaceans, squid and other invertebrates. Zooplankton, small or microscopic animals which are near the base of the marine food web and upon which the whole ecosystem (whales, fish, larger invertebrates, seabirds) depends, can be killed by noise pollution such as airguns (Table 2). This could have "enormous ramifications for … ocean health".[249]

The abundance of life in the twilight zone also supports a complex food web with connections to both the deep ocean and the surface. Many top predators of ecological, commercial and nutritional importance, including tuna and trevally, dive deep into the twilight zone to feed (Table 2). The twilight zone (and rest of the deep-water column) also plays a key role in the biological pump. Noise at the surface and in the deep-water column threatens to disrupt these processes through altered behaviour and biodiversity loss.

Impacts on deep-sea benthic species

Noise sources from DSM activities on or near the deep seafloor include the riser system, survey equipment and the extraction and machinery, although noise from a particular depth may have impacts on other depths (Section 3). Deep-sea benthic and benthopelagic (just above the seafloor) species span many taxa groups including crustaceans, bryozoans, polychaetes, cephalopods, and fishes, and are expected to have varying reactions to noise (Table 2). Studies on species from shallower water imply that these could include stress, spatial avoidance, hearing damage, and injury (including severe ear damage with little recovery) for mobile species (Table 2). Sessile species, many of which may be long-lived, could experience impacts from stress, altered behaviour and injury, which, if the noise is prolonged, could result in death (Table 2). Recovery is unlikely to be possible given the slow pace of many deep-sea sessile species.[250,251]

Many deep-sea animals live within the sediment, especially in nodule fields. Both impulsive and continuous broadband noise in shallower waters was shown to repress burying and bioirrigation behavior (or water circulation within lobster burrows), and to reduce movement in the Norway lobster (Table 2). Noise thus changed the fluid and particle transport (i.e. bioturbation) that invertebrates provide, which are key to nutrient and elemental cycling on the deep seabed. The authors noted that "…exposing coastal environments to anthropogenic sound fields is likely to have much wider ecosystem consequences than are presently acknowledged.".[252] This study shows that responses to noise can be subtle and may take long periods of time to become detectable at the population or ecosystem level. Similar effects are likely to be relevant in the deep sea.

Polymetallic sulphides at hydrothermal vents

Active hydrothermal vents have lots of life, many rare species (many species comprise <5% of total abundance in samples), and high endemicity, with about 70% of species occurring only at vents.[253,254] Detailed ecological knowledge has been collected for a few charismatic species, including the identification of foundation species that play a disproportionate role in structuring and maintaining a community.[255] However, the majority of species inhabiting active vents, especially those of small sizes, are still not well understood. At inactive vents, very little is known of their fauna.[256]

Noise impacts at polymetallic sulphide sites will likely permeate through the water column affecting many species, including at the oases of life found at active vents. For instance, mussels are a foundation species at active hydrothermal vents in the Atlantic and Indian Oceans [257], and shallower-water mussel species are known to show stress and altered behaviour, with the potential for cascading ecological impacts (Table 2). Noise impacts on cephalopods can also be profound: Andre *et al.* (2011) and Solé *et al. (*2013) found that experimental exposure to low-frequency sounds resulted in "...massive acoustic trauma, not compatible with life".[258,259] As seen in Table 2, polychaetes and zooplankton such as copepods are also impacted by noise. Noise is also known to impact crustaceans such as shrimps, which form key parts of hydrothermal communities, especially in the Atlantic Ocean, as well as lobsters and crabs. Noise can also distract crustaceans, making them more vulnerable to predation, cause stress, and alter their behaviour (Table 2).

Maintaining the connections between these island-like habitats (hydrothermal vents) is essential to the survival of inhabiting species. This occurs, to a large degree, via larval transport on currents, though there are concerns that increases in noise could mask the natural noises used by larvae and fauna to find these isolated habitats[260] (Table 2). Seabed vibration, via direct contact with the seabed, needs to be considered along with waterborne particle motion and acoustic pressure when looking at the effects of noise on bottom-dwellers. For example, Roberts *et al.* (2015) found clear behavioural changes to vibration in mussels, mainly valve closure, which is an energetically and otherwise costly behaviour, disrupting breathing, heart rate and excretion. Therefore, vibration is likely to impact overall mussel health and reproduction in both individuals and whole mussel beds, which could have ecosystem-wide and commercial consequences.[261]

Polymetallic nodules in abyssal fields

Species of the Clarion-Clipperton Zone and their ecology are comparatively better known than those of the Indian Ocean and West Pacific nodule fields. However, there are still considerable gaps in characterizing the CCZ's biodiversity. Approximately 70-90% of species collected as of 2019 are new to science (and include new genera), and it is estimated that a further 25-75% of total species remain to be collected at sites already sampled.[262] This fauna spans bivalves, octopods, squid, bryozoans, many gelatinous animals such as medusa, filter-feeding jellies, ctenophores, salps, and siphonophores, as well as crustaceans, polychaetes, barnacles, copepods, zooplankton, shrimp, corals, sponges, and echinoderms, many of whose shallower-water relatives are impacted by noise (Table 2). It is important to note that many of the seafloor fauna of nodule areas are sessile, so will not be able to evade the impacts of noise. Additionally, as this is a soft sediment environment and noise is known to affect bioturbation[263], there could be impacts to the functionality of many of the fauna inhabiting the sediments, including their ability to aerate sediment, cycle nutrients and sequester carbon[264].

Ferromanganese-encrusted seamounts

Seamounts (like active vents) often support productive hotspots of biodiversity and are considered vulnerable marine ecosystems (VMEs) subject to special protection from fishing activities.[265,266,267] These habitats can be home to dense assemblages of attached suspension feeders (e.g. corals and sponges) that act as foundation species supporting a wide variety of associated fauna (e.g. crustaceans, echinoderms, molluscs, and commercially important fish)[268,269,270,271,272] and to species that are very large and long lived[273,274]. As shown in Table 2, noise is known to impact on a wide range of invertebrates, especially as many of these species are sessile and thus unable to avoid noise. Even for species that can avoid the noise, avoidance of important habitats is a serious impact in itself, both because it displaces animals from vital feeding or breeding grounds and introduces costs of energy, time, and missed opportunities.

Additionally, as the majority of the cobalt-rich seamounts and ridges in the South Atlantic and West Pacific have not been taxonomically or ecologically characterized (benthic or pelagic), many species from multiple size classes remain unknown and/or poorly understood, including their ecology, functions and how they might be impacted by noise. Similar to polymetallic sulphide sites, maintaining the connections between these island-like habitats is essential to the survival of inhabiting species. This occurs, to a large degree, via larval transport on currents, though there are concerns that increases in noise could impair larval stages or species that use sound as an orientation cue[275] (Table 2).

Table 2. *An overview of potential impacts of noise from DSM activities on marine species. *this refers to homologous taxa*

Taxa Group	Species	Noise source	Impact	Ocean Layer where related species are found*				Reference
				Sunlight Zone (0-200 metres)	Twilight Zone (200-1000 metres)	Midnight Zone (1000-3500 metres)	Abyssal Zone (3500-6500 metres)	
Fishes	Trevally (*Pseudocaranx dentex*)	Airguns	**Altered behaviour** – showed fast, burst swimming in tighter groups, alarm responses	x	x			Fewtrell & McCauley 2012[276]
	Bluefin tuna (*Thunnus thynnus*)	Vessel	**Altered behaviour** – schools lost their aggregated structure and became uncoordinated. This can affect the accuracy of migration to spawning and feeding grounds	x	x	x		Sarà *et al.* 2007[277]
	Mesopelagic fishes (herring, blue whiting, etc.)	Seismic shooting	**Altered behaviour** – avoided both horizontally (longer term) and vertically (over the shorter term)	x	x			Slotte *et al.* 2004[278]
	European Sprat (*Sprattus sprattus*)	Simulation of percussive pile driver	**Altered behaviour** – break up of fish schools and changes in depth of schools.	x				Hawkins & Popper (2014)[279]
	Atlantic mackerel (*Scomber scombrus*)	Simulation of percussive pile driver	**Altered behaviour** – break up of fish schools and changes in depth of schools.	x	x			Hawkins & Popper (2014)[280]
	Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*)	Seismic airgun shooting	**Reduced catch rates** – Trawl catches and longline catches dropped by 50% and by 21% respectively. Reductions in catch rates occurred 33 km from the seismic shooting area but the most dramatic reductions happened within the small shooting area (103 sq. km.), where trawl catches of both species and longline catches of haddock dropped by 70% and longline cod catches by 45%. Abundance and catch rates did not return to pre-survey levels during the 5-day period following the survey.	x	x			Engås *et al.* 1996[281]
	Haddock (*Melanogrammus aeglefinus*)	Seismic survey	**Reduced catch rates** – Longline catch rates fell for Greenland haddock (25% decrease). Haddock length decreased throughout the seismic survey and after, compared to the pre-exposure period, indicating larger fish were more likely to leave the area. During seismic shooting, the stomachs of longline-caught haddock were also emptier, even of non-mobile prey. Increasingly more gillnet-caught pollock had empty stomachs from before to during and after shooting. Seismic surveys could have impaired feeding or the motivation to find food in fish alarmed by the noise.	x	x			Løkkeborg *et al.* 2012[282]
	Atlantic cod (*Gadus morhua*)	Seismic survey	**Reduced catch rates** – longline catch rates dropped by 55-80% for longlines within the seismic survey area. Bycatches of cod in shrimp trawls dropped by 80-85% during seismic shooting.	x	x			Løkkeborg 1991[283]; Løkkeborg & Soldal 1993[284]
	Atlantic cod (*Gadus morhua*)	Shipping noise	**Developmental effects and altered behaviour** – Larvae had poorer body condition and a greater risk of being caught by predators.	x	x			Nedelec *et al.* 2015[285]
	Cod (*Gadus morhua*)	100-1000 Hz linear sweep	**Stress, injury** – higher content of cortisol in eggs significantly suppressed the fertilization rate and cod spawning performance. This translates to a loss of about 300,000 individuals in a hatchery.	x	x			Sierra-Flores et al 2015[286]
	Cod (*Gadus morhua*)	Boat noise (82-92 dB re 1 µPa/Hz)	**Altered behaviour** – reacted to an approaching trawler, perhaps because of the low background noise (65 dB re 1 µPa/Hz) in the area.	x	x			Engås *et al.* 1998[287]
	Cod (*Gadus morhua*)	Pile driving	**Altered behaviour** – "froze" at the beginning and end of noise . Likely to be heard by cod up to 80 km away.	x	x			Mueller-Blenkle *et al.* 2010[288]; Thomsen *et al.* 2006[289]
	Pollock (*Pollachius virens*)	Seismic survey	**Altered behaviour** – reduction in density during and after the seismic survey , with especially larger fish moving out of the seismic survey area.	x				Løkkeborg *et al.* 2012[290]

Fishes	Greenland halibut *(Reinhardtius hippoglossoides)*	Seismic survey	**Reduced catch rates** – longline catch rates fell for Greenland halibut (16% decrease)	x	x	x		Løkkeborg *et al.* 2012[291]
	Pink snapper (*Chrysophrys auratus*)	Seismic airgun shooting	**Injury** – extensive ear damage, with no recovery after 58 days post-exposure	x	x			McCauley *et al.* 2003[292]
	Snapper (*Pagrus auratus*)	Noisy tank	**Injury** – juveniles had significant hearing loss of 10 dB. Indicating this farm-raised fish can hear reef sounds at half the distance (18 km) that wild fish could (36 km).	x				Caiger et al 2012[293]
Cetaceans	Harbor porpoise (*Phocoena phocoena*)	Dredging	**Altered behaviour** – avoidance extending >400m from noise source	x				McQueen *et al.* 2020[294]
	Cuvier's (*Ziphius cavirostris*), Gervais' (*Mesoplodon europaeus*), True's (*M. mirus*), and Sowerby's (*M. bidens*) beaked whales	Single-beam echosounders operating simultaneously at the frequencies of 18, 38, 70, 120 and 200 kHz	**Altered behaviour** – displacement/avoidance/fewer vocalisations/less feeding	x	x	x		Cholewiak *et al.* 2017[295]
	Beaked whales: Cuvier's (*Ziphius cavirostris*), Hubb's (*Mesoplodon carlhubbsi)*, Stejneger's (*M. stejnegeri*), Baird's (*Berardius bairdii*), *Mesoplodon* spp., unidentified ziphiids	Low amplitude (135 dB re 1 µPa SL) pingers operating at frequencies from 10 to 12 kHz on gillnets	**Altered behaviour** – eliminated bycatch indicating avoidance of sounds	x	x	x		Caretta *et al.* 2008[296]
	Short-finned pilot whales (*Globicephala macrorhynchus*)	Commercial echosounder	**Altered behaviour** – changed their movement when exposed	x	x			Quick *et al.* 2016[297]
	Melon-headed whales (*Peponocephala electra*)	12 kHz multibeam echosounder system	**Death** through stranding	x	x	x		Southall *et al.* 2013[298]
	Bowhead whales (*Balaena mysticetus)*	Recorded drillship and dredging noise (around 115 dB re 1 µPa broadband or about 110 dB in one third octave band (20-30 dB above ambient noise), which equates to levels 3-11 km from a drillship and dredge)	**Altered behaviour** – calling less, ceasing to feed, and possibly changing their diving and breathing cycles	x	x			Richardson *et al.* 1990[299]
Cephalopods	Squid (*Sepioteuthis australis*)	Airguns	**Altered behaviour** – alarm responses, avoidance, aggression	x	x	x	x	Fewtrell & McCauley 2012[300]
	Squid (*Loligo vulgaris and Illex coindetii*)), cuttlefish (*Sepia officinalis*), Octopus (*Octopus vulgaris)*	Low-frequency sound	**Injury, Death** – massive, permanent acoustic trauma to statocycsts and neurons, not compatible with life	x	x	x	x	André *et al.* 2011[301]; Solé *et al.* 2013a[302], b[303], 2017[304]
	Giant squid *(Architeuthis dux)*	Seismic surveys	**Injury, Death** – mass-stranded, some live, showing massive internal injuries	x	x			Guerra *et al.* 2004[305], 2011[306]
Jellyfishes	Fried egg jellyfish (*Phacellophora camtschatica*) and Barrel jellyfish (*Rhizostoma pulmo*)	Low-frequency noise	**Injury** – massive acoustic trauma to statocyst structures. These injuries increased over time and could prevent or hinder orientation.	x	x	x	x	Sole *et al.* 2016[307]
Polychaetes	Polychaetes (*Pomatoceros* sp.)	Shipping noise through a vessel's hull in port	**Altered behaviour** – enhanced the settlement and growth	x	x	x	x	Stanley *et al.* 2014[308]

Crustaceans	Zooplankton: Copepods (*Temora turbinata, Acartia tranteri, Oithona* spp.), cladoceran (*Evadane* spp.), krill (*Nyctiphanes australis*)	Airguns	**Death** – a 2-3-fold increase in dead zooplankton overall	x	x	x	x	McCauley *et al.* 2017[309]
	Crab (*Coenobita clypeatus*)	Boat motor	**Altered behaviour** – distraction making them more vulnerable to predators	x	x	x	x	Chan *et al.* 2010[310]
	Hermit crab (*Pagurus bernhardus*)	Ship noise	**Altered behaviour** – changes in grouping or social behaviour	x	x	x	x	Tidau & Briffa 2019[311]
	Hermit crab (*Pagurus bernhardus*)	Anthropogenic noise	**Altered behaviour** – distraction leading to interference with shell selection. This is a critical process as individuals in poor shells suffer lower reproductive success and higher mortality.	x	x	x	x	Walsh *et al.* 2017[312]
	Crab (*Carcinus maenas*)	Ship noise	**Stress, altered behaviour** – a higher metabolic rate which can indicate higher cardiovascular activity. Feeding interupted and more exposed to predation.	x	x	x	x	Wale *et al.* 2013[313]
	Crab (*Austrohelice crassa and Hemigrapsus crenulatus*)	Wind and tidal turbines	**Altered behaviour** – larval settlement and delayed metamorphosis due to masking of important natural acoustic settlement cues.	x	x	x	x	Pine *et al.* 2012[314]
	Common prawn (*Palaemon serratus*)	Boat noise	**Stress, Injury** – physiological signs of stress, as well as DNA fragmentation	x	x	x	x	Filiciotto *et al.* 2016[315]
	Brown shrimp (*Crangon crangon)*	Noise (reared in louder tanks)	**Stress, Injury, Death** – stress, increased metabolism, decreased growth, food consumption, lower reproductive rates, fewer egg-bearing females, and increased mortality because of a higher incidence of disease and cannibalism	x	x	x	x	Lagardere 1982[316]; Regnault & Lagardere 1983[317]
	Rock lobster (*Jasus edwardsii*)	Seismic surveys	**Altered behaviour** – impaired complex reflexes which can compromise their anti-predator defenses.	x	x	x	x	Day *et al.* 2019[318]
	Rock lobster (*Jasus edwardsii*)	Seismic airgun noise	**Altered physiology** – chronically reduced immune competency and impaired their nutritional condition 4 months after the noise had stopped.	x	x	x	x	Fitzgibbon *et al.* 2017[319]
	Lobster (*Palinurus elephas*)	Boat noise (82-92 dB re 1 µPa/Hz)	**Stress, Altered behaviour** – significantly increased movement and biochemical indicators of stress, which implied immune depletion and an increased risk of infection Also abandoned their group formation, a common reaction to imminent threat.	x	x	x	x	Filiciotto *et al.* 2014[320]
	Lobster (*Homarus americanus*)	Airguns	**Stress, Altered behaviour** – Increase in feeding several weeks after noise, an indication of stress via increased metabolic demand.	x	x	x	x	Payne *et al.* 2008[321]
	Norway lobster (*Nephrops norvegicus*)	Impulsive and continuous broadband noise	**Altered behaviour** – repressed burying and bioirrigation behavior (or water circulation within lobster burrows), and reduced movement. Noise thus changed the fluid and particle transport that invertebrates provide, which are key to nutrient cycling on the seabed.	x	x	x	x	Solan *et al.* 2016[322]

Bivalves	Barnacle	Low-frequency sound	**Altered behaviour** – larvae were inhibited from metamorphosing and settling. Could not perform the important ecological service of water filtration.	x	x	x	x	Branscomb & Rittschof 1984[323]
	Mussel (*Perna canaliculus and Mytilus edulis*)	Ship noise	**Altered behaviour** – Larvae settled 40% faster and decreased the size of the settler with "potential cascading ecological impacts"	x	x	x	x	Wilkens *et al.* 2012[324]; Jolivet *et al.* 2016[325]
	Blue mussels (*Mytilus edulis*)	Ship noise	**Injury, altered physiology and behaviour** – Changes in DNA integrity, oxidative stress, reduced oxygen consumption, reduced filtration	x	x	x	x	Wale *et al.* 2016[326]; Wale *et al.* 2019[327]
	Blue mussels (*Mytilus edulis*)	Pile driving noise and ship noise	**Stress, altered behaviour** – higher metabolic demand, increased feeding, as well as reduced growth, reproduction, and immune response	x	x	x	x	Spiga *et al.* 2016[328]; Wale *et al.* 2016[329]
	New Zealand Scallop (*Pecten novaezelandiae*) larvae	Low frequency sounds similar to seismic surveys	**Injury** – body malformations and developmental delays	x	x	x	x	De Soto *et al.* 2013[330]
	Giant clams (*Tridacna maxima*)	Motorboat noise (particle motion) in the presence of water flow	**Altered behaviour** – delayed valve closure, an anti-predator response	x	x	x	x	Doyle *et al.* 2020[331]
Tunicates	Tunicate larvae	Vessel generator noise	**Altered behaviour** – increased rates of settlement, metamorphosis, and survival	x	x	x	x	McDonald *et al.* 2014[332]
Bryozoans	Brown bryozoan larvae (*Bugula neritina*)	Boat noise	**Altered behaviour** – Decreased swimming activity when compared with reef noises, showing this species could distinguish between the two. Enhanced the settlement and growth of biofouling organisms including brown bryozoans.	x	x	x	x	Stocks *et al.* 2012[333]; Stanley *et al.* 2014[334]

Community-level impacts

Species interact with each other in their ecological community via competition, mutualism, predator-prey interactions, etc. What impacts one species will likely have domino or "knock-on" effects across the marine food web. Noise can also affect predator-prey relationships, in some cases making prey more available to predators or the opposite. "Keystone species" are species (mostly of high trophic status) whose activities exert an oversized influence on the patterns of species occurrence, distribution, and density in a community. "Ecosystem engineers" are organisms that directly or indirectly change the availability of resources to other species by causing physical state changes in living or non-living materials.[335] Noise impacting either keystone species or ecosystem engineers will likely affect the community more widely. Additionally, given the connectedness of the surface ocean to the deep ocean, as well as horizontally, impacts could be more pervasive. These sorts of broader-scale interactions are often ignored by environmental impact assessments but can have large-scale implications for the environment. While often very difficult to assess, they nevertheless need to be addressed as they are essential for understanding the true impact on the environment.

Cumulative and synergistic impacts

Human activities impact natural systems in many ways, yet the cumulative effect of multiple stressors on ecological communities, and how these stressors may interact, remains largely unknown. Crain *et al.* (2008) found that, in marine and coastal systems, cumulative effects in individual studies were either the sum of the effects of each stressor or additive (26%), greater than the sum of the effects of each stressor or multiplicative/synergistic (36%), or less than the sum of the effects of each stressor or mitigative/antagonistic (38%). The overall interaction effect across all studies was synergistic. Adding a third stressor changed interaction effects significantly in two thirds of all cases and doubled the number of synergistic interactions. Since most studies were performed in laboratories where stressor effects can be carefully isolated, these three-stressor results suggest that synergies may be quite common in nature where more than two stressors almost always coexist.[336]

The threats that marine animals, including in the deep sea, are confronted with, such as DSM, fisheries bycatch, habitat degradation, chemical pollution, marine litter, vessel strikes, and climate breakdown, do not often occur in isolation. Such stressors may interact cumulatively or synergistically.[337,338,339] Anthropogenic noise could interact with marine mammal bycatch or ship collisions by preventing animals from sensing fishing gear or oncoming vessels (through either hearing damage or masking), making them more vulnerable to injury or death. In deep-sea mining, animals are faced with several stressors (habitat destruction, plumes, chemical pollution, light pollution, noise). All of these may interact to make the effect greater than the sum of the impacts of each individual stressor. While an animal may be able to cope with one stressor from DSM, it could quickly be overwhelmed by facing many at once. In fact, synergistic impacts have already been suggested for dredging-related stressors, where the effects of contaminated sediment had significantly higher effect sizes than studies on clean sediment alone or noise.[340] Giant clams exposed to a combination of: a) changes in particle motion through motor boat noise, and b) increased water flow, delayed their valve closure, an anti-predator response.[341] Multiple sources of noise could also interact cumulatively or synergistically, as when several different noise sources produce a confusing sound field. Studies on fish have demonstrated that "... failure to properly account for interactions occurring between stressors can lead to substantial underestimation of stressor effects, particularly as stressor intensity rises".[342]

SECTION 5. LEGAL AND POLICY FRAMEWORKS ON UNDERWATER NOISE

This section gives an overview of the recognition of anthropogenic underwater noise as a significant component of marine pollution in important international fora, and of relevant international regulations on underwater noise emissions from human activities. This is however not exhaustive, but aims, as an initial overview, to assist decision-makers in approaching stringent and robust underwater noise regulations for deep-sea mining in line with best available practice.

The United Nations and its entities

The United Nations (UN) has been essential in recognizing the potential adverse effects of underwater noise and in encouraging countries to address such impacts. In both its resolutions on Sustainable Fisheries (e.g. A/RES/75/89) and on Oceans and the Law of the Sea (e.g. A/RES/75/239), the international community took note of the potential impact of ocean noise on marine species and highlighted the importance of further exploring the impacts on fish stocks and fisheries (see also UNGA resolutions from 2005[xxi], 2006[xxii], 2007[xxiii], 2010[xxiv], 2011[xxv], 2012[xxvi], and 2013[xxvii]). In 2015, the General Assembly adopted resolution A/RES/70/235 and drafted two important operative paragraphs on ocean noise, *inter alia,* highlighting the potential significant impacts of noise on marine resources and calling "upon States and competent *international organizations* [emphasis added] to cooperate and coordinate their research efforts in this regard so as to reduce these impacts and preserve the integrity of the whole marine ecosystem"[xxviii].

The United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea – a forum established in 1999 with a view to identifying areas of importance regarding ocean affairs and the law of the sea – dedicated its nineteenth meeting in 2018 to anthropogenic underwater noise. Delegates *inter alia* discussed the need to fill existing knowledge gaps, but also addressed potential management approaches as well as the transboundary nature of underwater noise and its pollutant characteristic. Delegations raised the necessity to also consider the socioeconomic impacts associated with anthropogenic underwater noise, including on the fishing sector, which remains a critical avenue for food security in many countries.[343]

The United Nations Convention on the Law of the Sea of 10 December 1982 (UNCLOS) defines "pollution of the marine environment" in Art. 1 para. 1 (4). The definition encompasses "noise" within *introduction of energy into the marine environment*.[344,345,346] State Parties to UNCLOS have a general obligation to protect and preserve the marine environment (Part XII UNCLOS). Under Art. 194(1), States are to take measures necessary to prevent, reduce and control pollution of the marine environment from any source, including noise. This includes necessary measures to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life under Art. 194(5). Necessary measures are to be taken in accordance with the Convention with respect to activities in the Area to ensure effective protection of the marine environment from harmful effects which may arise from such activities under Art. 145 UNCLOS.

In 2017, with the adoption of Resolution 72/249, the United Nations General Assembly decided to convene an Intergovernmental Conference (IGC) with a view to develop a new international legally binding instrument under the United Nations Convention on the Law of the Sea (UNCLOS) on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ Treaty). This ongoing process represents an important opportunity to advance efforts to manage (and mitigate) pollution in areas that transcend any national jurisdiction. For example, in Part IV of the Draft Agreement[xxix], delegations are currently addressing environmental impact assessments as a tool for assessing the potential effects of planned activities and it is an important opportunity to manage highly transboundary forms of pollution, such as underwater noise. The BBNJ will be relevant to all activities conducted in the high seas.

In 2019, the United Nations Environment Programme (UNEP) undertook a rigorous and comprehensive assessment of the current state of the environment. In accordance with the theme "Healthy Planet, Healthy People", the Assessment set out to assist Member States and relevant entities in achieving internationally agreed environmental objectives (UN Environment (GEO-6) Report Summary, 2019, 04). Notably, the Report acknowledged the increasing concern over the potential impact of anthropogenic underwater noise generated by seismic surveys, shipping, offshore construction,

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xxi See para. 84 of Resolution A/Res/60/30
xxii See para. 107 of Resolution A/Res/61/222
xxiii See para. 120 of Resolution A/Res/62/215
xxiv See para. 186 of Resolution A/Res/65/37
xxv See para. 185 of Resolution A/66/231
xxvi See para. 205 of Resolution A/RES/67/78
xxvii See para. 153 of Resolution A/RES/68/71
xxviii UNGA A/RES/70/235: 2015, operative para. 242 & 246
xxix Other parts of the Draft Agreement are also relevant, including Part III on Area-Based Management Tools, including Marine Protected Areas. Transboundary pollutants (including underwater noise pollution) play an important role in identifying, designating, and managing conservations efforts in marine protected areas. For more details on this matter see Reeve, L. (2018). *Managing ocean noise pollution through the new BBNJ Instrument under the UN Convention on the Law of the Sea*. In: Guide to the Navigation of Marine Biodiversity beyond National Jurisdiction. Toledo, A. de P., Tassin V.J.M. (Eds.), pp. 455-487.

and military operations, if not regulated (UN Environment (GEO-6) Report, 2019, 180 & 190). More recently, in 2021, the UN released the Second World Ocean Assessment (WOA II) and specifically noted with concern the increase of anthropogenic underwater noise pollution in the ocean. In this respect, it is worth highlighting that WOA II also refers to the potential economic losses for concerned fisheries during seismic surveys, generally noting that "[t]he impacts of noise on species that are of particular social, economic and cultural relevance may have socioeconomic effects on coastal communities, in particular if they alter the availability of commercially … important marine species" (WOA II, 2021, 308).

Food and Agriculture Organisation

Considering the potential impacts of underwater noise on fisheries, international bodies entrusted with administering fisheries have acknowledged the potential threats by such a pollutant. In 2018, the Committee on Fisheries of the Food and Agriculture Organisation (COFI) 'noted with concern' the issue of underwater noise and advised the FAO to further consider its impacts, including impacts that are socioeconomic in nature.[xxx]

The matter of underwater noise was addressed in the joint workshop between the General Fisheries Commission for the Mediterranean (GFCM), a regional fisheries management organization (RFMO)[xxxi], and OceanCare in February 2019. The workshop culminated in recommendations to address anthropogenic underwater noise, which *inter alia* include:

- The coordination with relevant international organizations and fora (i.e. CMS, CBD, IMO) to ensure coherence at the regional level in the implementation of existing policies addressing the impacts of anthropogenic underwater noise on marine biodiversity;
- The application of multi-sectoral Strategic Environmental Assessments (SEAs) and Environmental Impact Assessments (EIAs) so that the impacts of anthropogenic underwater noise, including cumulative and synergistic impacts on marine biodiversity, be adequately addressed and monitored;
- To conduct a study on the impacts of anthropogenic underwater noise on fish stocks and fishing catch rates, as well as associated socio-economic effects.[xxxii]

In the context of the programme of work adopted for the period of 2019-2021 at the 43rd session of the GFCM in 2019, the need to conduct "a study on the impact of anthropogenic underwater noise on fish stocks and fishing catch rates, as well as associated socio-economic effects" was also reiterated.[xxxiii]

International Maritime Organization

The International Maritime Organization's (IMO) work on anthropogenic underwater noise emitted by shipping first received attention in 2004. Due to increasing awareness of the impact of continuous (ambient) noise emitted during shipping, the IMO's Marine Environment Protection Committee (MEPC) developed non-mandatory technical guidelines in 2008. In 2014, these guidelines, formally coined the Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life, were approved, introducing general advice to designers, shipbuilders and operators on how to reduce underwater noise.[xxxiv]

In 2020 the 75th session of the MEPC set out to advance international coordination and collaboration on the reduction of underwater noise generated by shipping. And at the 76th session (2021), a "Review of the 2014 Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life and identification of next steps" until 2023 was agreed.[xxxv]

xxx See para. 108 of the Report of the Thirty-third Session of the Committee on Fisheries, 2018. Available at: http://www.fao.org/3/ca5184en/ca5184en.pdf
xxxi established under the provisions of Article XIV of the Constitution of the Food and Agriculture Organisation
xxxii See Report of the Joint GFCM/OceanCare Workshop on anthropogenic underwater noise and impacts on fish, invertebrates and fish resources, page 7, available at: http://www.fao.org/gfcm/technical-meetings/detail/en/c/1194253/
xxxiii See Report of the forty-third session (2019), page 19, available at: http://www.fao.org/3/ca8379en/ca8379en.pdf
xxxiv See IMO MEPC.1/Circ. 833, 2014 for a more detailed reading on the IMO Guidelines on the reduction of underwater noise from commercial shipping.
xxxv MEPC 76-WP.1- Draft Report of the Marine Environment Protection Committee on its Seventy-Sixth Session (Secretariat)

Convention on Environmental Impact Assessment in a Transboundary Context

The Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention), a United Nations Economic Commission for Europe (UNECE) convention, sets out the obligation of State Parties to assess the environmental impact of activities and to consult one another on all projects that are likely to have a transboundary impact. This is particularly important in the case of anthropogenic underwater noise as the impact of noise-generating activities can be registered far from the point of origin.[xxxvi] Specifically, the Convention notes that "Parties shall … take all appropriate and effective measures to prevent, reduce and control significant adverse transboundary environmental impact from proposed activities." (Art 2(1)). More so, "[e]ach Party shall take the necessary legal, administrative or other measures to implement the provisions of this Convention, including, with respect to proposed activities listed in Appendix I that are *likely to cause significant adverse transboundary impact*, the establishment of an environmental impact assessment procedure that permits public participation and preparation of the environmental impact assessment documentation described in Appendix II." (Art 2(2))[emphasis added].

Ocean Noise and the Global 2030 Agenda for Sustainable Development

Anthropogenic underwater noise and its impacts are linked to the Sustainable Development Goals (SDGs) in a number of different ways. A failure to adequately address anthropogenic ocean noise, as one of the most far-reaching and cumulative sources of pollution with significant impacts on marine life, would prevent achieving SDG 14 on conserving and sustainably using the oceans, seas and marine resources for sustainable development. It is worth emphasising the nexus between the propagation of underwater noise and food security, as well as human livelihoods. An estimated 56.6 million people around the world depend on the fisheries and aquaculture sector as a source of income and to secure their livelihood.[xxxvii] The continued propagation of underwater noise and the subsequent impact on seafood is a danger to food security and the successful attainment of SDG 1 on ending poverty as well as SDG 2 on ending hunger and achieving food security. Conserving biodiversity for sustainable development will hence continue to remain difficult if the propagation of underwater noise persists or increases.

International Seabed Authority

The International Seabed Authority (ISA) is an autonomous international organization established under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea (1994 Agreement).[xxxviii] The obligation of the International Seabed Authority (ISA) to ensure effective protection for the marine environment from harmful effects of activities in the Area and adoption of respective rules, regulations and procedures is enshrined in Art. 145 UNCLOS. ISA's binding regulations on prospecting and exploration for the three mineral types (polymetallic nodules, polymetallic sulphides, cobalt-rich ferromanganese crusts)[xxxix] do not include specific provisions on underwater noise. The corresponding, non-binding *Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area*[xl] list noise in the context of environmental baseline studies and noise pollution exceeding baseline levels in depths relevant to affect marine life (e.g. from grinding up mineral deposits). *Annex I Explanatory commentary* includes para. 43 with some specific recommendations on how to assess background noise levels and to estimate the depth of the Sound Fixing And Ranging (SOFAR) channel. Para. 51 acknowledges: "Other information especially relevant to marine-mammal impacts includes studies of the ambient noise throughout the water column and the levels of noise generation expected to result from mining activities." However, these recommendations are not fit for purpose. For example, they do not require disclosure of frequencies emitted, and do not specifically require surveys of marine mammals and other marine species, including identifying specific species that may be present and at what times and depths, nor their susceptibility to noise. Noteworthy, the activities listed under *A. Activities not requiring environmental impact assessment during exploration* include acoustic exploration techniques that are known to emit underwater noise harmful to marine species.

xxxvi Although some areas with potential for DSM may be located far away from land masses, noise emitted in international waters would likely penetrate Exclusive Economic Zones (EEZ) of coastal states. The extreme distances that underwater noise can travel was already shown in a study of 1991 (https://gizmodo.com/a-forgotten-underwater-sound-experiment-almost-changed-1820659353).

xxxvii See Ocean Noise and the Sustainable Development Goals, available at: https://www.oceancare.org/wp-content/uploads/2017/12/Noise_neutral_2018_web.pdf

xxxviii https://www.isa.org.jm/about-isa

xxxix ISBA/19/C/17 Annex; ISBA/16/A/12/Rev.1 Annex; ISBA/18/A/11 Annex

xl ISBA/25/LTC/6/Rev.1. https://isa.org.jm/node/19270

The *Environmental Management Plan for the Clarion-Clipperton Zone*[xli] has no provisions on underwater noise, and noise is mentioned only once in the *Guidance to facilitate the development of Regional Environmental Management Plans (REMPs)*[xlii] as an impact on pelagic species from mining.

There was some discussion about noise within the *Workshop on the Regional Environmental Management Plan for the Area of the Northern Mid-Atlantic Ridge* (2019)[xliii]: Noise pollution was mentioned as a main effect of mining, especially on the seafloor and at the sea surface. It was also acknowledged that "… the relationships between anthropogenic stressors and biotic/abiotic components as well as ecological factors and responses (i.e. negative or positive response), are yet unknown for specific deep-sea organisms and/or particular taxa found in the MAR habitats.". Pressure of mining noise from polymetallic sulphide mining as well as sound emissions from mining vessels and shipping was identified to have impacts on several ecosystem components. Responses to noise and vibration were inferred from shallow-water studies, while studies pertaining to the relevant habitats are lacking. Moreover, the potential entering of noise emissions from pumps on the riser pipe system into the SOFAR channel, where sound travels large distances very efficiently, was mentioned. It was also acknowledged that noise emissions from mining activities would spread far beyond the mined areas.

The Legal and Technical Commission (LTC) of ISA is currently developing regulations, standards and guidelines for the exploitation of mineral resources in the Area.[xliv] Again, no binding specific provisions on noise and noise impact assessment are included in the draft texts at this stage. However, the *Draft Guidelines for environmental impact assessment process*[xlv] include some guidance on the measurement of the magnitude of impacts from noise, but as guidelines they are not binding. *Appendix I: Information available from selected peer industries relevant to EIA for deep-sea mining (courtesy BBJ Consultants)* names noise as an impact to consider from various sources (vessel or platform operations, transport of materials through the water column, return-water discharge, extraction of materials) and ecosystems affected as well as some (limited) information on assessment of impacts from 'peer industries' (oil & gas, dredging, seafloor massive sulphide mining (Solwara 1 project)) and 'academia'. It is noteworthy that state of the art EIA provisions on noise from MEAs listed above were not included in this appendix.

The *Draft Guidelines for the establishment of baseline environmental data*[xlvi] state that noise is emitted from numerous sources both in the water column and on the ocean surface. Again, as guidelines they are not binding. The Guidelines name some (incomplete) impacts on marine organisms and give (limited) guidance on noise characteristics to be measured. Moreover, the potential impacts of noise on routes of migratory species are mentioned. It is noteworthy that several acoustic exploration techniques are mentioned in these guidelines, too, without addressing the potential harmful impacts of these techniques on marine life. Marine mammal or larger ecosystem surveys are not specifically required and nor is the assessment of frequencies and source levels emitted.

The *Draft Guidelines for the preparation of an environmental impact statement*[xlvii] (again, not binding) contain guidance on the inclusion and description of noise in the environmental impact statement (EIS), on impacts of noise on the food chain and prey availability, as well as on the description of noise impacts at different water depths (surface, water column, and sea floor), but again do not specifically require marine mammal surveys or frequencies emitted. The *Draft Guidelines for the preparation of environmental management and monitoring plans*[xlviii] name noise as a monitoring criterion for impact reference zones (IRZs) and preservation reference zones (PRZs). The *Draft Guidelines on tools and techniques for hazard identification and risk assessments*[xlix] name noise affecting the food chain and the availability of prey as a hazard to be identified within the risk analysis process. Neither of the latter documents are binding.

xli ISBA/17/LTC/7
xlii https://www.isa.org.jm/files/files/documents/remp_guidance_.pdf
xliii https://www.isa.org.jm/files/files/documents/Evora%20Workshop_3.pdf
xliv *Draft regulations on exploitation of mineral resources in the Area (ISBA/25/C/WP.1); Draft Standards and Guidelines: https://isa.org.jm/mining-code/standards-and-guidelines*
xlv Draft Standard and Guidelines for environmental impact assessment process
Developed by the Legal and Technical Commission: https://isa.org.jm/files/files/documents/Standard_and_Guidelines_for_environmental_impact_assessment-rev1.pdf
xlvi https://isa.org.jm/files/files/documents/expected_scope_and_standard_of_baseline_data_collection.pdf
xlvii https://isa.org.jm/files/files/documents/preparation_of_an_environmental_impact_statement.pdf
xlviii https://isa.org.jm/files/files/documents/environmental_management_monitoring_plans.pdf
xlix https://isa.org.jm/files/files/documents/tools_and_techniques_for_hazard_identification_and_risk_assessments.pdf

Regional and international multilateral environmental agreements

Over the past decades, countries have come together to cooperate on a broad range of global environmental challenges, including the loss of biodiversity, adverse impacts caused by climate breakdown, and marine pollution. With respect to anthropogenic underwater noise, the international community, through declarations, resolutions and other instruments, has considered commitments that set out actions to address impacts from a broad range of anthropogenic activities.[l] Such efforts build an important pillar in international efforts to tackle the consequences of ocean noise pollution.

Convention on Biological Diversity

Advances made within the Convention on Biological Diversity (CBD) have acknowledged and addressed the threat of ocean noise pollution. The Subsidiary Body on Scientific, Technical and Technological Advice of the CBD has addressed the issue of underwater noise and its impacts in its preparation for the CoP and made note of the CBD report on the impacts of anthropogenic underwater noise on marine and coastal biodiversity and habitats.[li] The 15th CoP to the CBD, postponed to 2022, is a further useful example.

The Convention on the Conservation of Migratory Species of Wild Animals family

a) Convention on the Conservation of Migratory Species of Wild Animals

The Convention on the Conservation of Migratory Species of Wild Animals (CMS) acknowledged the threat posed by anthropogenic underwater noise and took legislative and regulatory measures. At the 12th Conference of the Parties (CoP) in 2017, State Parties to CMS recognized anthropogenic underwater noise as a form of pollution and specifically noted that "[w]ildlife exposed to elevated or prolonged anthropogenic noise can suffer direct injury and/or temporary or permanent threshold shifts … These impacts are experienced by a wide range of species including fish, crustaceans …" (UNEP/CMS/Resolution 12.14/Annex, 2017, 8). In addition, State Parties adopted the *CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities* (*CMS Family Guidelines*) to assist in determining the impact on wildlife. The *CMS Family Guidelines inter alia* include detailed provisions on description of the area where the activity takes place, description of equipment and activity, modelling of noise propagation loss, species impact, mitigating and monitoring plans, reporting plans, and consultation and independent review.

The 13th CoP endorsed a process with a view to developing guidance for the application of Best Available Technology (BAT) and Best Environmental Practice (BEP) for shipping, seismic airgun surveying, and pile driving activities.[lii]

b) Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area, and Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas

The consequences of ocean noise pollution are also under discussion within the ongoing work undertaken within the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS). Since 2004, ACCOBAMS has adopted a range of resolutions aimed at assessing and addressing the impact of anthropogenic underwater noise on marine mammals.[liii] At the 7th Meeting of the Parties (MoP) held in November 2019, Parties adopted Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area in Annex 2 of Resolution 7.13.[liv]

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l It is important to take note that while not mentioned in the course of this report, other conventions or fora are also relevant. Of special relevance is for example the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention). The Convention established a series of rights for both individuals and associations, including the right to access to environmental information (Article 4) and the right to participate in environmental decision-making (Article 6). A right to review and challenge environmental decisions that have been made without granting access to environmental information is also established by the Convention (Article 9).

li See "Progress Report on Ecologically or Biologically Significant Marine Areas" (CBD/SBSTTA/24/6) for a more general overview of the work of the CBD in respect to underwater noise, available at: https://www.cbd.int/doc/c/8040/a363/f73193dc9717705faa1ffe10/sbstta-24-06-en.pdf
It is specifically worth noting, that in 2012 the CBD introduced the report "Synthesis on the Impacts of Underwater Noise on Marine and Coastal Biodiversity and Habitats" (UNEP/CBD/SBSTTA/16/INF/12), available at: https://www.cbd.int/doc/meetings/sbstta/sbstta-16/information/sbstta-16-inf-12-en.pdf. A more recent version of the report was produced by Simon Harding (see UNEP/CBD/SBSTTA/INF/8) in 2016 and is available at: https://www.cbd.int/doc/meetings/sbstta/sbstta-20/information/sbstta-20-inf-08-en.pdf.

lii See UNEP/CMS/COP13/Inf. 9, endorsed at the 13th Meeting of the Conference of the Parties in Gandhinagar, India (2020).

liii For a detailed listing of resolutions adopted by ACCOBAMS and its Member States see https://accobams.org/documents-resolutions/resolutions/

liv See Annex 2 in ACCOBAMS-MOP7/2019/Doc38/Annex15/Res. 7.13.

ASCOBANS has likewise addressed the matter of underwater noise pollution, merging its working group efforts on underwater noise with ACCOBAMS in 2012 and CMS in 2014 which resulted in the Joint Noise Working Group of CMS, ACCOBAMS and ASCOBANS. Particularly relevant are resolution 6.2[lv] on the adverse effects of underwater noise on marine mammals during offshore construction activities for renewable energy production, adopted by the Parties to ASCOBANS in 2009, and the more recently adopted (at the 9th Meeting of the Parties in 2020) resolution 8.11[lvi]. The latter resolution adopted the *CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities* (see above) and reiterated the recognition of the threat posed by underwater noise on marine life.

Other international agreements and bodies

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) and the International Whaling Commission (IWC) are other bodies that have addressed anthropogenic underwater noise. For instance, in 2017 OSPAR conducted its first regional assessment of the pressure from impulsive noise, which was later updated in 2019.[lvii] Closely mirroring the language of the European Union's MSFD, OSPAR "endeavours to keep the introduction of energy, including underwater noise, at levels that do not adversely affect the marine environment".[lviii] Within the Baltic Marine Environment Protection Commission (HELCOM), work is currently ongoing to establish a first operational core indicator on distributions of impulsive sounds until 2021.[347] The International Whaling Commission has recognized anthropogenic underwater noise as one the priority threats in its Strategic Plan of the Conservation Committee[lix] and in 2018 Contracting Parties to the IWC adopted Resolution 2018-4 on Anthropogenic Underwater Noise.[lx] The IWC Resolution makes an important reference to the precautionary approach, noting that "the lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to address the effects of anthropogenic underwater noise".[lxi] Moreover, the resolution recommends to contracting governments to take into consideration best practice guidelines that ensure comprehensive and robust impact assessments and mitigation efforts, making specific reference to the CMS Family Guidelines for Environmental Impact Assessments for Marine Noise-generating Activities (see above).[lxii]

The European Union and its Member States

In 2008, the European Union adopted a comprehensive framework directive with the aim to protect the marine environment more effectively across the EU. The Marine Strategy Framework Directive (MSFD) was put in place to address the threats posed to biodiversity and marine ecosystems. It uses 11 descriptors, each of which illustrates good environmental status (GES). GES was defined as: "The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive." Descriptor 11 of the MSFD is intended to provide Member States with guidance on how to achieve GES in respect to anthropogenic underwater noise, noting that GES is achieved when the "introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment".

A further regulatory mechanism worth noting is the EIA Directive (85/337/EEC), which was adopted in 1985 and most recently amended and codified in Directive 2011/92/EU of December 2011. The EU's EIA Directive makes specific note of the importance of providing information on the description of the project and the expected emissions of noise (Annex IV, with reference to Article 5(1)). The EIA Directive differentiates between projects for which an EIA must be carried out by default (Annex I) and those where Member States have to determine whether an assessment should be carried out (Annex II). Considering that the EIA Directive has a wide scope and purpose, a number of noise-generating activities fall within the scope of the Directive and are thus subject to EIA requirements.

lv UNEP/ASCOBANS/Resolution 6.2
lvi UNEP/ASCOBANS/Resolution 8.11 (Rev.MOP9)
lvii See https://www.ospar.org/work-areas/eiha/noise
lviii See https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/distribution-reported-impulsive-sounds-sea/
lix Conservation Committee: Strategic Plan 2016-2026.
lx Resolution 2018-4, available at: https://iwc.int/document_3685.download
lxi IWC Resolution 2018-4, operative para. 2.
lxii IWC Resolution 2018-4, operative para. 3(d).

SECTION 6. SHORTCOMINGS OF UNDERWATER NOISE MANAGEMENT FOR DSM ACTIVITIES IN THE AREA

The ISA is responsible for securing effective protection of the marine environment, from "… both harmful effects directly resulting from activities in the Area or from shipboard processing of minerals immediately above a mine site …"[lxiii] and hence has the responsibility to effectively regulate noise emissions from DSM activities at the seabed and along the whole water column, including the sea surface. Noise emissions from increased shipping activities or other noise generating activities related to DSM need to be regulated in cooperation with relevant bodies, such as the International Maritime Organization (IMO), other relevant legal instruments and frameworks, and relevant global, regional, subregional and sectoral bodies, in particular multilateral environmental agreements (MEAs) relevant for the affected marine environment.

Environmental Impact Assessment

The ISA acknowledges noise as a potentially significant harmful pollutant but its representation within regulations and guidance is very limited and specifies neither the potential sources of noise nor requirements to specifically assess them and species which may be affected, and how to mitigate those. No specific requirements on noise measurement and monitoring and noise impact assessments are found in binding provisions. Moreover, acoustic exploration techniques with potential harmful effects are explicitly excluded from EIA requirements within the *Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area*[lxiv]. The draft exploitation regulations as well as the draft standards and guidelines, all currently being developed by ISA, still lack binding requirements for noise and noise impact assessments as described above.

Environmental impact assessment of noise emissions needs to be a binding requirement for DSM activities and specific requirements need to be established. This binding requirement needs to encompass all noise-generating activities, including acoustic exploration methods, and specify the potential noise sources and basic impact criteria that must be measured and the scope and nature of all surveys that are needed to establish the baseline and potentially affected species. Regulation of a major pollutant of DSM activities cannot be left to the discretion of contractors. And, on a technical level, specific state-of-the-art guidelines for noise and noise impact assessment need to be delivered by ISA to the contractors. Limited and incomplete reference to peer industry regulations, academia and one single DSM project (that made only very limited noise assessments in artificial settings) within the current draft standards and guidelines are not sufficient, particularly if state-of-the-art noise regulations from major MEAs (such as the *CMS Family Guidelines*) are neglected.

ISA's EIA regulations on noise also need to encompass recommendations for Best Available Technology and Best Environmental Practice to reduce noise emissions and their impacts. And they need to include a serious evaluation of all possible alternatives to the proposed activity/technology which could significantly reduce noise emissions of the activity/technology, including a 'no action' alternative. Moreover, noise levels and their propagation should not just be modelled, but verified through measurements made in the field. Also, any impact studies should include a power or sensitivity analysis showing how likely the statistical analysis and sample size are to detect subtle impacts.

Community-level impacts need to be addressed in the management of noise in DSM. These include, but are not limited to, predator-prey interactions, competition, and domino or "knock-on" effects across the marine food web. Impacts across the entire water column need to be considered due to the connectedness of the near-surface ocean to the deep ocean.

Interactions in nature are usually multiplicative or synergistic, i.e. greater than the sum of the individual impacts. The "...failure to properly account for interactions occurring between stressors can lead to substantial underestimation of stressor effects, particularly as stressor intensity rises".[348] The cumulative and synergistic impacts of multiple stressors

lxiii UNCLOS, annex III, art. 17 (2) (f)
lxiv ISBA/25/LTC/6/Rev.1

need to be factored into effective management and robust EIAs of DSM. Both the cumulative effects of multiple noise sources and the interactions of noise with non-noise stressors need to be considered. In addition to the multiple threats from DSM, marine animals face fisheries bycatch, habitat degradation, climate breakdown, ocean acidification, marine litter, chemical pollution, etc. In DSM, marine fauna will be faced with several simultaneous stressors, such as habitat destruction, plumes, chemical pollution, light pollution, and noise.

Marine Spatial Planning

Due to the vast regions, lengthy temporal scales, and complex ecosystems affected by noise emissions from DSM activities as well as various cumulative and synergistic impacts, Marine Spatial Planning (MSP) encompassing noise and noise impact assessments should be compulsory. Regional Environmental Management Plans (REMPs) are an "… essential element of the strategies that ISA implements to protect the marine environment"[lxv]. They need to include detailed provisions on noise assessments for previous, simultaneous, ongoing and planned activities in the same or adjoining areas. Moreover, noise modelling, noise budgeting and noise limits as well as assessments of cumulative and synergistic effects with noise as well as non-noise threats for the managed region should be compulsory. Additionally, 'quiet zones' using scientific advice from *Important Marine Mammal Areas* (IMMAs)[lxvi] and *Ecologically and Biologically Significant Marine Areas* (EBSAs)[lxvii], as well as *Vulnerable Marine Ecosystems* (VME)[lxviii] need to be defined. Time-area closures to minimize the impact of noise and other stressors on marine life, particularly during sensitive seasons, are crucial to effectively protect the marine environment from impacts of DSM activities.

The only implemented REMP existing at ISA so far, the *Environmental Management Plan for the Clarion-Clipperton Zone*[lxix] lacks provisions on underwater noise, and noise is mentioned only once in the *Guidance to facilitate the development of Regional Environmental Management Plans (REMPs)*[lxx] as an impact from mining on pelagic species. Moreover, the report of the *Workshop on the Regional Environmental Management Plan for the Area of the Northern Mid-Atlantic Ridge (2019)* shows some serious underestimation of the species affected by noise from DSM and a highly dubious merging of the factors noise and light into one single pressure. It hence did not properly address noise impact assessment. Specific requirements to assess and manage noise impacts from DSM activities as well as from other sources (e.g. transiting ships) within *Areas of Particular Environmental Interest* (APEIs) do not exist. Hence, noise management on MSP level is highly underdeveloped within ISA's regulations.

No need to reinvent the wheel

The issue of anthropogenic underwater noise has seen considerable attention in a wide range of global, regional and sectoral settings, albeit to different degrees and dedications. Although the adopted measures briefly alluded to in the previous section need to be understood within their own specific context and with regional and sector-specific experiences in mind, they nevertheless serve as a useful foundation for the development of future efforts to curb the threat posed by underwater noise. Indeed, with a view to regulating activities related to DSM activities, whether direct or associated, the measures previously outlined have the potential of providing a useful starting point. Regulations and guidance on EIA and MSP need to be tailored to DSM activities. However, decision-makers do not need to start from the beginning but can instead draw on the experiences and measures already in place. For instance, in the case of shipping and dredging, both of which are activities associated with DSM, one can draw on the *CMS Family Guidelines* on Environmental Impact Assessment for Marine Noise-generating Activities and their Technical Support Information that specifically provide advice on appropriate standards to manage noise originating from such sources.[lxxi]

lxv https://isa.org.jm/minerals/environmental-management-plan-clarion-clipperton-zone
lxvi https://www.marinemammalhabitat.org/
lxvii https://www.cbd.int/ebsa/
lxviii http://www.fao.org/in-action/vulnerable-marine-ecosystems/criteria/en/
lxix ISBA/17/LTC/7
lxx https://www.isa.org.jm/files/files/documents/remp_guidance_.pdf
lxxi See CMS Family Guidelines on EIAs, pages 15-16 and 20-22.

SECTION 7. CONCLUSION AND RECOMMENDATIONS

This report focusses on noise emissions as a major pollutant of DSM activities and their impacts on marine life. While habitat destruction remains the number one concern regarding biodiversity loss from DSM, underwater noise is also a major, and largely understudied, threat to marine life. Lacunae include the cumulative and synergistic impacts with other major pollutants (i.e. toxicants in sediment plumes). All major and potentially harmful effects need to be assessed and addressed properly to effectively regulate the environmental impacts of DSM activities.

What is known and what is not known

As described in the previous sections, sound (both its pressure and particle motion components) and/or vibration are vital for almost all marine animals for orientation, communication, mating, foraging, and avoidance of predators and other hazards. This is particularly the case for species in the dark deep ocean. The detrimental impacts of underwater noise emitted from various sources, such as shipping, acoustic exploration techniques, and pile-driving, on marine life has been documented and discussed in a growing body of scientific literature, with noise now recognized as a significant pollutant by a multitude of international organizations, agreements, and bodies (as shown in the previous sections of this report). The emerging industry of DSM is likely to inject many additional sources of noise, including in areas of the ocean where exposure to noise thus far is thought to be minimal.

The issue with assessing noise emissions from DSM activities at this stage is that DSM is still at the developmental stage. Many of the explorative and extractive components that may be used in DSM have not yet been built at full scale, let alone tested in the field. Of the existing components, noise measurements are also very limited. Noise levels from DSM sources that are supplied in this report are gleaned from the grey literature or communications with DSM contractors. These measurements will need to be independently verified in the field. However, there are various existing technologies and activities (e.g. shipping, dredging, acoustic exploration measures) that allow for extrapolation of some of the noise emissions to be expected from DSM. Information on particle motion and vibration caused by these sources is still largely missing, requiring further study.

Assessing noise impacts on marine life in the context of DSM is even more difficult as the majority of species inhabiting the deep-sea ecosystems that could be impacted by mining are still to be discovered. Adding to this, many of the known species are not well understood, including how they might be impacted by DSM underwater noise or what knock-on ecological effects might occur as a result.

Apart from noise levels and frequencies, duration of DSM activities is an important criterium to estimate the potential harmful impacts of noise. It is anticipated that most noise from DSM activities would be emitted nearly constantly (at least during mining cycles or during exploration and positioning with acoustic techniques) over long periods of time (decades), increasing the harmful effects significantly beyond mere loudness and frequency.

What needs to be done

We recommend to:

a) Incorporate and follow the Precautionary Principle

Even if considerable effort is invested immediately in assessing noise emissions from DSM activities and their impact on marine life, it is likely that science will only partly be able to provide the desired comprehensive understanding of DSM noise emissions and their impacts within the next few years. However, according to Principle 15 of the Rio Declaration on Environment and Development of 1992, "…lack of full scientific certainty shall not be used as reason for postponing cost-effective measures to prevent environmental degradation."[lxxii] Hence, cautious, comprehensive and binding state of the art regulations as well as technical guidance on underwater noise emissions of DSM activities

lxxii http://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf and their impact on marine species should be restrictive and only relaxed if the upcoming scientific knowledge allows for it without significantly harming the marine environment and species.

b) Create a solid scientific basis

The knowledge basis for drafting robust regulations to effectively protect the marine environment from harmful effects of activities in the Area is clearly lacking at this stage. We consider the following steps as crucial to approach a solid understanding of the potential harmful effects of noise emitted by DSM activities on marine species:

1. Conduct a transparent workshop on noise emissions from DSM activities and their impacts on marine life involving the most distinguished internationally recognised experts from bioacoustics, marine biology (including deep-sea experts), engineering, geology, and marine policy in order to:

   i. discuss how best to approach the issue of effective protection of the marine environment from noise emissions from DSM activities;
   ii. specify precise methods and requirements for collecting ambient noise data, baseline information and surveys, oceanographic data as well as animal surveys, including of surface-dwelling fauna such as marine mammals, as well as those from deeper realms;
   iii. set up an action plan and timeline for research projects to close knowledge gaps and define critical factors for effective protection (with restraint and caution concerning invasive research activities);
   iv. estimate needed funding and identify potential contributors;
   v. make recommendations on how restrictions of DSM activities, including spatial-temporal measures, can reduce the impacts of noise on marine life.

   Outcomes of the workshop should be publicly available, and the action plan and timeline should be open to a public and transparent stakeholder review process.

2. Significantly increase scientific efforts (from sea surface to deep-sea floor) to identify marine species, particularly in the deep-ocean habitats that will likely be impacted by DSM. This should include multi-year surveys to ensure that temporal differences are captured.

3. Increase scientific studies of the ecology of those marine species that will likely be impacted by DSM. This should include their sensitivities and behavioural responses to (anthropogenic) noise and vibration. Additionally, more scientific information on the ecological functions and community-level impacts of noise should be gained to allow further understanding of community-level impacts from DSM.

4. Place research efforts also towards improving our knowledge of baseline sound emissions and propagation. This should include an understanding of noise propagation loss in different environments. Baseline studies should be carried out annually for at least three years ahead of any impact for robust comparisons to be made. If conducting BACI (Before, After, Control, Impact) studies, each phase should be months, if not years to a decade, in duration to capture natural variability, especially for abyssal habitats.

5. Comprehensively study all noise sources already being used by peer-industries (and having characteristics similar to the noise sources in DSM) and assess their impact on marine species.

6. Comprehensively identify and study cumulative as well as synergistic effects from current and future noise emissions and other stressors, and assess their impact on marine species.

7. Let impact studies be comprehensively monitored by independent scientists to verify measurements.

8. Include clear information into completed impact studies on the statistical power of the studies and the likelihood of actually detecting subtle impacts, if they exist (power or sensitivity analysis).

9. Take the aforementioned and create models of noise impacts of DSM activities on marine species, taking into account cumulative and synergistic effects.

Although measurement from full-scale mining activities in the field by independent scientists would be the most effective way to get robust noise emission data, development and testing of full-scale DSM equipment should not be the next steps. Instead, there is still much to study from already existing noise sources and their impact on known species, let alone the ones still to be discovered, in order to build up a scientifically sound knowledge basis for effective protection of the marine environment from DSM activities in the Area.

To conclude the above steps, considerable efforts, substantial investment, long periods of time, and cooperation between a range of DSM stakeholders are required.

These steps, together with impact studies on all other major potentially harmful impacts of DSM, would provide a basis for effective decision-making on how to proceed with DSM, how to draft regulations to effectively protect the marine environment from activities in the Area, how to protect marine areas set aside for conservation purposes effectively from noise pollution, and how to develop technology to minimize and mitigate noise emissions from DSM activities.

c) Policy measures

Departing from the lack of knowledge and the negligence of the issue of underwater noise, a pause in the drafting of respective regulations and guidance to rectify the obvious lacunae would be welcome. Pausing the drafting of the Mining Code by the International Seabed Authority will allow the following to be undertaken immediately:

- align drafting and adoption of regulations and guidance within the Mining Code (including review of the elements already in force) as well as environmental protection regulations and guidance, and Marine Spatial Planning with the action plan and timeline from the abovementioned workshop.

In the scenario that the drafting of the Mining Code as well as environmental protection regulations and guidance continues without a break, minimum actions should include:

1. adopt a general policy explicitly stipulating that introduction of energy, including underwater noise, in mined areas and their vicinity should be at levels that do not adversely affect the marine environment[lxxiii];

2. study existing state of the art noise regulations such as the *Convention on the Conservation of Migratory Species of Wild Animals (CMS) Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities* (together with its Technical Support Information) and consult with noise expert groups from existing international organizations, MEAs etc., such as the *Joint CMS/ASCOBANS/ACCOBAMS Noise Working Group* (*Joint NWG*);

3. amend the exploration regulations and recommendations in force in order to account for the harmful effects of acoustic exploration activities, define mitigation measures in order to reduce impacts on marine species, and consider a ban on seismic activities as one of the most harmful noise sources;

4. call on contractors, sponsoring states, and tech firms related to research and development of DSM equipment to provide ISA with any noise assessments available so they can be made accessible for the public;

5. require DSM contractors to perform source level and frequency measurements for all components of their DSM activities (including acoustic surveys, vessel-based noise and submersibles), as well as noise propagation loss modelling, and bindingly request contractors to follow state-of-the-art technical guidance on noise assessment and propagation modelling;

lxxiii Guidance on a general policy can be derived from the Marine Strategy Framework Directive of the European Union (Directive 2008/56/EC).

6. follow minimising noise (and other pollution) as a key objective in research and development of all components of DSM (including *inter alia* vessels and submersibles), as reducing input at the source will be the most effective way of reducing impacts. Measurements of source levels (both the sound pressure and particle motion components of sound emissions) and frequencies as well as assessment of vibration should be mandatory at the early prototype stage in the laboratory as well as when being tested in natural surroundings. The latter stage should also include noise propagation loss assessments;

7. measure background levels as well as existing noise sources in contracted areas and their surrounding areas, and define and monitor noise exclusion zones and quieting regions within Areas of Particular Environmental Interest (APEIs);

8. amend the *Environmental Management Plan for the Clarion-Clipperton Zone* with provisions on underwater noise, and draft detailed guidance on underwater noise for *Regional Environmental Management Plans* (*REMPs*).

Final note

We would like to emphasize once again that in order to effectively protect the marine environment and species from harmful effects of activities in the Area, and to properly manage our common heritage, priority should be on:

1. efforts to better understand the marine environment, particularly deep-sea life, and impacts by DSM activities (including related to noise)

and

2. carefully drafted regulations and guidance to minimize DSM environmental impacts (including from noise).

Until a solid understanding of the potential harmful effects of DSM activities on marine species is reached, there should be a pause in steps towards exploitation of deep-sea minerals.

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Short questionnaire for assessing noise emissions from Deep-Sea Mining (DSM) activities

1. Which technologies are used for **surveying/exploring** areas for:

    a. Polymetallic Nodules

    b. Seafloor Massive Sulphides

    c. Ferromanganese Crust

2. What sound-based **exploration** methods are applied when surveying/exploring for reserves (e.g. seismic methods, echo sounding)?

    a. Polymetallic Nodules

    b. Seafloor Massive Sulphides

c. Ferromanganese Crust

For 1. and 2.: Please state, as far as available and applicable, the following information regarding each sound-based **exploration** method described above:

a. Source level: Sound Pressure Level (SPL) (dB re 1 µPa @ 1 m)

b. Sound Exposure Level (SEL) (dB re 1 μPa^2 s)

c. Power (W)

d. Total energy per pulse (J)

e. Bandwidth Δ = 10 dB (Hz)

f. Source direction

g. Pulse duration (s)

h. Particle motion (acceleration, rms: ms^{-2})

3. What are the major noise sources from DSM activities (**exploration** and **exploitation**)?

   a. Polymetallic Nodules

   b. Seafloor Massive Sulphides

   c. Ferromanganese Crust

4. Please state, as far as available and applicable, the following information regarding each noise source:

   a. Source level: Sound Pressure Level (SPL) (dB re 1 µPa @ 1 m)

b. Sound Exposure Level (SEL) (dB re 1 µPa^2 s)

c. Power (W)

d. Total energy per pulse (J)

e. Bandwidth Δ = 10 dB (Hz)

f. Source direction

g. Pulse duration (s)

h. Particle motion (acceleration, rms: ms^{-2})

5. How are noise emissions from **exploration** and **exploitation** activities addressed within the Environmental Impact Assessment? Is particle motion addressed?

6. What environmental impacts are expected from noise-emissions from DSM activities?

7. Are noise-mitigating measures applied to reduce sound emissions from Deep-Sea Mining activities?

8. How and in which context should, in your opinion, noise-emissions from DSM activities be regulated?

Any additional information on noise emissions from DSM activities and their potential environmental impacts not covered in the questions above would be appreciated.

Do you agree on disclosing the name of your company/institution regarding the information given in this questionnaire in a publication on underwater noise emissions from DSM activities?

☐ Yes, I agree. Company name:

☐ Do not disclose the name of my company/institution

Thank you very much for your collaboration. Your information is of invaluable importance to us.

To return questionnaire or for further information please contact Mr. Cyrill Martin, Ocean Policy Expert and Lead Deep-Sea Mining Programme at OceanCare, cmartin@oceancare.org

About OceanCare:

OceanCare is a Swiss non-profit organisation. It was founded in 1989 and has a strong commitment to realistic and cooperative initiatives. The organisation works at national and international level in the areas of marine pollution, environmental changes, fisheries, whaling, sealing, captivity of marine mammals and public education.
OceanCare holds Special Consultative Status with the Economic and Social Council of the United Nations (ECOSOC) and is a partner of the General Fisheries Commission for the Mediterranean (GFCM), the Convention on Migratory Species (CMS), and the UNEP/CMS Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), as well as UNEP/MAP. OceanCare is accredited observer at the Convention on Biological Diversity (CBD). OceanCare has also been accredited as a Major Group to the United Nations Environment Assembly (UNEA), which is the governing body of UNEP and is a part of the UNEP Global Partnership on Marine Litter.

To receive further information about
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