OSPAR technical report on current understanding of deep seabed mining resources, technology, potential impacts and regulation along with the current global demand for minerals

Environmental Impacts of Human Activites

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OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the “OSPAR Convention”) was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

La Convention pour la protection du milieu marin de l´Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d´Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties contractantes sont l´Allemagne, la Belgique, le Danemark, l´Espagne, la Finlande, la France, l´Irlande, l´Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume- Uni de Grande Bretagne et d´Irlande du Nord, la Suède, la Suisse et l´Union européenne

Contents

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Contributions also from the EIHA Deep-Sea Mining Task Group, with additional representatives to those listed above from Sweden, Belgium, Greenpeace and Seas At Risk.

EXECUTIVE SUMMARY

The OSPAR Convention is the mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic. OSPAR assesses and manages a wide range of human activities, including the extraction of non-living resources, in particular through its Offshore Industries Committee and the Committee on Environmental Impacts of Human Activities (EIHA).

In 2019 the OSPAR Commission agreed to establish a task group on deep seabed mining in order, inter alia, to exchange information and positions related to deep seabed mining and help Contracting Parties ensure that obligations under the OSPAR Convention are upheld.

This technical report, prepared by the task group and agreed through the EIHA Committee, contains the most current and up-to-date scientific, technological and high-level governance information on deep seabed mining of relevance and interest to the OSPAR Contracting Parties. The report covers global demand for minerals, governance of seabed mining, resources and activity within the OSPAR maritime area, mining techniques and technology, environmental effects, mitigation and restoration, monitoring, and knowledge gaps.

The report concludes that OSPAR will need to consider how the knowledge gaps and uncertainties should be addressed, including consideration of what actions are necessary to ensure that the general obligations and specific measures and approaches agreed under the Convention and its Annexes are upheld, which includes inter alia the application of the precautionary principle, the polluter pays principle, BAT/BEP and the ecosystem approach. In that regard, a second report in this series will provide an overview of which OSPAR principles, measures and approaches are applicable/relevant to deep seabed mining.

RÉCAPITULATIF

OSPAR est le mécanisme par lequel quinze gouvernements et l'Union européenne, coopèrent pour protéger l'environnement marin de l'Atlantique du Nord-Est. OSPAR évalue et gère une vaste gamme d'activités humaines, y compris l'extraction des ressources un large éventail d'activités humaines, y compris l'extraction de ressources non vivantes, notamment par le biais de son Comité industrie de l'offshore et du Comité impact environnemental des activités humaines (EIHA)

En 2019 la Commission OSPAR est convenue d'établir un groupe d'intervention sur l'exploitation minière du fond marin afin, entre autres, de partager des informations et des positions relatives à l'exploitation minière du fond marin et d'aider les Parties contractantes à s'assurer que les obligations de la convention OSPAR sont respectées.

Le présent rapport technique, préparé par le groupe d'intervention et approuvé par le Comité EIHA, contient les informations scientifiques, technologiques et de gouvernance de haut niveau les plus actuelles et les plus récentes sur l'exploitation minière du fond marin, pertinentes et intéressantes pour les Parties contractantes d'OSPAR. Le rapport couvre la demande mondiale en minéraux, la gouvernance de l'exploitation minière des fonds marins, les ressources et l'activité au sein de la zone maritime OSPAR, les techniques et technologies d'exploitation minière, les effets environnementaux, l'atténuation et la restauration, la surveillance et les lacunes en matière de connaissances.

Le rapport conclut qu'OSPAR devra examiner la manière dont les lacunes et les incertitudes en matière de connaissances devraient être abordées, y compris l'examen des actions nécessaires pour s'assurer que les obligations générales et les mesures et approches spécifiques convenues dans le cadre de la Convention et de ses Annexes sont respectées, ce qui inclut entre autres l'application du principe de précaution, du principe du pollueur-payeur, des BAT/BEP et de l'approche écosystémique. À cet égard, un deuxième rapport de cette série fournira une vue d'ensemble des principes, mesures et approches OSPAR qui sont applicables/pertinents à l'exploitation minière du fond marin.

INTRODUCTION

There is an increasing demand for specific resources (manganese, copper, cobalt, nickel, lithium and silver along with rare earth elements and critical metals[1]), due to growing populations, high-technology applications, increasing rarity of high-grade land-based deposits and the push towards adopting low carbon technologies to help meet climate change goals (Calas, 2017; Dominish et al., 2019; Hund et al., 2020; Hein et al., 2020) [2345]. Deep Seabed Mining has the potential to meet these growing mineral resource demands. However, there is a concern regarding our limited knowledge of deep sea ecosystems and the potential impacts mining may have on deep sea biodiversity, habitats and fisheries (Van Dover, 2014; Levin et al 2016; Gollner et al., 2017; Van Dover et al., 2017a,b; Niner et al., 2018; Miller et al., 2018; Sharma & Smith, 2019; Washburn et al., 2019; Levin et al., 2020, Christiansen et al., 2020).

For the purposes of this report, deep seabed mining (DSM) means:

- For areas beyond national jurisdiction: all activities of exploration for, and exploitation of, the resources of the Area (UNCLOS Article 1(3)), where the "Area" means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (UNCLOS Article 1(1)), and where "resources" means all solid, liquid or gaseous mineral resources *in situ* in the Area at or beneath the seabed, including polymetallic nodules (UNCLOS Article 133(a)).
- For areas within national jurisdiction: all activities of exploration for, and exploitation of, polymetallic nodules, polymetallic sulphides and polymetallic crusts.

Global demand for minerals

[1] http://researchbriefings.files.parliament.uk/documents/POST-PN-0508/POST-PN-0508.pdf [viewed 16/03/2018]

[2] Saleem H. Ali et al., 2017, Mineral supply for sustainable development requires resource governance, Nature, 6th March 2017, Volume 54

[3] Marcel J. C. Rozemeijer et al, 2018, Seabed mining. In Building Industries at Sea: 'Blue Growth' and the New Maritime Economy

[4] Saleem H. Ali et al., 2017, Mineral supply for sustainable development requires resource governance, Nature, 6th March 2017, Volume 54

[5] Marcel J. C. Rozemeijer et al, 2018, Seabed mining. In Building Industries at Sea: 'Blue Growth' and the New Maritime Economy

It is estimated that by 2100 there will be almost 11 billion people on the planet[6]. This will put huge pressure on already strained resources and so investment in low-carbon infrastructure will be critical to economic growth and sustainable development. The Intergovernmental Panel on Climate Change (IPCC) estimated that 70% to 85% of our energy supply must come from renewable sources by 2075 if we are to meet the 2°C target[7]. To achieve this, the IPCC calculates that we need a fivefold increase in investment in renewables and energy storage. Clean energy technologies, such as solar panels and wind turbines, are metal-intensive. They require, variously, nickel, manganese, cobalt, copper, lithium, rare earth elements and other speciality metals (Dominish et al., 2019). Other technologies are also advancing, with an increased use and reliance on electronic devices including mobile phones, computers, artificial intelligence, and quantum computing. All of these applications require sensors, chips and power sources, amongst others, which require the same rare earth minerals (Ayres, 2019). The business-as-usual scenarios of the OECD, the World Bank and UNEP's International Resource Panel project a doubling of demand for minerals by 2050-2060. However, a recent report by the World Bank[8] notes that "The increases in demand for specific minerals from the model should be regarded as a possibility that could emerge and are subject to shifts in policy or technologies" and that "Relatively small changes in the amount and type of energy storage technologies and sub-technologies deployed could have large implications for the markets of these minerals". All projections therefore are based on numerous assumptions including elements such as technology development and policy choices

The demand for nickel (Ni) and cobalt (Co), in particular, are forecast to increase, although there is considerable uncertainty by how much (Tisserant and Pauliuk, 2016; Dominish et al., 2019; Lapteva et al., 2020; Paulikas, et al., 2020). Increased demand will be affected by (1) current mining operations and (2) current recycling rates as well as (3) proved and (4) potential future mining projects. It is important to note that this is based on current transport models, including assumed rates of growth in vehicle sales/use. Any changes in those scenarios would have a major effect on projected mineral demand. They are also based on current electric vehicle (EV) battery technology, changes to which could have a dramatic effect on demand for individual minerals (e.g. cobalt free EV batteries, as already available on the market, or new technologies expected long before 2050 e.g. lithium-sulphur batteries).

The demand for specific minerals puts increased pressure on terrestrial deposits due to the fact that (among others) (i) metal grades are decreasing, (ii) economic deposits are deeper in the earth's crust necessitating removal of more overburden, (iii) deposits occur in ecologically sensitive areas (rain forest for Ni and Co), (iv) there is growing conflict of use for mining, agriculture, tourism etc. The need for new extraction of materials might be tempered by making significant efficiency gains in consuming and producing via a circular economy approach (Kinnunen and Kaksonen, 2019). Up to 90% of the world's electronic waste is illegally traded or dumped, and less than 16% of global e-waste volumes are recycled. Every year, 160 million mobile phones in the EU go unused, with less than 15% recycled. This represents a huge amount of precious metals that could be made available provided that adequate rules are adopted for this purpose and complied with accordingly. A report from the Institute for Sustainable Futures in Sydney (Teske et al., 2016) concluded that even under the most ambitious renewable energy scenarios, mineral demand could be met without mining the deep sea. However, others suggest that the metal demand associated with the transition to a low carbon society is by far higher than what is currently available, even if the metals used could be

[6] https://population.un.org/wpp/Publications/Files/WPP2019_10KeyFindings.pdf
[7] https://www.ipcc.ch/sr15/
8 http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

recycled to 100% (Vidal et al., 2017). New technologies are also under development that could make exploitation of new forms of resources dispensable (e.g. cobalt-free batteries). All projections have uncertainties related to technology and policy choices which can have a major impact on all projections.

The UNEP's International Resource Panel (IRP) recent report (IRP, 2019) also brings a different perspective on the future needs for metals and calls for a transformational economy and a new global governance mechanism to oversee the sustainable use and supply of mineral resources. Under its 'Towards sustainability' scenario for 2060, the extraction of metals would increase by only 12% by 2060, compared to a doubling under a business-as-usual scenario (IRP, 2019). However, these projections did not include the metals required to transition to renewable energy, which is metal intensive. In its future reports, the IRP aims to integrate the metal requirements of the energy transition into its assessments, and to establish a link with the integrated assessments models and as such combine the demand for materials and metals with energy use and climate change. Two key global challenges for the energy transition lie ahead: (1) to scale up the production of materials and metals required for the energy transition, and (2) to do so while avoiding negative environmental, social and economic impacts through consideration of a circular economy, recovery, reuse, recycling and other approaches to minimise primary mineral extraction.

All methods of mining, whether at land or sea are, however, inherently unsustainable, as the amount of minerals extracted per period of time is greater than the rate of new formation. Mineral deposits in the deep sea are also often found in areas with species that are slow-growing and long-lived. Some of the resources that are targeted for mining harbour unique ecosystems that have taken thousands of years to evolve, and in areas that are not sufficiently mapped, or have limited descriptions, and have very little knowledge on the biology.

Historically, technical challenges, the cost of extraction, depressed markets and environmental and legal concerns kept DSM development slow (Sparenberg, 2019). However, with technology further developing, and growing geo-political concerns about security of land-based supplies and the need to diversify supply, along with the perception that multi-metal deposits might result in fewer environmental and social impacts than land-based mining (Hein et al., 2013), the interest in obtaining minerals from polymetallic deposits on the seafloor is increasing (Koschinsky et al., 2018). These factors, along with the push for a low carbon economy, create a complex landscape resulting in a rise in the number of contracts for exploration issued by the ISA over the past decade.

There has been, and continues to be, concerns from - scientists, civil society and State Parties about how to manage the environmental impacts of mining of the seabed in areas beyond national jurisdiction (the Area), including calls from some of civil society for a moratorium on deep-seabed mining (DSCC, 2020), as well as questions around whether there is a need for deep sea mining.

Governance of seabed mining activities.

The United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Agreement is the overarching legal framework for the world's oceans, including the legal framework for deep-sea mining in the Area. It contains many general provisions relevant to deep seabed mining. Of note is Part XI, Principles governing the Area, including; Common Heritage of Mankind, Legal status of the Area and its resources, General conduct of States in relation to the Area, Responsibility to ensure compliance and liability for damage, Benefit of Mankind, Use of the Area exclusively for peaceful purposes, Rights and legitimate interests of coastal States, Marine Scientific Research, Transfer of Technology, Protection of the marine environment, Protection of human life, Accommodation of activities in the Area and in the marine environment, Participation of developing states in activities in the Area, Archaeological and historical objects. The full scope of these principles can be seen in UNCLOS Part XI, Section 2.

DSM activities conducted beyond the national jurisdiction of a State i.e. in the Area are regulated by the ISA, whilst deep sea mining activities on the continental shelf fall within the jurisdiction of the State. When mining on the continental shelf, UNCLOS Article 208 provides that the state must incorporate the ISA rules as a minimum. Article 208(1) provides that the coastal state shall adopt laws to address pollution. Article 208(3) provides: 'such laws, regulations and measures shall be no less effective than international rules, standards and recommended practices and procedures', although it is noted that States can go beyond this e.g. in terms of environmental protection. Article 208(4) provides that states should endeavour to harmonise laws at the regional level.

The ISA is an autonomous international organisation established under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and Part XI of the 1994 Implementing Agreement The Authority is 'the organisation through which States Parties to the Convention organise and control all mineral resource-related activities in the Area for the benefit of mankind'[9] The ISA is therefore also mandated under UNCLOS to protect the marine environment from harmful effects that could arise from DSM activities. Since 2014, the ISA has undertaken work via expert workshops, studies and discussion papers to develop regulations for exploitation of mineral resources in the Area in accordance with UNCLOS and the 1994 Agreement. At the time of writing, the Draft exploitation regulations are still being negotiated although due to Covid-19, these negotiations have been put on hold until July 2021.

The ISA is looking to implement the following management tools, amongst others, within its governance of the DSM activities.

- Internationals rules for exploration activity (3 text corpuses have been edited for the 3 types of resources)
- Regional Environmental Management Plan (REMPS): a strategic area-based management tool to support informed decision-making that balances resource development with conservation, including identify particular areas thought to be representative of the full range of habitats, biodiversity and ecosystem structures and functions within the relevant management area. The REMP for the Clarion-Clipperton Zone (CCZ) was adopted by the Council in 2012 (ISBA/18/C/22) and REMPs for other areas are being developed. Many State Parties have stressed that fully developed and agreed plans should be legally binding and made a condition for the approval of plans of work (IBSA/26/C/2, ISBA/26/C/CRP.1, ISBA/26/C/7). A standardized procedure and template for REMP development has also been proposed by delegations of Germany and the Netherlands, with co-sponsorship by Costa Rica and is currently considered by the ISA.
- Baseline Studies: under ISBA/25/LTC/6.Rev.1, the ISA identify the importance of having baseline studies to document the natural conditions prior to the test mining, to inform environmental impact assessments. The studies should include physical oceanography; chemical oceanography; geology and geological properties; biological communities and

[9] https://www.isa.org.jm/about-isa

bioturbation activity; sediment oxygen and the evaluation of food web structure of the pelagic and benthic habitats.

- Environmental Impact Assessment/Environmental Impact Statement (EIA/EIS): under the exploration regulations and draft exploitation regulations, each proposal requires an environmental impact assessment to be carried out and reported as an Environmental Impact Statement to the ISA for consideration. The EIA will use the baseline studies to assess the potential impacts and the significance. The EIA will be used as the primary basis on which the ISA will base its environmental decision.
- Public Consultation: under the exploration regulations and draft exploitation regulations the ISA has to ensure the application documents are available for public consultation to allow transparency. Discussions around confidentiality are ongoing regarding public availability of some information. The ISA will then consider the representations made as part of their decision-making process.

  Environmental Monitoring and Management Programmes (EMMP) are plans which are agreed between the contractor and the ISA for any mitigation measures and monitoring requirements during test mining, exploration and/or exploitation.
- Closure Plan- under the draft exploitation regulations, each application for approval of a Plan of Work shall be accompanied by a Closure Plan. Closure Plans are required for when the exploitation activities are coming to a close (either due to reduced resource or contract expiry), or when being suspended. The plan should set out the responsibilities and actions of a Contractor for the decommissioning and closure of activities in a mining area, this includes how infrastructure will be removed, and any monitoring beyond the exploitation activities to monitor the impacts of mining. A closure plan is first required to be submitted and approved by the Council of the ISA with the application for a plan of work for exploitation, and updated through the life cycle of the mine in the light of any material change, as well as taking into account the results of monitoring, data and information gathered over time the ISA.
- Sponsorship by a State
- Environmental compensation fund

The Draft exploitation regulations require certain issues to be addressed in accordance with standards and guidelines developed by the organs of the ISA, with standards being legally binding, and guidelines recommendatory. The Legal and Technical Commission (LTC) has undertaken work on standards and guidelines on behalf of the Authority, and have recommended a three phased approach:

> Phase 1: standards and guidelines deemed necessary to be in place by the time of adoption of the draft regulations on exploitation.
> Phase 2: standards and guidelines deemed necessary to be in place prior to the receipt of an application of a plan of work for exploitation.
> Phase 3: standards and guidelines deemed necessary to be in place before commercial mining activities commence in the Area

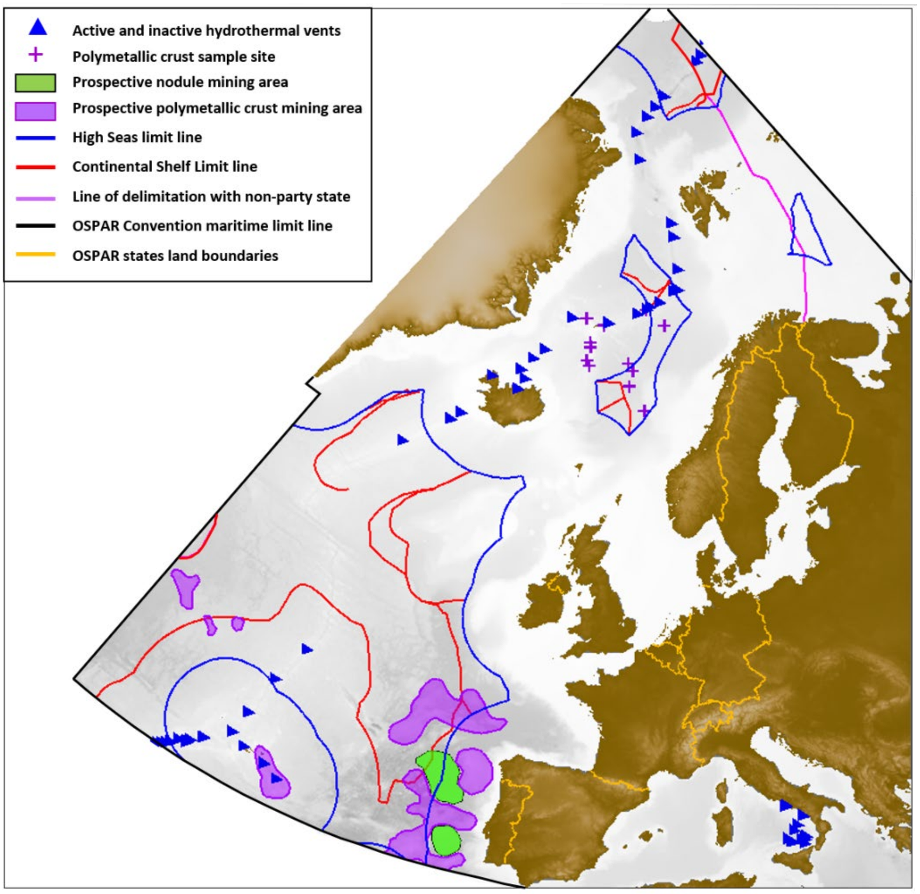
A set of nine guidelines were recommended for Phase 1, which includes Guidelines for environmental impact assessments (EIA) and the preparation of an environmental impact statement (EIS), Guidelines for the preparation of environmental management and monitoring plans.

Deep Sea Mining (DSM) resources in the OSPAR area

Within the OSPAR maritime area several areas have been identified that could become the target of future mineral exploration/exploitation interests (Figure 1). The area also contains a network of Marine Protected Areas (MPAs) which will need to be considered in terms of any mining effects on their conservation goals. This report sets out a summary of knowledge to date with regards to mining of different deep-sea mineral resources, including aspects of the technology, potential environmental effects and current knowledge gaps. Its purpose is not to advocate for or against deep seabed mining.

Under the current Subsea Minerals Act, the Norwegian Government last year initiated an opening process for offshore mineral activity, including an impact study[10][11][12]. A data Government acquisition program has been in place since 2018 (geological and geophysical data). Sweden does not have any deep-sea mining activities. However, as of June 2021, there is an application for seabed mining on the shallow continental shelf in the Bothnian Bay for consideration by the Swedish government.

No other OSPAR Contracting Parties have reported any current or planned prospecting, exploration or exploitation of deep-seabed minerals in the OSPAR Maritime Area.



[10] Konsekvensutredningsprogram for mineralvirksomhet - regjeringen.no
[11] Høring - forslag til konsekvensutredningsprogram for mineralvirksomhet på norsk kontinentalsokkel - regjeringen.no
[12] The Shelf in 2020 - The Norwegian Petroleum Directorate (npd.no)

Figure 1. **Compilation of confirmed and potential metallic deep sea mineral deposits within the OSPAR area[13].** Ocean areas are cut along the limits of the OSPAR Maritime Area (black lines). The limit of the High Seas (blue lines) is the boundary between the Area and the combined Exclusive Economic Zones (EEZs) of all coastal States within and adjacent to the OSPAR Maritime Area. The red lines indicate coastal States' outer limits of the continental shelf beyond 200 nautical miles as submitted to, or recommended by the Commission on the Limits of the Continental Shelf (CLCS). Data credits; bathymetric data are SRTM15_PLUS extracted from NOAA[14]; resource data and information are extracted from the Royal Society[15] and the Norwegian Petroleum Directorate[16].

SYNOPSIS OF BACKGROUND INFORMATION

DEEP-SEA RESOURCES

Deep-sea resources of interest which occur within the OSPAR region include seafloor massive sulphide deposits within hydrothermal vent fields and areas that potentially contain rich deposits of polymetallic nodules ("nodules") and cobalt-rich ferromanganese crusts ("crusts").

Seafloor massive sulphides (SMS) are commonly found along mid-ocean ridges and tectonic plate boundaries in water depths between 500 and 5000m [17] and are the main contracted mining resource in the OSPAR area. Deposits are precipitated during the mixing of metal-rich hot hydrothermal vent fluid with cold bottom water. Such deposits can be found at either active or inactive vent sites, typically consisting of ores of copper, gold, zinc and silver. Different biological communities are associated with active and inactive sites. Communities associated with active hydrothermal vents (Figure 2) are supported by chemosynthetic bacteria, which are reliant on the methane or sulphide-rich vent fluids for primary production, and often show physiological and behavioural adaptations associated with the extreme conditions (Karl et al., 1980). Despite the high faunal and bacterial abundance and biomass typical for vent systems, species richness is often low (Chapman et al., 2018), although most of the species are endemic to the vent ecosystem making them particularly susceptible to extractive mining (Desbruyères et al., 2000; Desbruyères et al., 2001; Wolff, 2005; Van Dover, 2011a; Harden-Davies., 2017; Van Dover et al., 2018). Globally, the active vent ecosystem is a rare habitat, comprising an estimated 50km^2 or <0.00001% of the surface area of the planet (Van Dover, 2018). Communities associated with inactive vents resemble the fauna of seamount communities. Organisms are typically sessile, filter-feeding, long-lived and slow-growing, and include taxa such as sponges and corals (Boschen et al., 2013), These specialised communities colonise the hard substratum and may utilise the chemical energy provided by the sulphide oxidation processes of the inactive SMS deposits. Nevertheless, it can be stated that the knowledge of inactive vents is still limited.

[13] Compilation and layout: Norwegian Petroleum Directorate, Stavanger, Norway
[14] Backdrop bathymetry: https://www.ncei.noaa.gov/archive/accession/0150537 [viewed 16/02/2021]
[15] Resource information: https://royalsociety.org/topics-policy/projects/future-ocean-resources/ [viewed 16/02/2021]
[16] Resource information: Norwegian Petroleum Directorate, Stavanger, Norway
[17] https://www.eu-midas.net/science/sulphides [viewed 11/02/2020]

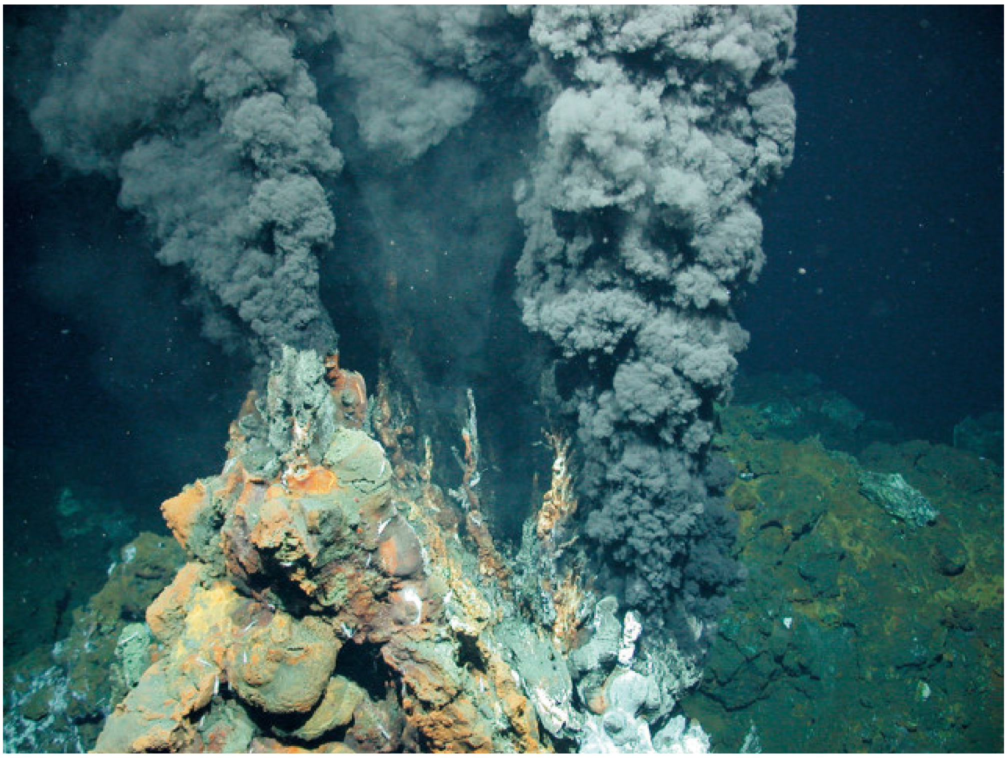


Figure 2: SMS deposits at an active hydrothermal vent site. Image credit: World Ocean Review.

Polymetallic nodules (Figure 3), also known as manganese nodules, are comprised of concentric layers of iron and manganese oxy-hydroxides, are usually up to ~15 cm in diameter and contain manganese, nickel, copper, cobalt, iron and rare earth elements. Nodules occur mainly in abyssal areas in water depths of 4000-6500m with low sedimentation rates. Nodules acquire metals from two sources; cold seawater (hydrogenetic) and sediment pore water (diagenetic) precipitation, with most nodules acquiring metals from both sources but in varying proportions (Hein, 2016; Kuhn et al., 2017). The rate of nodule formation is dependent on the precipitation source, with hydrogenetic nodules grow extremely slowly, 1-5 mm per million years, and diagenetic nodules growing several hundred mm per million years (Hein, 2016). As most nodules form by both hydrogenetic and diagenetic precipitation, average nodule growth rate is several tens of mm per million years[18] (Kuhn et al., 2017; Krishnaswami et al., 1982).

[18] https://core.ac.uk/download/pdf/33666816.pdf

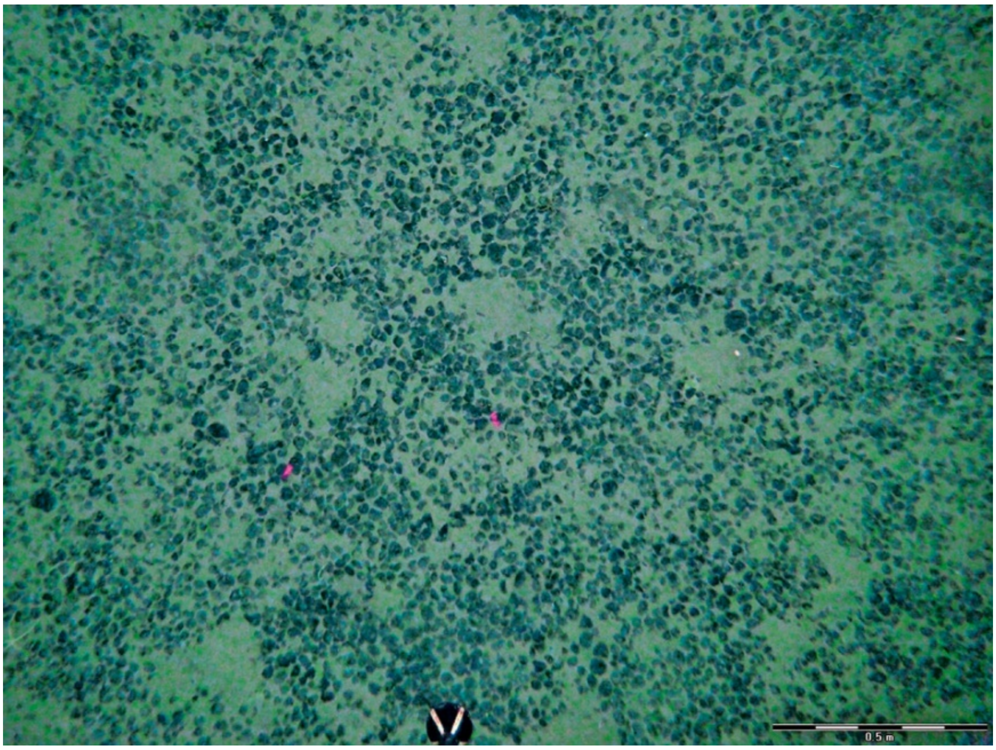


Figure 3: Polymetallic nodules on the seafloor in the Clarion-Clipperton Zone, central eastern Pacific. Image credit: German Federal Institute of Geosciences (Bundesanstalt für Geowissenschaften und Rohstoffe)19.

Cobalt-rich ferromanganese crusts (Figure 4) are associated with areas of elevated topography, usually seamounts and large rises (800-2500 m below sea level) and grow at extremely slow rates of 1 to 6 mm per million years by the precipitation of metals dissolved in seawater on the sediment-free substrate of seamounts [20]. Crusts can be up to ~20-25 cm thick, and contiguous deposits may cover several square kilometres. Typical metal contents are cobalt, iron, manganese and a number of rare elements (e.g. titanium, cerium, tellurium, platinum). Many seamounts are hotspots of biodiversity, providing habitat to fauna such as cold-water corals, sponges, anemones and crinoids, the composition of which will vary according to the topography, location and water depth of the seamount.

[19] http://worldoceanreview.com/en/wor-3/mineral-resources/manganese-nodules/ [viewed 07/02/2018]
[20] https://www.eu-midas.net/sites/default/files/downloads/Briefs/MIDAS_brief_seamounts_Lowres.pdf

Figure 4: Piece of ferro-manganese crust (top) and cross-section of seafloor (bottom) from a seamount in the west Pacific (ca. 23°N, 153°E). Image Credit: Japan Agency for Marine-Earth Science and Technology[21].

[21] https://www.youtube.com/watch?v=DN98OVZjc4c [viewed 07/02/2018]

Mining Techniques and Technology

A European Union funded project undertaken by Ecorys (2014) provided a review of the state of knowledge of DSM and identified two systems in particular as being critical for the commercial exploitation of deep-sea resources:

- The seafloor mining vehicles for the removal of resources from the seabed, and;
- The vertical transport system (usually known as a Riser and Lifting System or RALS) to transport ore from the seabed to the surface using either an air lift system, hydraulics or mechanical (i.e. Continuous Bucket Line).

The seafloor mining vehicles and RALS are currently under development, with the testing of certain designs already underway. Much of the technical development of the mining vehicles has related to operation at depth, including transfer of material to the surface, and effective removal of crushed or displaced ores. Different designs have been considered depending on the target resource (SMS, nodules, crust). The technology underpinning this industry is, however, likely to evolve over a period of years, even after exploitation licences have been awarded, meaning that the assessment of their impacts will also need to be iteratively updated.

The subsections below provide examples of the mining techniques and equipment currently being considered for each type of resource and current knowledge on the riser technology.

Seafloor Massive Sulphide (SMS) mining

Mining SMS deposits will have a relatively small spatial footprint (compared to a nodule mining area) on the seabed (typically 0.5 – 1.0 km^2 for the total life time of a mining project) compared to mining of nodules and crusts (typically 150 – 200 km^2/year for nodules, and 10 – 20 km^2/year for crusts) but will involve a deeper excavation of the seafloor (up to 30 m below seafloor, compared to 10-30 cm in nodule and crust mining areas).

Mining operations will be conducted by different (one or more) seafloor vehicles (depending on the type of raw material), remotely operated from a support vessel.[22] The seafloor vehicles must cut, crush and collect mineralised material, which will then be fed (via either a riser or mechanical lift system) to the support vessel (SPC, 2013a). For example, Nautilus Minerals commissioned three remotely controlled mining vehicles designed to mine seafloor massive sulphides at the Solwara 1 deposit in the Bismarck Sea off Papua New Guinea (although the company went into administration in 2019 before the vehicles could be deployed[23]). The vehicles consisted of an auxiliary cutter (to prepare/flatten the seafloor), a bulk cutter (the main mining vehicle) and a collector machine (Figure 5).

[22] Mining vehicles: http://www.nautilusminerals.com/irm/content/video-gallery.aspx?RID=421 [Viewed 01/02/2018]
23 https://www.theguardian.com/world/2019/sep/16/collapse-of-png-deep-sea-mining-venture-sparks-calls-for-moratorium

Figure 5: Mining vehicles designed to mine seafloor massive sulphides. Left to right: Collector machine, bulk cutter, auxiliary cutter. Image credit: Soil Machine Dynamics[24]

Conversely, a single vertical mining system for SMS has been developed by BAUER Maschinen GmbH, which is based on trench cutter technology (generally used on land for foundation work) (Dombrowsky, 2018) (Figure 6). The trench cutter is a static system made up of a heavy steel frame with cutting wheel drums at the bottom. This type of design has been successfully used to mine diamonds at a depth of 165m (Spagnoli et al., 2016).
Testing of this device at sea depths of 2.000-3.500 m is currently foreseen for 2026.

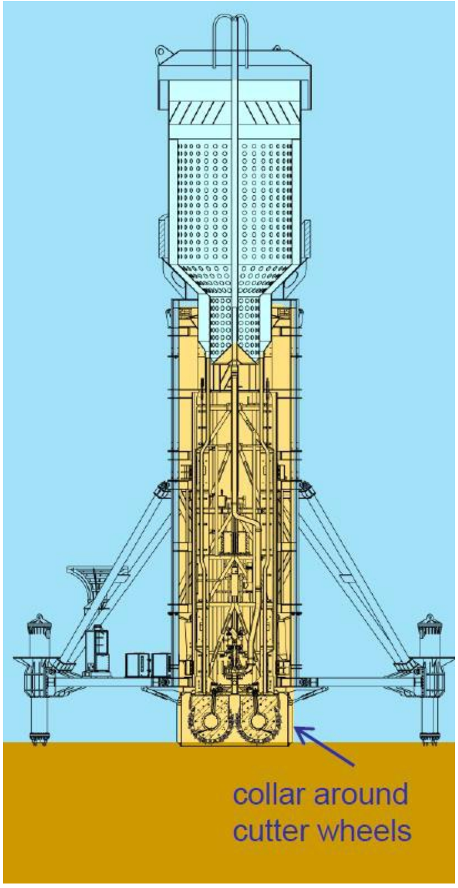


Figure 6: BAUER trench cutter (Spagnoli et al., 2016)

[24] http://www.rovplanet.com/news/news?id=384 [viewed 08/02/2018]

Nodule Mining

The deposits of nodules are largely surficial (see Figure 3), therefore mining vehicles will have to cover wider areas of seafloor and the majority of the disturbance will be limited to the top 10-20 centimetres of sediment. To date, there have been three basic designs for the nodule mining technology, namely (see Figures 6 and 7 for design impressions):

- collecting nodules with a hydraulic, mechanical, or hybrid collector and lifting them through a pipe (the hydraulic mining system);

- collecting nodules with a bucket-type collector and dragging up the bucket with a rope or cable (the continuous line bucket mining system); or

- collecting nodules with a dredge-type collector and having the collector ascend by the force of its own buoyancy (the modular or shuttle mining system).

Hydraulic mining systems have received the most attention to date. The system includes collection of nodules and separating the nodules from mud, crushing and then pumping nodules to the surface platform, where they are transferred to transport vessels for delivery to an onshore processing facility (see Jones et al., 2017 and references therein).

In 2018, Global Sea Mineral Resources (GSR) of Belgium and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) of Germany planned a joint test of a pre-prototype collector and separator for nodules, the Patania II (Figure 7) (Global Sea Mineral Resources, 2018, Bundesanstalt für Geowissenschaften und Rohstoffe, 2018). The testing was planned to take place in April 2019 at oceanic depths in the Clarion-Clipperton Fracture Zone (CCFZ). However, technical problems on site led to abortion of the test, to be continued in 2021. The purpose of in-situ trials with Patania II is to validate the working principle of the hydraulic collector in the CCFZ, and to obtain an insight into environmental impact induced and the monitoring approach to measure this impact.

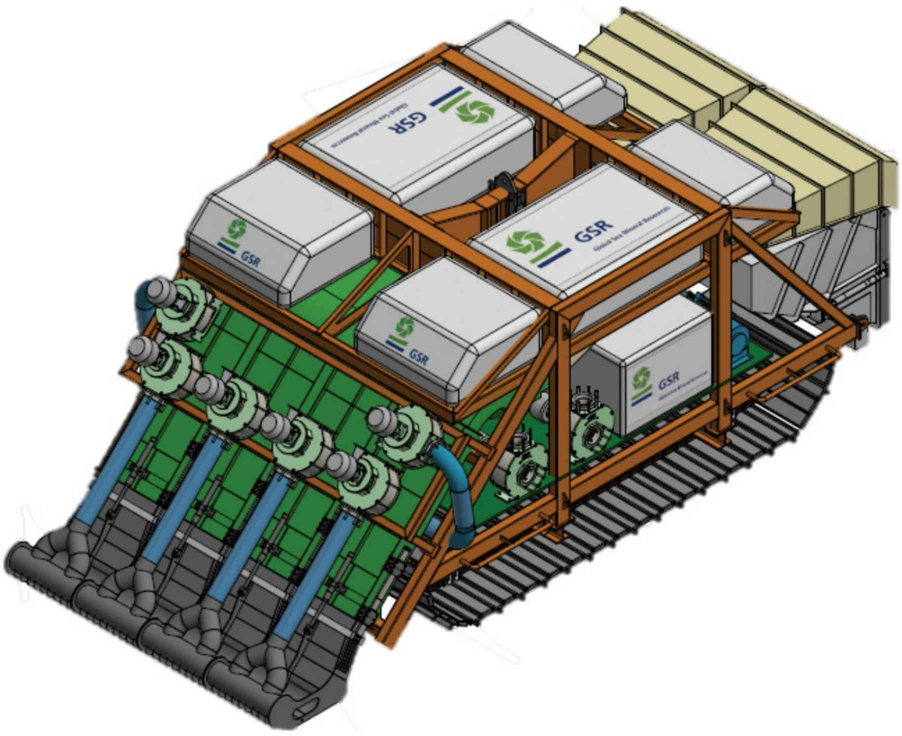


Figure 7. The Patania II prototype collector and separator for nodules.

Under the Blue Nodules project[25] new systems for the harvesting of polymetallic nodules were also developed, and, in 2019, were tested at depths of 300m[26]. The tests included an assessment of environmental impacts from the sediment plume and noise generated by the test collector vehicle using an array of moored sensors.

The follow-on project, Blue Harvesting[27], which commenced in April 2019, will be developing a novel hydraulic nodule collector and separation system with the aim of reducing plume generation and dispersion caused by the collector, with full-scale field trials planned for 2021. Royal IHC, partners in both projects, are currently developing a deep sea mining collector and vertical transport system for operating in depths of up to 5, 000 metres (Figure 8).

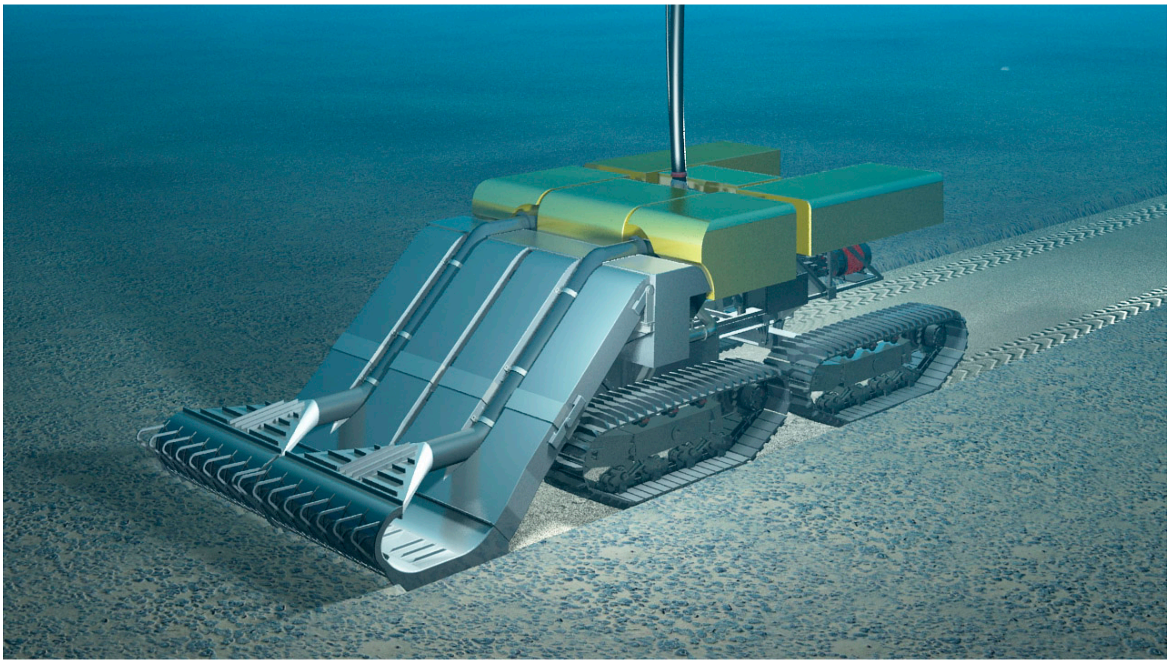


Figure 8: Polymetallic nodule mining test vehicles (Image credit: Royal IHC)

Crust Mining

The mining of crusts is expected to involve steps most similar to those identified for SMS (a cutting step is required), but this resource has been subject to the least technical development of any of the minerals reviewed here. Technology for mining these crusts is likely to be much more complex than for mining SMS or nodules as the variable thickness of the crusts (see Figure 4) and the steep, rugged environment pose significant challenges to the design and operation of remotely operated collection tools (SPC, 2013c). Most of the engineering data related to crust mining in China, Russia, and Japan are proprietary and, therefore, the extent to which the relevant technology currently exists is not publicly known (SPC, 2013c). As with SMS and nodules, several methods have been investigated for lifting the ore to the surface and cutting the cobalt crusts from the seamount.

[25] https://blue-nodules.eu/ [viewed 25/02/2020]
[26] https://blue-nodules.eu/second-blue-nodules-field-trial-succesfully-accomplised/
[27] https://blueharvesting-project.eu/about-blue-harvesting

Riser Technology

To transport the minerals to the surface, mechanical/ discontinuous lift systems are being developed. Several designs to date consist of a vertically hanging submerged pipe whereby the ore is transported upwards through a number of booster stations to the support vessel (Verichev et al., 2011; 2H Offshore[28]). One such system has been developed within the EU funded Blue Mining project[29], led by Royal IHC. The vertical transport system was designed to include pumps operated by seawater lubricated electric motors. The design eliminates the risk of an oil spill as the motor is filled, cooled and lubricated with seawater. Twelve motorised units would be required for a five-kilometre pipeline and fourteen for six kilometres. The riser pipes will consist of up to five different thickness of high-tensile steel to account for the different water depths and pressures, with thinner construction as depth increases [30]. Some of the processed material will need to be discharged as wastewater, known as dewatering. This material (consisting of sediment and dissolved metals) will either be discharged to the mid water or just above the seabed[31] (Miller et al., 2018; Washburn et al., 2019, Christiansen et al., 2020).

BAUER plan to use a discontinuous ore transportation system, whereby the ore is sucked up from the crusher and deposited into a container at the top of the mining system (Figure 6). Once this container is full it can be detached from the mining system and lifted to the support vessel. Transportation of the ore from the cutter to the storage unit would be facilitated by a cutting fluid within a closed system. The cutting fluid would then be recycled at the support vessel and reused, preventing the release of sediment plumes (see Dombrowsky, 2018).

More recently Liao (2020) proposes a different transport system which is based on buoyancy and gravity. This design is based on a pully system with 'cars' but has yet to be proven in terms of engineering viability and environmental impact in comparison to other technology.

As new ideas and solutions to this part of the operation are still being developed, the production techniques may also change – as will the consequences and possible environmental impacts. At present, it is difficult to make accurate predictions on the potential environmental impacts, given the lack of clarity in the technical approaches proposed.

[28] https://acteon.com/products-services/deep-sea-mining-engineering/
[29] https://bluemining.eu/
30 https://www.royalihc.com/en/blog/blue-mining-leads-the-way-in-vertical-transport-technology
31 https://www.pnas.org/content/pnas/117/30/17455.full.pdf

EXPECTED ENVIRONMENTAL EFFECTS OF DEEP SEABED MINING

The deep-sea environments targeted for DSM provide ecosystem services, such as nutrient cycling and carbon dioxide storage, which benefit mankind and play a significant role in terms of climate regulation and food production (Thurber *et al*., 2014). Active vent ecosystems, in particular, are valued for their genetic diversity and for the potential for discovery of marine genetic resources, such as extremozymes (i.e. enzymes that function under extremes of temperature, chemistry and pressure). Given the obligations on contracting parties to prevent such losses, this should be a major concern for OSPAR.

There will be environmental impacts associated with DSM, some of which are common across some or all the resource types (although to differing extents and magnitudes depending on, for example, the duration of impact, the type of technology used, size of area impacted, nature of the (sedimentary) environment, species resilience and potential for recovery), and some of which are unique to each resource type. The scale and significance of impacts from deep seabed mining and timescales of recovery are largely unknown (see Jones et al., 2017, Simon-Lledo et al., 2019). Recent findings from the DISturbance and reCOLonisation experiment (DISCOL), undertaken in the Peru Basin, indicate impacts are still evident 26 years after simulated mining took place (Simon-Lledo et al., 2019).

Possible impacts associated with different DSM activities are summarised in Table 2, though these are subject to current understanding of the technical approaches under consideration and are likely to change as the industry develops. Based on present knowledge, there are common impacts across all resource types, all with potential direct or indirect detrimental effects on biodiversity (see Figure 6 and Table 1 below regarding the potential of impacts and uncertainties) (ICES, 2015; ECORYS, 2014; SPC 2013a-b, Gollner et al., 2017, Jones et al., 2017, Miller at al., 2018, Christiansen et al., 2020) such as (not exhaustive):

- Loss of substrate;
- Changes to seabed integrity (due to compaction, removal of topmost sediments, changes in geochemical conditions, changes in topography);
- ;
- Operational sediment plume: sediment, wastes and other effluent plume and resuspended sediment from activity on the seabed which extends through the benthopelagic environment, containing fragments of the mineral substrate and potentially biologically active metal concentrations.
- Discharge of sediment, wastes and other effluent in the water column or on the seabed: comprising sediment, wastes and other effluent which may contain chemicals that could disassociate once released and potentially biologically active metal concentrations
- Increase in light;
- Increase in noise levels and potential vibration; and
- Release of sediment-bound or subsurface porewater toxic metals into the water column.

In addition to the above, there also lacks knowledge about the potential impacts of DSM activities on other sectors, such as fisheries and/or the exploitation of biota for marine genetic resources.

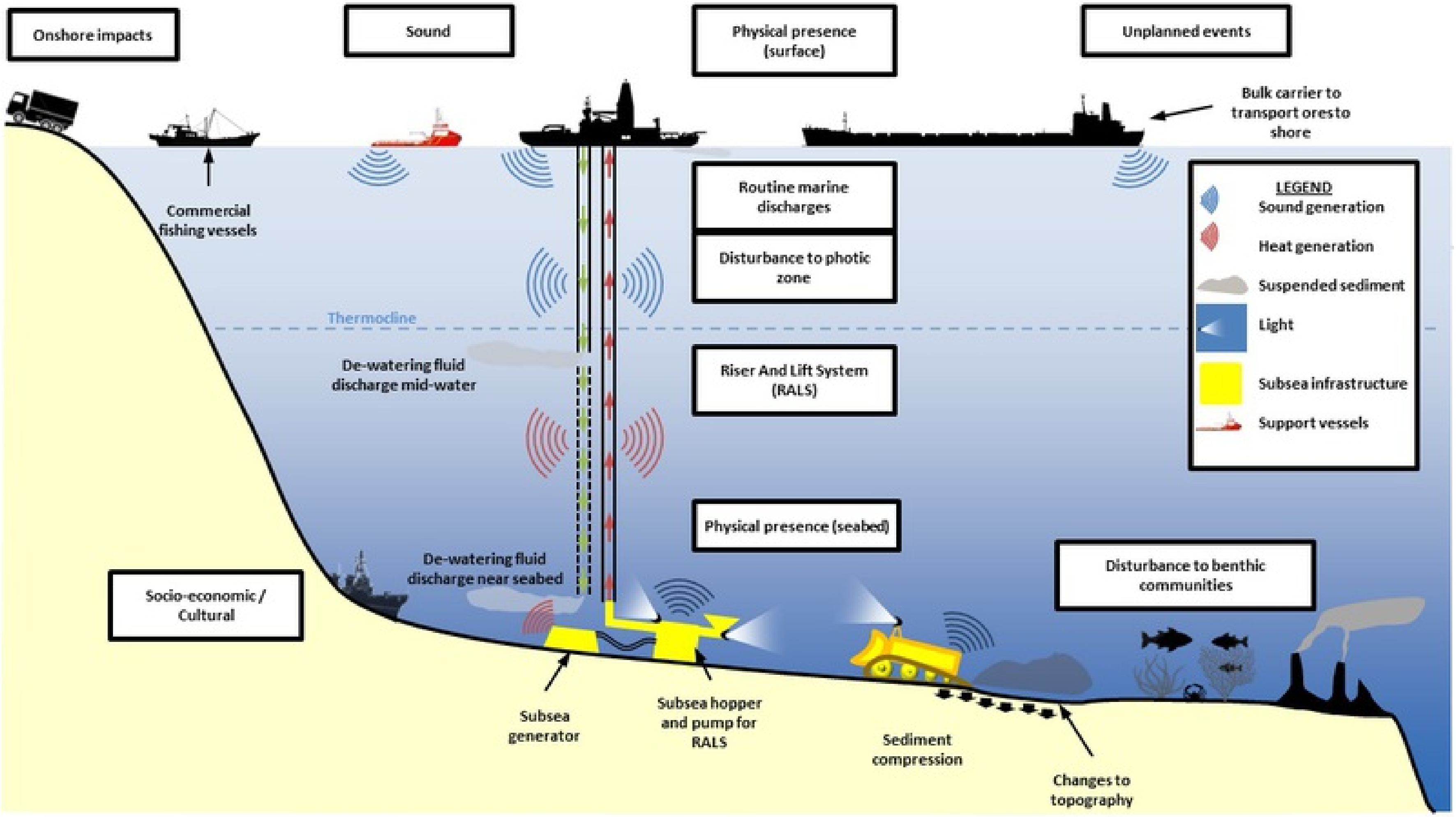


Figure 9: Potential impacts of seabed mining (Source: Central Dredging Association)[32]

[32] CEDA Infographic from: https://dredging.org/news/news/ceda-deep-sea-mining-information-portal-goes-live/detail_news=0048_000334_000000 [Viewed 01/02/2018]

Table 1 – Potential impacts associated with different resource mining activities, subject to further technical developments in extractive equipment. Based on ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC) (ICES, 2015)[33] and Washburn et al., 2019 and references therein. Future developments (e.g. in closed systems to constrain plumes) may negate some of these impacts.

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
SMS	Removal of surface or sub-surface ores	Variable – depends on SMS precipitation rate	Immediate area, likely focusing on inactive sites.	Habitat removal is considered a high risk source at both active and inactive vents, because of the following biological consequences: <u>Active vents:</u> biodiversity loss, loss of reproductive capacity, trophic modifications, altered organism behaviour, connectivity disruptions, local extinction and loss of standing stock. <u>Inactive vents:</u> altered primary and secondary production, trophic modifications and altered organism behaviour and community structure. Hydrothermal fluid changes are also considered high risk at active vents, because of the following biological consequences: biodiversity loss, loss of reproductive capacity and connectivity disruptions. These fluid changes are not as high risk to inactive vents, where habitat alteration is considered more important. Removal of surface or sub-surface ores is also likely to cause; destruction of habitat of attached epifauna; altered hydrography; mineral alteration (hard substrata).	For active sites: unknown - depends upon substrate precipitation/ fluid geochemistry. For inactive sites: no recovery of sulphide deposits. Mine site will be buried by background sedimentation.
	Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Could be tens of kilometres beyond licensed area boundaries.	Plume toxicity is considered high risk at active vents, but a higher risk to inactive vents. Plumes of all nature are also likely to cause: alteration of water properties; masking of	Tens to hundreds of years if epifaunal organisms are impacted on bare rock surfaces

[33] https://www.researchgate.net/profile/Jeroen_Ingels/publication/275348702_Report_of_the_ICESNAFO_Joint_Working_Group_on_Deep-water_Ecology_WGDEC_16-20_February_2015_Horta_Azores_Portugal_ICES_CM_2015ACOM27/links/553a0fa80cf247b858815eea/Report-of-the-ICES-NAFO-Joint-Working-Group-on-Deep-water-Ecology-WGDEC-16-20-February-2015-Horta-Azores-Portugal-ICES-CM-2015-ACOM27.pdf

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
				bioluminescence; sunlight attenuation (at applicable depths); increased POC deposition; nutrient enrichment. Sediment plumes near the seabed, whether vehicle generated or tailings return plume are also likely to cause; Smothering of seabed fauna e.g. clogging of suspension feeding structures; organism burial; alteration in deposit-feeding behaviour; sediment particle size changes.	
	Release of sulphides, metals and industrial chemicals	Variable – depends on depth, mining process, local ecology	Local area affected by dissolution and dispersal of chemicals released at the mining site	Plume toxicity is considered high risk at active vents because of the following biological consequences: trophic modifications, local extinction, changes in primary and secondary production and regional extinction. Plume toxicity is considered an even higher risk at inactive vents because of the biological consequence of changes in primary and secondary production. Acute and/ or chronic toxicity effects are likely in elevated concentrations	Unknown
	Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres	Plumes of all nature are likely to cause: toxic effects (see below); alteration of water properties; masking of bioluminescence; sunlight attenuation (at applicable depths; nutrient enrichment. Sediment plumes in the water column, whether vehicle generated or tailings return plume, are also likely to cause the release of CO_2 in surface waters. If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient	Recovery will be rapid once activity ceases

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
				load from deep waters introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area.	
	Size and ecosystem function fractionated impact on life	Variable timescales Shifts in sediment grain size distribution. May also include changes in fine scale (biologically relevant) bathymetry Sediment compaction	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition. Shifts at crust sites likely larger than nodule mining sites Sediments below and adjacent to mining vehicle tracks compressed	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively. Changes in biogeochemistry. Sediments compacted by vehicle tracks can kill fauna living in the sediments.	These effects may be long lasting as background sedimentation rates are low.
	Noise, and electromagnetic radiation	During mining activity	The sound characteristics of DSM mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The Area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short-term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.
	Light Pollution	During mining activity	The introduction of light at these depths, which are characteristically dark environments, is not yet	Introduction of light in dark environment, , where some deep-sea species are sensitive to low amounts of light.	Impacts on species not known. Short term, likely to recover but unknown impacts on

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
			known but likely to impact feeding and spawning behaviours.		population from long term exposure.
	Species introduction or spread	Variable, depends on conditions and whether species survive and establish	Likely just area covered by equipment in short term, but long term could be wider reaching if introduced species spread.	Scientific sampling equipment has potential for unintentional transport of animals from one site to another. Such species could establish permanently, altering community structure.	Potential for recovery unknown as no study on recovery in minimal recorded cases of species introduction
Crusts	Removal of crusts	Long term. Probably hundreds to thousands of years	Immediate area, down to 5 cm to 25 cm of the seabed. A single crust mine may typically disturb 10 – 20 km^2 of seabed per year.	Habitat removal is considered the highest risk impact to crust environments because of the following biological consequences: changes to secondary production, connectivity disruption and loss of reproduction. Removal of crusts is also likely to cause; Destruction of habitat of attached epifauna; mineral alteration (hard substrata).	For the crust, some hard substrate will remain. For biota, tens to hundreds of years, if the same biota ever return.
	Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Could be tens of kilometres beyond licensed area boundaries. Plumes are likely to flow down the seamount flanks	The near-seabed plume is considered a high risk impact, particularly in light of the potential smothering of seabed animals, particularly including clogging of suspension-feeding and respiratory structures. This is because of the following biological consequences: altered organism behaviour, loss of standing stock, connectivity disruption, trophic modifications, altered community structure, local extinction and loss of reproduction. Plumes of all nature are also likely to cause: alteration of water properties; masking of bioluminescence; sunlight attenuation (at applicable depths); toxic effects; increased POC deposition; nutrient enrichment.	Likely to be very slow (tens to hundreds of years) if epifaunal organisms are impacted on bare rock surfaces

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
				Sediment plumes near the seabed, whether vehicle generated or tailings return plume are also likely to cause; organism burial; alteration in deposit-feeding behaviour; sediment particle size changes.	
	Release of metals from crusts, and industrial chemicals	Variable – depends on depth, mining process, local ecology	Local area affected by dissolution and dispersal of chemicals released at the mining site	Acute and/ or chronic toxicity effects	Unknown
	Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres	Plumes of all nature are likely to cause: toxic effects (see below); alteration of water properties; masking of bioluminescence; sunlight attenuation (at applicable depths); increased POC deposition; nutrient enrichment. Sediment plumes in the water column, whether vehicle generated or tailings return plume are also likely to cause the release of CO2 in surface waters. If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area.	Recovery will be rapid once activity ceases
	Size and ecosystem function fractionated impact on life	Variable timescales Shifts in sediment grain size distribution. May also include changes in fine scale (biologically	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition.	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively. Changes in biogeochemistry. Sediments compacted by vehicle tracks can kill fauna living in the sediments.	These effects may be long lasting as background sedimentation rates are low.

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
		relevant) bathymetry Sediment compaction	Shifts at crust sites likely larger than nodule mining sites Sediments below and adjacent to mining vehicle tracks compressed		
	Noise and electromagnetic radiation	During mining activity	The sound characteristics of DSM mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The Area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short-term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.
	Light Pollution	During mining activity	The introduction of light at these depths, which are characteristically dark environments, is not yet known but likely to impact feeding and spawning behaviours.	Introduction of light in dark environment, where some deep-sea species are sensitive to low amounts of light.	Impacts on species not known. Short term, likely to recover but unknown impacts on population from long term exposure.
	Increased temperature	During mining activity	Drilling and vehicle operation will release heat. Dewatering material may be up to 11° warmer than surrounding seawater (Steiner, 2009)	Elevated temperature of dewatering material may have measurable effects on the bathypelagic fauna Increased heat in deep sea could affect growth, metabolism, reproductive success and survival of some species (Bashir et al., 2012, Miller et al., 2018)	Unknown

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
	Species introduction or spread	Variable, depends on conditions and whether species survive and establish	Likely just area covered by equipment in short term, but long term could be wider reaching if introduced species spread.	Scientific sampling equipment has potential for unintentional transport of animals from one site to another. Such species could establish permanently, altering community structure.	Potential for recovery unknown as no study on recovery in minimal recorded cases of species introduction
Nodules	Removal of nodules	Long term, dependant on the fauna, which can range from years to hundreds of year, whereas sessile organisms that live in the modules will probably never return[34]. Probably millions of years (Sharma and Smith, 2019; Krishnaswami *et al.*, 1982)	Down to 30cm of the seabed. A single nodule mine may disturb up to 300km^2 of seabed per year (ECORYS, 2014)	Habitat removal is considered the highest risk impact to both the nodule and surrounding nodule sediment environments, as it is likely to cause; removal of habitat for attached epifauna; mineral alteration (hard substrata) Habitat removal is considered high risk because of the following biological consequences: <u>Nodules:</u> the loss of reproductive capacity, trophic modifications, altered community structure, altered organism behaviour, local extinction and loss of standing stock. <u>Nodule sediments:</u> altered community structure, decreased secondary production, trophic modifications, loss of standing stock.	Millions of years for nodules to reform[23] (Krishnaswami *et al.*, 1982).
	Sediment laden plumes near seabed	During mining activity and drift away from the mining area	Spread will depend on mining process and technology, sediment concentration and local currents. Could be tens of kilometres beyond licensed area boundaries.	Burial of seabed animals by plumes is considered a high risk impact to both the nodule and surrounding nodule sediment environment. There is also a high risk from the vehicle-generated plume in general, particularly as: Plumes of all nature are also likely to cause: alteration of water properties; masking of bioluminescence; sunlight attenuation (at applicable depths); toxic effects; increased POC deposition; nutrient enrichment.	Tens to hundreds of years if epifaunal and pelagic organisms are impacted on nodule or seabed surfaces

[34] Except that a certain amount of nodules is left over and/or restoration measures are functioning

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
				Sediment plumes near the seabed, whether vehicle generated or tailings return plume are also likely to cause; alteration in deposit-feeding behaviour; sediment particle size changes. Vehicle-generated plumes, in particular subsequent burial, are considered high risk because of the follow biological consequences: Nodules: decreased secondary production, loss of reproductive capacity, trophic modifications, altered community structure, altered organism behaviour and disruptions in connectivity. Nodule sediments: reproduction loss, loss of standing stock, biodiversity loss, connectivity disruptions and regional extinction.	
	Release of metals from nodules, and industrial chemicals	Variable – depends on depth, mining process, local ecology	Local area affected by dissolution and dispersal of chemicals released at the mining site	Acute and/ or chronic toxicity effects	Unknown
	Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume (concentration) of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres – but the sediment cover on the seafloor after final settling of suspended particles will be extremely thin (few 10ths to 1000ths of a millimeter)	Plumes of all nature are likely to cause: toxic effects; alteration of water properties; masking of bioluminescence; sunlight attenuation (at applicable depths); increased POC deposition; nutrient enrichment. Sediment plumes in the water column, whether vehicle generated or tailings return plume are also likely to cause the release of CO2 in surface waters. If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters may stimulate primary production and of	Recovery will be rapid once activity ceases

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
				different species than those normally occurring in the area.	
	Size and ecosystem function fractionated impact on life	Long term. Shifts in sediment grain size distribution. May also include changes in fine scale (biologically relevant) bathymetry Sediment compaction, long term, tens of thousands of years (Krishnaswami *et al*., 1982)	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition. Shifts at crust sites likely larger than nodule mining sites Sediments below and adjacent to mining vehicle tracks compressed Down to 30cm of the seabed. A single nodule mine may disturb up to 300km^2 of seabed per year (ECORYS, 2014). However, typical numbers are 50 – 150 km^2 per year, assuming annual production of 3 Mill tons per year.	Removal/disturbance of habitat of microorganisms, meiofauna, macrofauna and changes in biogeochemistry. This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively. Changes in biogeochemistry. Sediment compaction is considered a high risk impact at nodule sediment environments. This is because sediments compacted by vehicle tracks can affect organisms within the sediment by reduced mobility, which can kill fauna living in the sediments by compacting them.	These effects will be long lasting as background sedimentation rates are low.. For example Vonnahme et al. (2020) suggest that microbiologically mediated biogeochemical functions need over 50 years to return to undisturbed levels. Regarding sediment compaction, this is unknown, and depends on benthic activity within the sediment column (Krishnaswami *et al*., 1982).
	Noise and electromagnetic radiation	During mining activity	The sound characteristics of deep-sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The Area	Possible masking effects on marine mammals that use the main frequencies emitted. The CCZ is not known as a breeding or feeding ground, although some migrating species may be present. Impact may be a relatively small diversion to normal migration routes to avoid noise.	Impacts on species are not known. While short-term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.

Resource Type	Impact	Longevity of impact	Potential impacted area	Nature of impact	Potential for recovery
			impacted is generally a product of frequency and amplitude, so cannot be determined at present.		
	Light Pollution	During mining activity	The introduction of light at these depths, which are characteristically dark environments, is not yet known but likely to impact feeding and spawning behaviours.	Introduction of light in dark environment, where some deep-sea species are sensitive to low amounts of light.	Impacts on species not known. Short term, likely to recover but unknown impacts on population from long term exposure.
	Species introduction or spread	Variable, depends on conditions and whether species survive and establish	Likely just area covered by equipment in short term, but long term could be wider reaching if introduced species spread.	Scientific sampling equipment has potential for unintentional transport of animals from one site to another. Such species could establish permanently, altering community structure.	Potential for recovery unknown as no study on recovery in minimal recorded cases of species introduction
	Increased temperature	During mining activity	Drilling and vehicle operation will release heat. Dewatering material may be up to 11° warmer than surrounding seawater (Steiner, 2009)	Elevated temperature of dewatering material may have measurable effects on the bathypelagic fauna Increased heat in deep sea could affect growth, metabolism, reproductive success and survival of some species (Bashir et al., 2012, Miller et al., 2018)	Unknown

Suspended sediments

As seen from Table 1, potential impacts to the deep-sea environment will not be confined to the physical removal of material from the seafloor. Dispersal of fine sediments in abyssal environments by bottom currents and diffusion is likely to occur over wide spatial and temporal scales. The sediment plumes (assuming that effective closed systems cannot be adopted) may be much more significant in flat nodule fields than at hydrothermal vent fields as vent fields are often more topographically constrained than abyssal hills and plains. Plumes of sediment-laden water may be generated by the mining operation and also result from sediment-laden discharge water slurries that are dewatered from the support vessel[35]. Depending on the depth of discharge they have the potential to be transported to and impact on adjacent Contract Areas and beyond. The formation, effects, and controlling of such fine sediment plumes are currently being investigated by e.g. the Jacobs University Bremen and the Massachusetts Institute of Technology & Scripps Institute of Oceanography, USA[36].

Light

If any mining operations take place under continuous illumination (e.g. to ensure performance surveyance by cameras), there are possible impacts upon local fauna. There are few precedents for prolonged exposure to light in the deep-sea, barring a small number of deep-water scientific or industrial installations, which makes it challenging to assess potential impacts.

Noise and vibration

The machines and pumps employed for the collection and transport of mineral ore are likely to be driven by electric power from the surface and emit a constant noise of unknown frequency range and amplitude. Other motors will likely operate in the water column and on or near the seabed. As it is envisaged that works will take place 24/7 this will be a source of constant noise impairing on acoustic communication underwater. The sphere of influence may be substantial. During exploration, SMS deposits and cobalt crust require core drilling for assessment although this will not be a constant source of disturbance. In addition, the stationary vessels above the mine site also generate a constant source of noise and will likely remain 'on station' for months at a time, if not for the full duration of the mining operation.

Whilst many studies have carried out investigations of the impacts of underwater noise on marine species (Williams et al., 2015), there is relatively little data available for the sensitivity of deep-sea organisms to noise (reviewed by Miller et al., 2018). For abyssal ecosystems there may also be fewer topographic barriers to noise than in ridge or seamount ecosystems (SMS deposits and crusts). Marine mammals and fish which rely on acoustic methods for hunting and communication may be impacted by noise generated by the mining collectors and riser pipes. The full extent of these potential impacts has yet to be determined as occurrence records of most deep-diving cetaceans are limited.

Along with underwater noise, there is a potential impact of vibration from mining equipment. However, few studies to date have investigated the effect of increased vibrations on benthic organisms (though see Roberts and Elliott, 2017), and the potential impact is uncertain.

Contaminants

[35] https://www.eu-midas.net/sites/default/files/downloads/Briefs/MIDAS_brief_Introduction_lowres.pdf [Viewed 06/02/2018]

[36] http://mseas.mit.edu/Sea_exercises/DeepSeaMining/; https://scripps.ucsd.edu/news/scripps-led-research-team-study-sediment-plumes-sea

Deep-sea mineral deposits comprise complex mixtures of potentially toxic elements, including metals (e.g. copper, zinc and lead) and sulphide (MIDAS, 2017; ECORYS, 2014; SPC, 2013). These toxicants may be released at sea during different stages of the mining processes. Toxicants will impact organism physiology and can perturb whole populations and lead to ecosystem impacts, making it essential to accurately predict toxic effects to assess the ecological impacts of DSM. Whilst there are extensive data assessing toxicity in shallow water organisms, these may not be representative of toxicity in deep-sea organisms, many of which differ biochemically and physiologically (MIDAS, 2017). Some vent species have uncharacteristically high metabolic rates for deep-sea fauna, suggesting that the scope for physiological variability across the breadth of potentially impacted fauna is considerable.

The mining of SMS for instance is likely to expose 'fresh' sulphide mineral surfaces to seawater which may result in the oxidation of those sulphides and the release of heavy metals, although the magnitude of such an effect is yet to be determined, given black smokers continuously produce "fresh" sulphide minerals to the seawater around it. The fauna associated with the black smokers are constantly exposed to these minerals and their oxidised derivatives. However, the quantities and composition of toxicants released by seabed mining may be different from natural levels, depending on the geochemical context. Although the majority of toxicity effects assessed by the MIDAS project were hydrothermal vent fauna, potentially toxic elements can be released at SMS, nodules and crust deposits. Avoidance behaviour has been exhibited by abyssal fauna (e.g. abyssal holothurian *Peniagone sp.,* Peru Basin) when exposed to contaminated sediments. It is therefore suggested that it will be necessary to assess the toxicity of individual mineral deposits independently to identify the potential toxic risk during mining (MIDAS, 2017).

MITIGATION AND RESTORATION

Mitigation measures are currently early in their development and implementation due to the newness of the sector. However, several possible mitigation measures have already been proposed (see Van Dover 2014, Miller et al., 2018, Cuvelier et al, 2018);

- Avoidance - establishment of marine protected areas or set aside areas to help maintain connectivity, population biodiversity and regional biodiversity, avoid clogging of vent fluid exits to allow survival of microbial population associated with the vent fluids (specific to SMS).
- Minimisation – reduction of plume extent and toxicity, spatio-temporal restrictions (maximum sizes and geographical positions of mining patches, seasonal closures), prevention of further human post-mining activities at previously mined sites, reduction in light and noise.
- Technological adaptations– closed mining systems, selective passage of fauna through collector, reduced weight of mining vehicles to avoid compaction of sediment (latter two are specific to nodule mining)

The Managing Impacts of Deep-sea Resource Exploitation (MIDAS) project recommends that mitigation and restorative actions, specific to each ecosystem are considered and, if proven feasible, could include; the deployment of artificial substrates (to allow benthic fauna to recolonise following resource removal), nutrient enhancement, and propagation and-transplant. However, proof of concept, and proof of technical feasibility of carrying out such restorative actions is currently lacking, and high levels of uncertainty remain in predicting the success of any of the restoration options discussed (MIDAS, 2016). Restoration experiments for nodule-associated fauna are currently being carried out in the German license area in the CCZ within the framework of the JPIO project MiningImpact II. In April 2019, ninety 50 x 50 cm frames containing artificial hard substrates (nodules and nodule substitutes made of deep-sea clay) were deployed on the seabed. These frames will remain on the seabed and will be revisited and studied during the next decade(s). Van Dover *et al*. (2014) concluded that mitigating loss of species richness and large-scale restoration of deep-sea ecosystems after mining is likely to remain expensive and technologically difficult, or impossible.

Van Dover *et al*. (2017a) discuss possibilities for in-kind or like-for-like offsets within a biogeographical region, noting the potential difficulties in offsetting spatially discrete deep-sea species and habitats, where the evidence base for ecosystem form and function, connectivity and recovery is limited. They also note that considering out-of-kind offsets, such as restoring coral reefs in exchange for loss of deep-sea biodiversity, assumes that any relationship between the two ecosystems in terms of value is understood and that compensating biodiversity loss in international waters with biodiversity gains in national waters could constitute a transfer of wealth that runs counter to the Law of the Sea. MIDAS (2016) also conclude that environmental offsetting is unlikely to be effective due to the lack of comparable ecosystems which require restoration.

MONITORING REQUIREMENTS

Monitoring of impacts

There is limited precedent for monitoring impacts of extractive activities on the deep seafloor, particularly over the likely spatial scales of nodule mining. SMS mining is likely to be confined to a number of consecutively mined small areas of the seafloor which each last only for 2-3 years of exploitation. Nodule mining however is likely to happen over 150 to 200 km^2 per year, per operator.

Generic and broad monitoring requirements for exploration contractors do exist: contractors are expected to carry out baseline investigations in their exploration area and should report on these annually to ISA following a long list of requirements (ISBA/25/LTC/6.Rev.1) although no strict temporal and spatial minimum measurement requirements have been set. As with all monitoring, monitoring programmes should be hypothesis driven, and it is only when the hypothesis is proven or disproven, with confidence, that monitoring should cease. Further guidance is needed on identifying hypotheses and an evidence–based time limit on the duration of monitoring.

Specific and detailed monitoring requirements associated with DSM have not yet been set by the ISA but will likely include the following considerations, with the relative importance varying between the different target ecosystems (see Van Dover *et al*., 2018b; Niner *et al*., 2018; Van Dover *et al*., 2017b; Van Dover *et al*., 2014; Van Dover *et al*., 2011):

- Release, persistence and dispersal of heavy metals and other naturally occurring toxicants
- Release, persistence and dispersal of introduced chemicals used in the mining process;
- Changes to local and distal pelagic sediment load and seafloor sedimentation rates;
- Recovery rates of physical habitat;
    - This is likely only a consideration for active SMS sites, since crust/ nodule and inactive SMS deposits will either recover over millennial scales or not at all.
- Recovery of local biodiversity, including;
    - Fauna endemic to the mineral deposits (either because of the physical habitat it offers, or the food resources derived from it).

- Opportunistic attendant fauna.

Legacy of impacts

It is generally accepted, despite the limited information, similar to other extractive industries, that impacts related to the near-total removal of a substantial portion of the immediate habitat and potential disturbance to the surrounding habitat will be observable for many years, maybe even decades to centuries , following the end of mining operations with site and mineral-specific differences. Beyond the immediate vicinity, where physical disturbances will occur, the extent and nature of these impacts is likely to be very variable between techniques and resources and still highly uncertain, not least because there are no exploitation operations underway[37]. However, approaches such as the step wise approach taken by GSR could help inform assessments. Some enduring impacts, potentially including permanent biodiversity loss, are considered likely (van Dover *et al*., 2017), introducing a strong element of value judgement into the assessment of 'recovery'. The international community must agree on what it considers to be an acceptable ecological cost for DSM operations to be permitted at any level of disturbance (Van Dover *et al*., 2017)

Given the uncertainties, it may not be practical to impose a time limit on the requirements for post-mining monitoring and perhaps more sensible to suggest that monitoring activities continue until the indicator returns to within an agreed range of its baseline value, dependant on site and receptor specifics (see method developed by Cooper, 2013). Further guidance is needed on identifying an evidence–based time limit on the duration of DSM monitoring, informed by research programmes on seabed recovery.

Instrumentation

It is increasingly possible for ecosystems to have instruments (such as sensors) installed to monitor impacts and/or changes. Both Canada (Ocean Networks Canada NEPTUNE Observatory[38]) and France[39] include such instruments in their national strategies. Such approaches may be tractable for monitoring of some impacts, even in relatively remote systems, given the costs of vessel operation. Until the range of potential impacts are better defined, it is difficult to draw any conclusions about the applicability of remote monitoring. Whilst the support vessel is on station, it may be relatively straightforward to meet observation and monitoring needs (see SERPENT programme for example from oil/gas[40]) but for the legacy aspects of monitoring, a (semi) permanent, communicable observatory may be the most practical option. Although it is noted that autonomous monitoring systems (e.g. robotics) are being developed that will be more cost-effective and have a higher spatial and temporal coverage.

KNOWLEDGE GAPS

[37] https://www.deme-gsr.com/about-gsr/
[38] https://www.oceannetworks.ca/article-tags/neptune [viewed 06/02/2018]
[39] http://www.fixo3.eu/observatory/momar/ [viewed 06/02/2018]
[40] http://www.serpentproject.com/ [viewed 06/02/2018]

DSM is an emerging industry and currently the knowledge of the ecosystems, and of the potential impacts upon them by mining activity, is limited. Commonly accepted methods of environmental impact assessment, subsequent management and the identification of mitigation and environmental compensation rely on the scientific understanding of the receiving environment. However, such understanding is only just emerging with a few scientific surveys being conducted in areas of interest to the DSM industry in order to identify ecological baseline conditions and to determine the suitability of common methods of impact assessment. In the absence of environmental understanding, risks and the ability to detect significant harm associated with DSM must be considered.

Current identified evidence gaps in scientific evidence, include, but are not limited to:

- Whether recovery would represent a return to previous communities and habitats, or whether the environment could shift to altered or depauperate states (ICES, 2015);

- Understanding of impacts, especially considering that environmental survey is expected to only be sought by regulators within potential mined areas and areas potentially affected by the mining activities. Clarity over cumulative impacts between DSM and other anthropogenic activities and naturally arising impacts is also required;

- Understanding of habitat and species ecology within baselines, including characterisation of pelagic and benthic biodiversity, species distributions and dispersal ranges, ecosystem resilience, endemicity, recruitment, functions and services;

- Regional variability in community composition, potential source and sink populations;

- Natural community variability, succession patterns and potential alternative states of the communities;

- Large-scale mining disturbance studies to allow assessment of the spatial scales and intensities of disturbance resulting from DSM;

- Assessment of recovery time scales of effected soft-sediment and nodule communities and pelagic ecosystems;

- Lack of understanding of connectivity of populations at active and inactive sites and the extent to which local populations are maintained through local or long-distance recruitment events; and

- Lack of understanding of ecotoxicology and sediment loading of plumes, including return plumes.

- Lack of knowledge about the methods and technologies that will be used. Magnitude of effects are difficult to predict without this information.

- Lack of a benefit sharing mechanism to comply with the principle of the Common Heritage of Mankind.

- Lack of baseline information

- Lack of knowledge about the business models of some contractors who want to accomplish deep sea mining.

Regarding deep sea mining within the OSPAR Maritime Area, OSPAR will need to consider how these knowledge gaps and uncertainties should be addressed, including consideration of what actions are necessary to ensure that the general obligations and specific measures and approaches agreed under the Convention and its Annexes are upheld, which includes inter alia the application of the precautionary principle, the polluter pays principle, BAT/BEP and the ecosystem approach. In that regard, a second report in this series will provide an overview of which OSPAR principles, measures and approaches are applicable/relevant to DSM.

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APPENDIX 1

Definitions/Glossary

ABNJ	Areas Beyond National Jurisdiction. Includes 'The Area' and the High Seas
Area	The seabed and its mineral resources in areas beyond national jurisdiction, i.e. also beyond the outer limits of the extended continental shelves of coastal states (Art. 136 UNCLOS).
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources, Germany)
CCFZ	Clarion-Clipperton Fracture Zone, a geological submarine fracture zone of the Pacific Ocean
Critical metals	Metals essential for economic development, including high-technology applications, but which may suffer a high supply risk
DSM	Deep Seabed Mining: all activities related to the prospecting, exploration and exploitation of mineral resources in waters deeper than 200m.
ECSC	Extended Continental Shelf Claims: submissions by coastal States concerning the establishment of the outer limits of the continental shelf beyond 200nm, which relates to the seabed and subsoil under the claimants jurisdiction. Approval process administered by the Commission on the Limits of the Continental Shelf. Mining rights and fishing rights (sedentary species) are exclusively allocated to the coastal State.
EEZ	Exclusive Economic Zone: water column under coastal States jurisdiction, which extends up to the maximum limit of 200nm from the landward baseline. Mining rights are exclusively allocated to the coastal State. Fishing rights are allocated to the coastal State.
EIA	Environmental Impact Assessment.
EIHA	Environmental Impacts from Human Activities, OSPAR Committee.
EIS	Environmental Impact Statement.
EMMP	Environmental Management and Monitoring Plan.
GH	Gas Hydrates: Sub-seafloor deposits of 'frozen' short-chain hydrocarbons (usually methane and ethane).
GSR	Global Sea Mineral Resources is a subsidiary of the DEME Group focused on the development of sustainable ocean mineral resources.
IPCC	Intergovernmental Panel on Climate Change
IRP	International Resource Panel: a body of scientists launched by the United Nations Environment Programme (UNEP) in 2007 to build and share the knowledge needed to improve our use of resources worldwide.
ISA	International Seabed Authority: established under UNCLOS, responsible for the managing the Area and its mineral resources for the benefit of mankind as a common heritage. ISA must ensure the effective protection of the marine environment from harmful effects of mineral resource extraction activities.
LTC	Legal and Technical Commission. Organ of the ISA Council, consisting of 30 members elected for a period of five years.
MPA	Marine Protected Areas.
OECD	Organisation for Economic Co-operation and Development
PMS	Polymetallic Sulphides: General term that includes SMS, nodules, and seafloor crusts. As ISA uses PMS, it is interchangeable with SMS.
RALS	Riser and Lift/ Lifting System: Riser system for transporting ore slurry from the seabed to the support vessel.

SMS	Seafloor Massive Sulphide (deposits): Any area of the seafloor which contains high concentrations of metal sulphides (or other ores) introduced by seafloor hydrothermal processes. May be found at active or inactive vent fields.
UNEP	United Nations Environment Programme.
UNCLOS	United Nations Convention on the Law of the Sea.

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Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.

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