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MEMOIRS
on the Marine Environment

Potential pressures and impacts of deep-seabed polymetallic nodule mining

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Perspectives of the Belgian stakeholders from the round-table meetings

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GENERAL PREFACE

Tasnim Patel, Ellen Pape, Ann Vanreusel & Steven Degraer

The report is at the sole discretion of the authors and should by no means be interpreted as a consensus view of any kind (e.g., agreement with the process or content) among neither the consulted [1] stakeholders nor the federal government bodies present during the round table meetings.

Deep-seabed mining for polymetallic nodules is an emerging industry poised for initial development in the Clarion-Clipperton fracture Zone (CCZ) in the northeast Pacific Ocean. This region is characterised by its high abundances of high-grade, economically viable polymetallic nodules. Therefore, 18 exploration contract areas have been delineated to date where future nodule mining may take place. One such contract was granted to the Belgian private company Global Sea Mineral Resources NV (GSR) in 2013, with Belgium acting as the sponsoring State.

The International Seabed Authority (ISA) is an autonomous organisation within the United Nations common system, established under the United Nations Convention on the Law of the Sea (UNCLOS). During the current exploration phase, the ISA faces the task of managing and regulating a nascent industry engaged in developing, testing, and monitoring the environmental impacts and effectiveness of mining (component) technologies, and conducting resource assessments and environmental baseline studies. Simultaneously, it must ensure that the resource environments which could be adversely affected by deep-seabed polymetallic nodule mining are adequately protected from harmful effects. Growing concerns about the environmental impacts of deep-seabed polymetallic nodule mining have been raised, prompting scientists to pinpoint the significant knowledge gaps that must be addressed prior to exploitation. To achieve a breakthrough in this stalemate, initiated in 2022–2024 by the Cabinet of the Belgian Minister for the North Sea and facilitated by Belgian scientists, this report is the culmination of round-table discussions held by the authors of this report, marine ecologists of Ghent University, and the Institute of Natural Sciences and multiple stakeholders i.e., federal government departments including legal specialists, Belgian Federal Public Services Economy, Environment, Foreign Affairs, and Public Health, industry, DEME-GSR and Jan de Nul, as well as Belgian representatives from the environmental non-governmental organisations, Greenpeace, Pew Charitable Trusts, and WWF.

This initiative aimed at forming an integral link between societal concerns about environmental impacts and pressures of deep-seabed mining and both current and potential future research questions. With the application of this method, it can be argued that the research being conducted considers and furthermore addresses the concerns of society at large. This method could therefore facilitate the development of meaningful and societally relevant research and monitoring programs, to collect the data and information which may aid and foster evidence-based decision making, for example, but not limited

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[1] The compilation of Chapter 1 involved the request to stakeholders for: (1) a comprehensive list of societal concerns with regard to deep-seabed mining, (2) a list of scientific experts with whom to consult, and (3) feedback on the text, including the formulation, and comprehensiveness of the concerns, overarching and operational questions, along with a description of the methodology and outcomes during multiple rounds of review. In Chapter 2, owing to time constraints the methodology was introduced during the round table meetings, and stakeholder feedback was integrated into the text, however no full written drafts were distributed to the round-table participants prior to publication.

to, prior to the sponsorship of an exploitation contract.

A first phase of the initiative consisted of round-table discussions, intended to encourage open discourse to identify the societal concerns about offshore environmental impacts of deep-seabed polymetallic nodule mining, and to determine what data and information is needed to address these concerns (Chapter 1). As a result, twenty-nine overarching and eighty operational questions translating and summarising nine societal concerns (sensu stricto) plus a tenth concern (sensu lato) were collated and put forward for consideration by 25 external scientific experts. These operational questions were informed by the scientific knowledge base at the time of writing.

A precedent exists for the Belgian part of the North Sea whereby a protocol was established for translating societal concerns into operational scientific questions (Gill *et al*. 2020). In Chapter 1 a stepwise method was adopted based on the four stages which were already outlined by *Gill et al*. (2020). For completeness, all ten societal concerns that were formulated by the stakeholders were longlisted, disregarding the differences in opinions between the stakeholders as to what degree these concerns could be tackled or whether the societal concerns were evidence-based. Furthermore, these societal concerns were also not categorised by their perceived relevance or importance.

In a second phase, an approach was developed through which it can be evaluated whether the data and information needed to answer the operational questions linked to all societal concerns are covered by the current draft of the ISA mining code (Chapter 2). This evaluation was based on six criteria, related to the coverage of: (1) the response variable, (2) the spatial scale of the response variable, (3) the temporal scale of the response variable, (4) the explanatory variable, (5) the spatial scale of the explanatory variable, and (6) the temporal scale of the explanatory variable. Within the eighty operational questions, both direct (occurring at the time of) and indirect (occurring as a consequence of) effects of deep-seabed mining on polymetallic nodule environments were considered. Chapter 2 has the sole aim of demonstrating the analytical approach (i.e., proof-of-concept). It does not claim exhaustiveness nor robustness of the presented results. At a more mature stage, this approach should allow for the identification of knowledge gaps and cross-checking to what extent these are addressed by the current draft of the ISA Mining Code for all operational research questions derived from societal concerns. The authors of this report do not assert that the data and/or information needed to answer the operational questions will address all present and future scientific questions or societal concerns. Instead, they believe that additional scientific information will provide them with the capacity to identify and possibly address a more exhaustive list of questions than those developed in Chapter 1. Even so, the current list of questions provides a wide-ranging overview of the potential environmental impacts of deep-seabed polymetallic nodule mining.

Given that there are several uncertainties about the potential environmental impacts of deep-seabed polymetallic nodule mining, the methodology outlined in this report may serve as a tool to continuously update the data and information needs in function of effective environmental management of polymetallic nodule-bearing regions.

The proof-of-concept for constructive stakeholder engagement has therefore been positively demonstrated at the Belgian national level, and now forms a lynchpin with which future research strategies may be streamlined. This endeavour may be opened up to the international audience, the resulting data from which may inform the decision-making, environmental policy, and legislation in the next ISA Council meetings. The methodology presented both in this report and in future larger-scale initiatives could together sufficiently address the scientific knowledge gaps ultimately providing scientifically sound support to ocean governance.

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CHAPTER 1

ALIGNING SOCIETAL CONCERNS ABOUT PRESSURES AND IMPACTS OF DEEP-SEABED MINING FOR POLYMETALLIC NODULES WITH SCIENTIFIC RESEARCH QUESTIONS

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1. Introduction

Different deep-seabed mining stakeholders such as non-governmental organizations (NGOs), government representatives, and environmental scientists have expressed concerns about the environmental impacts of the potentially imminent exploitation of minerals on abyssal plains, currently one of the least human-impacted marine realms (*e.g.*, Dover *et al*. 2017; Niner *et al*. 2018; Amon *et al*. 2022b). As a result, several stakeholders including 24 ISA state parties, more than 800 (marine) scientists and 36 companies, have called upon a moratorium or a precautionary pause on deep-seabed mining (see https://savethehighseas.org/moratorium_2022/; consulted on the 8th of February 2024). In contrast, mining companies and many other ISA state parties, but also several (climate and geo-)scientists, claim that these minerals [1] are needed for the transition to a carbon-neutral economy (*e.g.*, Hein *et al*. 2013; Paulikas *et al*. 2020) and that the deep-seabed mining industry will have certain environmental, economic and geo-political advantages over terrestrial mining, which is currently one of the main sources of these minerals (Hein *et al*. 2013, 2020; Paulikas *et al*. 2020). However, these arguments pro deep-seabed mining have been contested (Månberger & Stenqvist, 2018; Miller *et al*. 2021; Amon *et al*. 2022b).

The International Seabed Authority (ISA) has been mandated to “organize, regulate, and control” all mineral resource-related activities in the Area (see Appendix 1, and Article 157, UNCLOS), while also ensuring the effective protection of the marine environment from harmful effects (see Article 145, UNCLOS) through, amongst other, drafting and implementing exploration and exploitation regulations and regional environmental management plans. The exploitation regulations are, at the time of writing, still in draft. Obviously, sound environmental management cannot go without a sound scientific knowledge base. Scientific research tackling both priority knowledge gaps in deep-sea ecology and the link between the deep sea and other systems like the climate system, is therefore key. Only with sufficient understanding of the ecosystem it is possible to learn how it may

[1] Note that, at the moment of writing, a set of separate round table meetings is taking place addressing the economic impacts of deep-seabed mining (or the needs for minerals), organized by the Belgian FPS Economy.

respond to large-scale exploitation. However, crucial in the prioritization of knowledge gaps is a strong involvement of different societal representatives to align scientific research with societal concerns.

The current report chapter deals with societal concerns about offshore environmental impacts of deep-seabed mining of polymetallic nodules in the Clarion Clipperton Fracture Zone (CCZ) in the northeastern Pacific Ocean through round table discussions with – for the first time – various Belgian stakeholders, namely NGOs, industry, scientists and the federal government. There were multiple objectives of these round table meetings. Firstly, the goal was to gather several Belgian stakeholders around the table to facilitate a constructive dialogue. Secondly, an inventory of the societal concerns of all stakeholders was made without any judgement on the relevance or importance. These societal concerns were translated into (tangible) scientific research or operational questions, which can help ascertain what data and information are needed to assess the grounds of these concerns.

2. Methodology

2.1. Round table meetings

During a process of several consecutive round table discussions with multiple Belgian stakeholder communities represented (see Appendix 2 for the list of participants including stakeholders consulted) initiated by the Belgian minister of the North Sea and facilitated by the present scientists and the North Sea cabinet policy advisor, all societal concerns expressed by the round table participants at the time of writing were listed. Linking these concerns to specific research questions is not always straightforward. Therefore, by means of an iterative four-way interaction between representatives from society, industry, the federal government, and science, societal concerns have been linked or translated to (where possible, tangible) scientific or operational questions which can be answered through scientific research or monitoring. Its application is meant to maximally align scientific research with societal concerns (two-way interaction) and to ensure transparency about how scientific research findings serve societal needs and helps to meet relevant obligations to protect the marine environment, including those imposed by the ISA. This stepwise process is illustrated in Figure 1 and has been successfully adopted in the design of focused research programmes for offshore windfarms overlapping with a marine protected area in the Belgian part of the North Sea (Gill *et al.* 2020). Note that for the offshore windfarms, two additional steps were included, *i.e.*, (1) a selection of priority operational questions (= step 5), and (2) monitoring and research (= step 6). These two steps were not undertaken in the present round table meetings because of time restrictions, but these may be implemented in future initiatives.

2.2. Societal concerns

The round table meetings focused on identifying the scientific (operational)

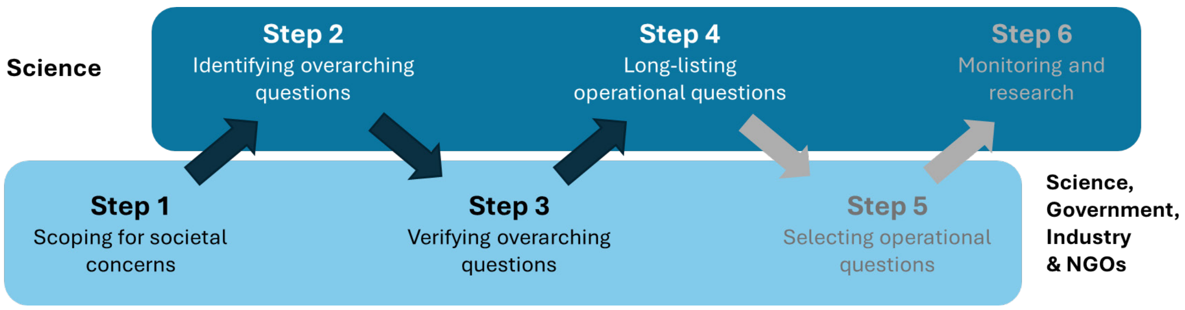

Figure 1. Schematic presentation of the stepwise approach toward linking societal concerns to society-informed monitoring and research programs. Modified from Gill *et al.* (2020). Steps 5 and 6 are shown in grey as they were not undertaken during the current round table meetings.

questions that need underlying scientific data and information to enable us to validate societal concerns about deep-seabed mining ecological impacts. We therefore explicitly focused on scientific data needs and excluded the societal concerns about guidance (*e.g.*, thresholds for and definitions of acceptability, meaningful harm), governance and decision processes (*e.g.*, procedural processes, societal impacts, who takes what decisions, representation at committees, data sharing, evaluation mechanisms, economic and global context) (see the two bottom categories of uncertainty displayed in Figure 2). The quantification terms used in the operational questions listed in this report *e.g.*, "how many…" therefore do not attempt to determine an acceptability threshold. Some elements excluded from this undertaking will be subject to future national stakeholder consultations prior to the consideration of a request for Belgian sponsorship of an exploitation license. Note that intersessional expert group meetings chaired by members of the Legal and Technical Commission of the ISA on thresholds for noise, sedimentation and ecotoxicology are being planned (ISBA/28/C/5) (ISA 2023). The intersessional expert group is expected to develop binding environmental threshold values for these three main environmental pressures potentially caused by deep-seabed mining operations, as identified by the ISA Council in 2022.

The societal concerns that were addressed here were expressed by the stakeholders consulted during the round table discussions, the facilitating Belgian scientific experts, and external scientific experts. The former group comprised of Belgian representatives of NGOs, the federal government and industry (see Appendix 2 for names and affiliations). The external scientific expert group consisted of 24 international deep-sea or open ocean scientific experts from various disciplines (see Figure 3), who responded to our request for input and which were either part of the JPIOceans (Joint Programme Initiative on Oceans) MiningImpact 2 project research consortium or who were named by the round table members. Collectively, this group comprised of well-informed members of society (mainly from Europe and North America) on the topic of deep-seabed mining and thus, have provided a critical viewpoint on the subject. Thus, the list of societal concerns arising from this process is a representative, albeit not necessarily exhaustive list. This list represents a mere snapshot, as data collection

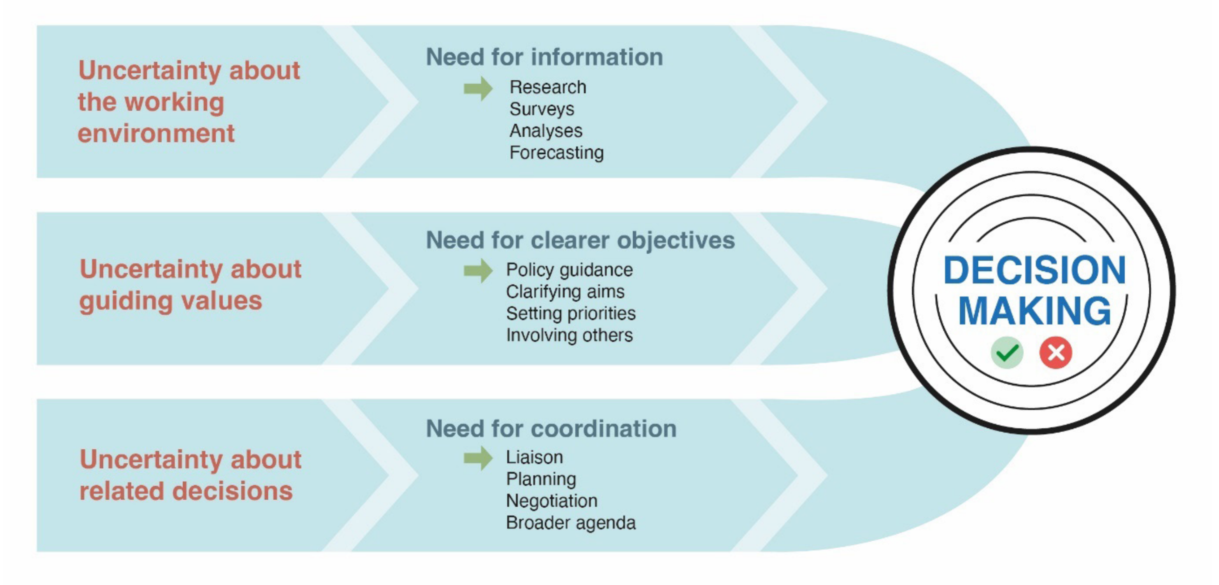

Figure 2. Schematic showing the three main categories of uncertainties that decision makers can be faced with, the needs that follow and how these can be met (indicated after the green arrow) (modified from Glasson *et al*. 2005). The current round table meetings focused on the category displayed on top, *i.e.*, the need for information.

and analyses are largely still ongoing and knowledge is continuously increasing. With this undertaking we wanted to assure that the science that is needed (= operational questions) to address the societal concerns as expressed during the round table meetings and to the degree possible at the time of writing, is correctly identified.

To obtain a comprehensive and clearly structured overview, the societal concerns expressed by the stakeholders consulted were linked to the subtopics defined by Amon *et al*. (2022a) to categorize key scientific knowledge gaps related to deep-seabed mining impacts (partly redrawn in Table 1). For some of the concerns listed in the Belgian round table meetings, new subtopics were added or existing subtopics were amended in case the concerns were not believed to be fully covered by the subtopics listed in the Amon *et al*. (2022a) study. Note that, contrary to Amon *et al*. (2022a), we focused on impacts of deep-seabed mining

2.3. Overarching and operational questions

Following the scheme shown in Figure 1, the round table discussions focused on linking societal concerns to scientific knowledge needs with regard to environmental impacts of deep-seabed mining. These discussions have led to the identification of broad overarching questions, and underlying, more specific operational questions. The latter questions, although of a generic and indicative nature, can be regarded as more tangible, scientific research questions. These accommodate for determining and selecting appropriate response variables or indicators later in the process by the scientific expert(s), which was beyond the scope of the present round table discussions. The relevant response variables or indicators will be based on the

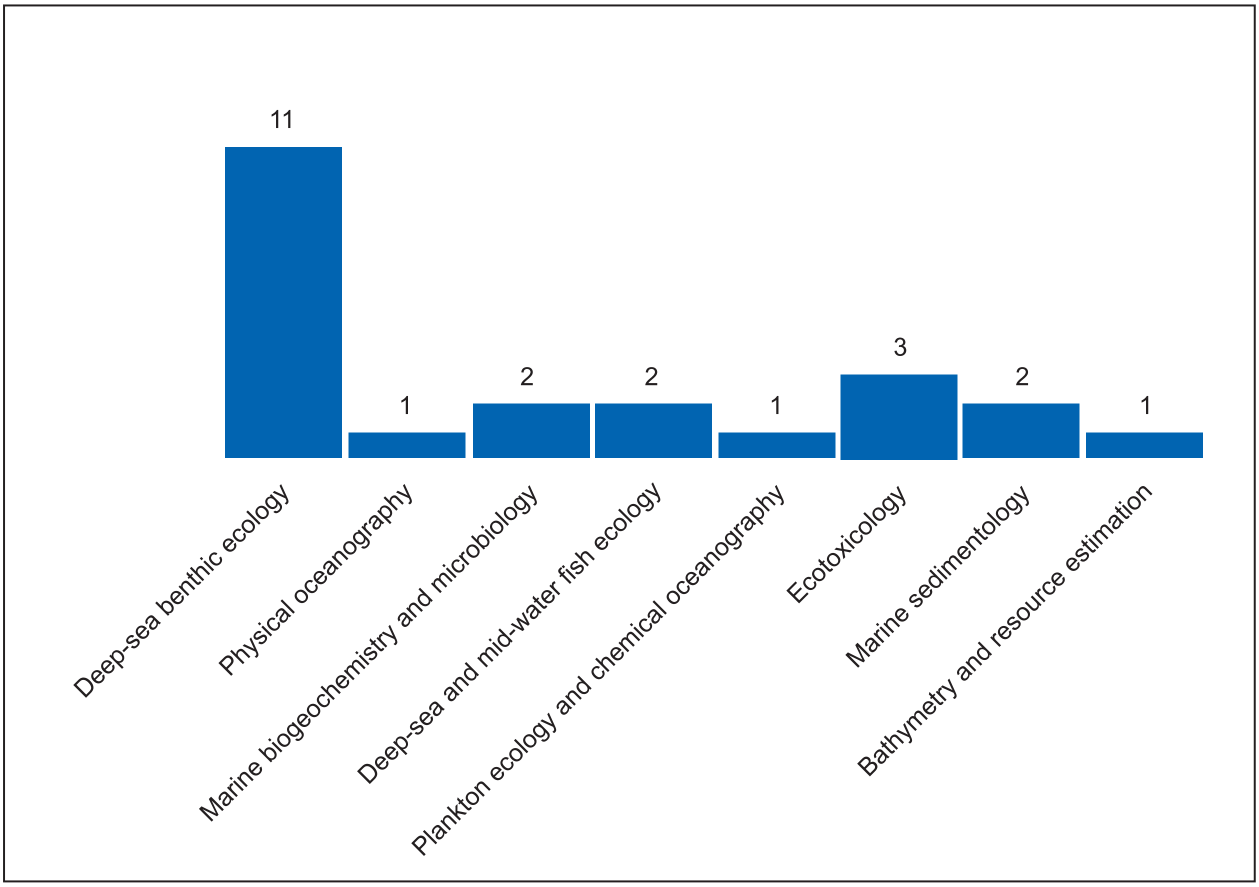

Figure 3. Graph showing the various scientific disciplines of the external experts who provided input on the societal concerns and associated operational questions. The numbers on top of the bars indicate the number of experts belonging to each discipline.

Table 1. Themes, topics and subtopics of scientific knowledge defined by Amon *et al*. (2022a) in relation to evidence-based environmental management of deep-seabed nodule mining in the CCZ. The shade of green indicates the level of scientific knowledge at the time of publication of the Amon *et al*. (2022a) study, with darker shades representing higher levels. The original table 1 in the study by Amon *et al*. (2022a) included information on all regions where exploration contract areas for deep-seabed mining have been delineated. Here, only the column on the CCZ has been retained, as this was the region focused upon in the present round table meetings. This table follows from a synthesis of the peer-reviewed literature and expert opinion. For more information, the reader is referred to the original study.

			CCZ
Theme	*Topic*	*Subtopic*	
Environmental baseline	Abiotic	High resolution bathymetry	
		Oceanographic setting (*e.g.*, currents, oxygen minimum zones, temperature, turbulence levels, sound, suspended particles)	
		Seabed properties (*e.g.*, sediment characteristics, oxygen penetration, redox zonation, metal reactivity)	
		Natural disturbance regimes	
	Biotic	Species taxonomy	
		Trophic relationships	
		Life histories (*e.g.*, age of maturity, longevity, reproduction, fecundity)	
		Spatial variability	
		Temporal variability	
		Connectivity (*e.g.*, dispersal mechanisms, species ranges, source/sink populations)	
		Ecosystem functions and services	
Deep-seabed mining	Impacts	Removal of resources	
		Plumes	
		Contaminant release and toxicity	
		Noise, vibration and light	
		Cumulative impacts	
	Resilience		
	Management	Environmental goals and objectives	
		Survey and monitoring criteria	
		Effectiveness of mitigation strategies	

outcomes of baseline and impact studies (*e.g.*, JPIO projects MiningImpact phases I and II, Biodiversa project DEEP REST) prior to addressing the operational questions. Once the response variables are specified, an appropriate spatiotemporal resolution and spatial coverage will have to be identified for each operational question separately. To clarify the approach used, an example from the Belgian offshore windfarms is provided in Table 2. Note that the method followed here is highly similar to that suggested by Heger *et al*. (2021), but these authors mentioned a hierarchy of hypotheses instead of questions.

2.4. Spatiotemporal scope of pressures and impacts

Benthic and pelagic systems (for definitions, see Appendix 1) have been mentioned separately to be comprehensive, but these are not to be considered as different entities given the well-documented coupling between these systems (Smith *et al*. 1997, 2009; Pape *et al*. 2013). The links between the benthic and pelagic system (and the potential disruption of these links) is inherent throughout the text.

The ISA has published draft guidance to facilitate the development of regional

Table 2. Example from the analysis of Belgian offshore windfarm (OWF) environmental impacts to illustrate the working method used in this chapter and to clarify the meaning of and relationships between societal concerns, overarching questions and operational questions.

Societal concern: OWFs will negatively affect cod fisheries Overarching questions: 1. What is the magnitude of change in cod productivity because of OWFs? 2. … Operational questions: 1.1. How much change is there in cod juvenile mortality because of piling noise? 1.2. How much change is there in nursery and spawning grounds of cods? 1.3. …

environmental management plans (REMPs), in which a strategic framework for the assessment of cumulative pressures in multiple contractor areas at regional scales has been outlined. In this report, cumulative pressures have been considered at a regional scale, which we equate here to the scale of ecoregions (see Appendix 1 for a definition and Section 2.5). The spatial extent of these cumulative pressures is addressed as a mapping exercise, thus assessing the degree to which these will propagate away from the mining site itself. The temporal extent of these pressures and impacts is to be monitored over at least a decadal timescale (> 10 years) to capture natural temporal variability and to encompass residual cumulative impacts that may persist even after mining and related activities have been decommissioned in a given contractor area.

2.5. Ecoregions

Since all habitats and associated communities are not equally sensitive to pressures, it is imperative that habitat heterogeneity in the deep sea is included in environmental impact assessments. It is vital that habitat-specific field data are collected, but it should also be considered that some operational questions may only be answered through extrapolative modelling. Furthermore, impacts are to be assessed at scales that are meaningful *e.g.*, at the level of populations. We therefore adopted so-called ecoregions (see Appendix 1 for a definition) which are defined at a regional scale and account for habitat heterogeneity. Wedding *et al*. (2013) subdivided the CCZ into nine subregions based on biophysical gradients (inferred from, amongst others, data on seamount occurrence, bathymetry, polymetallic nodule abundances and macrofauna abundances, that were available at the time). These nine subregions lie at the base of the first version of the REMP for the CCZ, with the allocation of an Area of Particular Environmental Interest (or APEI, see also Appendix 1), meant to conserve regional biodiversity and ecosystem functioning, to each of these subregions (ISA 2011). These nine subregions could potentially serve as initial "ecoregions", though the number, spatial extent and location of these remain to be thoroughly validated for homogeneity in abiotic and biotic characteristics via targeted scientific research. Local-scale observational studies complemented with regional-scale extrapolation may be instrumental to verifying these ecoregions. Impacts should be assessed at the level of population dynamics and at the regional level *i.e.*, risk to the population vs. risk to an individual, and regional-scale extrapolations stemming from local-scale data, acknowledging habitat diversity within and across ecoregions. Note that the CCZ REMP was recently revised to contain four additional APEIs (ISA 2021a), partly because some of the benthic habitat classes defined by McQuaid *et al*. (2020), were ill-represented by the original nine APEIs. However, this habitat classification scheme of McQuaid *et al*. (2020) did not take into account biological data, and so it remains to be investigated to what extent these habitat classes correspond to ecoregions.

3. Societal concerns and linked overarching and operational questions

Below we have listed the societal concerns about impacts of offshore deep-seabed polymetallic nodule mining environmental pressures (Section 3.1), and effectiveness of mitigation strategies, following the mitigation hierarchy (Ekstrom *et al.* 2015) (Section 3.2), as expressed by at least one of the stakeholders consulted during the round table meetings and/or by at least one of the external scientific experts. Since the concern pertaining to mitigation strategies relates to the management of environmental pressures and impacts in case deep-seabed mining would proceed, this particular societal concern is covered in a stand-alone section. Societal concerns are provided as statements, but their validity (based on available scientific data or information) remains to be verified.

For each concern, we have identified one to several overarching questions (regular font), which were then further subdivided into one or multiple operational questions (in *italics*). Since the operational questions fit within the overarching questions, we have numbered the questions to clarify the hierarchy of questions (*e.g.*, operational question 1.1 fits within overarching question 1, operational question 2.1 fits within overarching question 2). Even if there was only one operational question linked to an overarching question, it was numbered to illustrate this hierarchy. Operational questions that could be linked to all overarching questions were only listed underneath the first overarching question to avoid repetition, and these were marked with an asterisk (*).

3.1. Concerns about environmental impacts of deep-seabed mining related pressures

Seven out of nine societal concerns (3.1.1–3.1.7) address pressures and impacts of deep-seabed mining (Figure 4), with number 8 (3.1.8) dealing with the long-term impacts on the ecosystem of these pressures (*i.e.*, resilience). Societal concern number 9 (3.1.9) focuses on cumulative pressures and impacts.

3.1.1. Removal of resources and sediment disturbance in nodule collector tracks

<u>Societal concern</u>: There will be a change in benthic and pelagic ecosystem structure and ecosystem functioning following mineral and biological resource removal and associated disturbance of the surrounding soft sediments inside the track(s) of nodule collector vehicles.

<u>Overarching & *operational* questions:</u>

1. What proportion of nodule-bearing seafloor needs to remain untouched and at what spatial configuration without a change in pelagic and benthic ecosystem structure at the regional scale?

   1.1. *How do physical properties of the soft sediments in the nodule collector track change in response to the operation of the nodule collector vehicle?**

   1.2. *What is the response of pelagic and benthic ecosystem structure to nodule removal (and the disturbance of surrounding soft sediments) at different spatial and temporal scales?*

2. What proportion of nodule-bearing seafloor needs to remain untouched and at what spatial configuration without a change in pelagic and benthic ecosystem functioning at the regional scale?

   2.1. *What is the response of pelagic and benthic ecosystem functioning to nodule removal (and the disturbance of surrounding soft sediments) at different spatial and temporal scales?*

3.1.2. Collector sediment plumes

Note that we decided to split up societal concerns concerning ecological impacts of sediment plumes according to the type of sediment plume, *i.e.*, collector plumes (at the seabed, see definition in Appendix 1) and

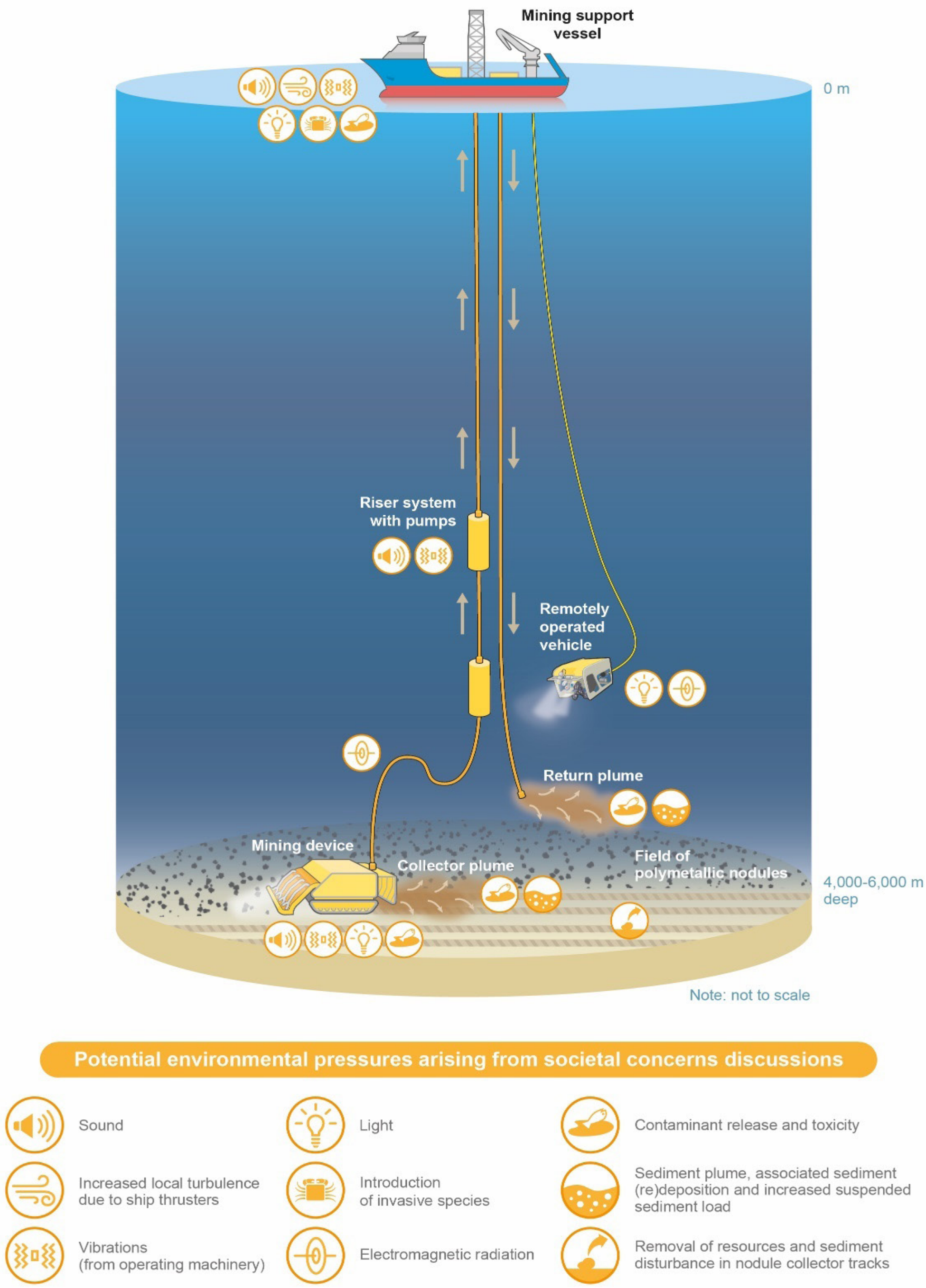

Figure 4. Illustration of a hypothetical polymetallic nodule deep-seabed mining operation scenario with an indication of the potential environmental pressures arising from the societal concerns discussed during the present round table meetings. The remotely operated vehicle shown represents some of the monitoring equipment, but it is expected that additional monitoring equipment will be used during commercial deep-seabed mining operations, which may also exert environmental pressure(s). Importantly, the pressures associated with a single deep-seabed mining operation shown here are unlikely to act in isolation but instead will be cumulative, potentially resulting in cumulative environmental impacts. Additionally, this illustration does not show the cumulative pressures from multiple deep-seabed mining operations, or from deep-seabed mining and other anthropogenic disturbances. Further note that this illustration represents the societal concerns expressed, and the knowledge of the environmental impacts of deep-seabed mining at the time of writing by the stakeholders and scientific experts consulted.

return plumes (which could be discharged at any point in the water column, and thus could be surficial, in the water column or near the seafloor; see Appendix 1) as these are presumed to have different physical and chemical properties and dynamics and to potentially affect different environments. Return sediment plumes are covered in Section 3.1.3.

Societal concern: There will be a change in pelagic and benthic ecosystem structure and functioning following the generation of nodule collector sediment plumes, and associated sediment (re)deposition and increased suspended sediment load, by deep-seabed mining activities inside and (mainly) outside the nodule collector tracks.

Overarching & *operational* questions:

1. At which concentration can sediment be (re)suspended and at what spatial and temporal scale without a change in benthic and pelagic ecosystem structure at the regional scale?
   - *1.1. What is the spatial and temporal extent and variability in the physical properties of the collector sediment plume (e.g., sediment particle size distribution and suspended sediment load as a function of distance from point of discharge)?**
   - *1.2. What is the response of benthic ecosystem structure to increased suspended sediment load in space and time?*
   - *1.3. What is the response of pelagic ecosystem structure to increased suspended sediment load in space and time?*
2. How much sediment can be (re)deposited and at what spatial and temporal scale without a change in benthic ecosystem structure at the regional scale?
   - *2.1. What is the response of benthic ecosystem structure to sediment (re)deposition in space and time?*
3. How much sediment can be (re)suspended and at what spatial scale without a change in benthic and pelagic ecosystem functioning at the regional scale?
   - *3.1. What is the response of benthic ecosystem functioning to increased suspended sediment load in space and time?*
   - *3.2. What is the response of pelagic ecosystem functioning to increased suspended sediment load in space and time?*
4. How much sediment can be (re)deposited and at what spatial and temporal scale without a change in benthic ecosystem functioning at the regional scale?
   - *4.1. What is the response of benthic ecosystem functioning to sediment (re) deposition in space and time?*

3.1.3. Return sediment plumes

Societal concern: There will be a change in pelagic and benthic ecosystem structure and functioning following the generation of sediment return plumes resulting from either surficial, water column or near-seafloor discharge from a surface operational vessel (dewater plant) in the frame of deep-seabed mining related activities. Environmental impacts could be related to increased suspended sediment load and/or physical disturbance because of the discharge flow.

Overarching & *operational* questions:

1. How much sediment can be discharged and at what spatial and temporal scale without a change in pelagic and benthic ecosystem structure at the regional scale?
   - *1.1. What is the spatial and temporal variability in the physical properties of the return plume for different discharge depths (e.g., particle size distribution and suspended sediment load as a function of distance from the point of discharge)?**

1.2. What is the response of pelagic ecosystem structure in space and time to increased suspended sediment load?

1.3. What is the response of benthic ecosystem structure in space and time to increased suspended sediment load?

1.4. What is the response of benthic ecosystem structure in space and time to increased sediment deposition (if any) from the return plume?

2. How much sediment can be discharged and at what spatial and temporal scale without a change in pelagic and benthic ecosystem functioning at the regional scale?

2.1. What is the response of pelagic ecosystem functioning in space and time to increased suspended sediment load?

2.2. What is the response of benthic ecosystem functioning in space and time to increased suspended sediment load?

2.3. What is the response of benthic ecosystem functioning in space and time to increased sediment deposition (if any) from the return plume?

3. Is change in pelagic and benthic ecosystem structure and ecosystem functioning in the presence of a return plume dependent on the discharge water depth?

3.1. Is there a difference in the response of pelagic and benthic ecosystem structure and ecosystem functioning to the presence of a return plume in space and time between different discharge depths?

3.2. In case of discharge near the seafloor how will the impact of the discharge flow compare to the impact of increased suspended sediment load on benthic ecosystem structure and functioning?

3.1.4. Contaminant release and toxicity

Societal concern: There will be a change in pelagic and benthic ecosystem structure and functioning in response to contaminant release, including that from radioactive nodule particles (Volz *et al*. 2020), from deep-seabed mining-related activities in the pelagic and benthic environment.

Overarching & *operational* questions:

1. What and how much contaminants can be released from surface vessels used in deep-seabed mining operations without a change in pelagic and benthic ecosystem structure and functioning on a regional scale?

1.1. What contaminants are potentially discharged from surface vessels used in deep-seabed mining operations and in what concentration ranges?

1.2. How are contaminants discharged from surface vessels used in deep-seabed mining operations dispersed in space and time?

1.3. What is the response in space and time of pelagic ecosystem structure to potential contamination from surface vessels used in deep-seabed mining related activities?

1.4. What is the response in space and time of pelagic ecosystem functioning to contamination from surface vessels used in deep-seabed mining related activities?

1.5. What is the response in space and time of benthic ecosystem structure to potential contamination from surface vessels used in deep-seabed mining related activities (through potential effects on pelagic larval stages)?

1.6. What is the response in space and time of benthic ecosystem functioning to potential contamination from surface vessels used in deep-seabed mining related activities (through potential effects on pelagic larval stages)?

2. What and how much contaminants can be released from deep-seabed mining related water column equipment (*e.g.*, riser pipes and pumps) without a change in pelagic

and benthic ecosystem structure and functioning on a regional scale?

2.1. *What contaminants are potentially released from deep-seabed mining related water column equipment and in what concentrations?*

2.2. *How are contaminants, potentially released from deep-seabed mining related water column equipment, dispersed in space and time?*

2.3. *What is the response in space and time of pelagic ecosystem structure to potential contamination from deep-seabed mining related water column equipment?*

2.4. *What is the response of pelagic ecosystem functioning in space and time to potential contamination from deep-seabed mining related water column equipment?*

2.5. *What is the response in space and time of benthic ecosystem structure to potential contamination from deep-seabed mining related water column equipment (through the effect on pelagic larval stages of benthic taxa)?*

2.6. *What is the response of benthic ecosystem functioning in space and time to potential contamination from deep-seabed mining related water column equipment (through the effect on pelagic larval stages of benthic taxa)?*

3. What levels of which contaminants, including radioactive nodule particles, can be released from nodule removal and related deep-seabed mining activities, including generation of collector and return plumes, at the seabed without a change in benthic and pelagic ecosystem structure and functioning on a regional scale?

3.1. *Which contaminants are potentially released from nodule removal and related deep-seabed mining activities at the seabed and in what concentrations?*

3.2. *How are contaminants, potentially released from nodule removal and related deep-seabed mining activities at the seabed, dispersed in space and time?*

3.3. *Does discharge depth affect the dispersion in space and time of contaminants from the return plume?*

3.4. *What is the response in space and time of pelagic ecosystem structure to potential release of contaminants from the return plume at different discharge depths?*

3.5. *What is the response in space and time of pelagic ecosystem functioning to potential release of contaminants from the return plume at different discharge depths?*

3.6. *What is the response in space and time of benthic ecosystem structure to potential release of contaminants from nodule removal and related deep-seabed mining activities at the seabed?*

3.7. *What is the response in space and time of benthic ecosystem functioning to potential release of contaminants from nodule removal and related deep-seabed mining activities at the seabed?*

3.1.5. Anthropogenic noise and turbulence, vibrations, electromagnetic radiation and light

Societal concern: There will be a change in pelagic and benthic ecosystem structure and functioning in response to human-induced sound, light, vibrations, increased local surface water turbulence (due to ship thrusters) and/or electromagnetic radiation generated by deep-seabed mining related activities in the pelagic and benthic environment.

Overarching & *operational* questions:

1. Is there a change in pelagic and benthic ecosystem structure and ecosystem functioning to sound on a regional scale?

1.1. *What is the spatial and temporal extent of noise, light, electromagnetic radiation,* *increased surface water turbulence and vibrations associated with deep-seabed mining related activities in the atmospheric, pelagic and benthic environment?**

1.2. What is the response of pelagic and benthic ecosystem structure in space and time to increased intensity, frequency and duration of sound?

1.3. What is the response in space and time of pelagic and benthic ecosystem functioning to increased intensity, frequency and duration of sound?

2. Is there a change in pelagic and benthic ecosystem structure and functioning to light on a regional scale?

2.1. What is the response in space and time of pelagic and benthic ecosystem structure to increased light intensity (spectrum, duration, ..)?

2.2. What is the response in space and time of pelagic and benthic ecosystem functioning to increased light intensity (spectrum, duration, ..)?

3. Is there a change in pelagic and benthic ecosystem structure and functioning to vibrations on a regional scale?

3.1. What is the response in space and time of pelagic and benthic ecosystem structure to vibrations?

3.2. What is the response in space and time of pelagic and benthic ecosystem functioning to vibrations?

4. Is there a change in pelagic and benthic ecosystem structure and functioning to electromagnetic radiation on a regional scale?

4.1. What is the response in space and time of pelagic and benthic ecosystem structure to electromagnetic radiation?

4.2. What is the response in space and time of pelagic and benthic ecosystem functioning to electromagnetic radiation?

5. Is there a change in pelagic and benthic ecosystem structure and functioning to increased surface water turbulence on a regional scale?

5.1. What is the response of pelagic and benthic ecosystem structure in space and time to increased surface water turbulence?

5.2. What is the response in space and time of pelagic and benthic ecosystem functioning to increased surface water turbulence?

3.1.6. Introduction of invasive species

Societal concern: Introduction of invasive species via ballast water, water column equipment or the hull of surface vessels involved in deep-seabed mining will change pelagic ecosystem structure and functioning.

Overarching & *operational* questions:

1. Will there be a change in pelagic ecosystem structure and functioning on a regional scale after the potential introduction of invasive species concurrent with deep-seabed mining operations?

1.1. Which and via what pathway(s) are invasive species introduced in the pelagic environment concurrent with deep-seabed mining operations?

1.2. Does the source environment of invasive species influence the effects of their introduction in (the waters overlying) the mining area on pelagic ecosystem structure and functioning on a regional scale?

1.3. What is the response in space and time of pelagic ecosystem structure to the introduction of invasive species on a regional scale?

1.4. What is the response in space and time of pelagic ecosystem functioning to the introduction of invasive species on a regional scale?

2. Will there be a change in benthic ecosystem structure and functioning on a regional scale after the potential introduction of invasive species concurrent with deep-seabed mining operations, through potential effects on pelagic larval stages?

   2.1. What is the response in space and time of benthic ecosystem structure to the introduction of invasive species on a regional scale, through potential effects on pelagic larval stages?

   2.2. What is the response in space and time of benthic ecosystem functioning to the introduction of invasive species on a regional scale, through potential effects on pelagic larval stages?

3.1.7. Presence of physical structures

Societal concern: There will be a change in pelagic and benthic ecosystem structure and functioning because of the increased and potential long-term presence of (hard) physical structures under the form of surface vessels, water column equipment and benthic equipment deployed, lost or abandoned for deep-seabed mining related activities, and potentially resultant collision, displacement or barrier effects.

Overarching & *operational* questions:

1. What, how many and for how long can physical structures for deep-seabed mining related activities be deployed at the seawater surface without a change in pelagic ecosystem structure and functioning on a regional scale?

   1.1. What is the spatial and temporal extent of physical structures deployed for deep-seabed mining activities at the seawater surface?

   1.2. What is the response in space and time of pelagic ecosystem structure to the introduction of physical structures at the seawater surface?

   1.3. What is the response in space and time of pelagic ecosystem functioning to the introduction of physical structures at the seawater surface?

2. What, how many and for how long can physical structures for deep-seabed mining related activities be deployed in the water column without a change in pelagic and benthic ecosystem structure and functioning on a regional scale?

   2.1. What is the spatial and temporal extent of physical structures deployed for deep-seabed mining activities in the water column?

   2.2. What is the response in space and time of pelagic ecosystem structure to the introduction of physical structures in the water column?

   2.3. What is the response in space and time of pelagic ecosystem functioning to the introduction of physical structures in the water column?

   2.4. What is the response in space and time of benthic ecosystem structure to the introduction of physical structures in the water column?

   2.5. What is the response in space and time of benthic ecosystem functioning to the introduction of physical structures in the water column?

3. What, how many and for how long can physical structures for deep-seabed mining related activities be deployed at the seabed without a change in pelagic and benthic ecosystem structure and loss of ecosystem functioning on a regional scale?

   3.1. What is the spatial and temporal extent of physical structures deployed for deep-seabed mining activities at the seabed?

   3.2. What is the response in space and time of pelagic ecosystem structure to the introduction of physical structures at the seabed?

3.3. *What is the response in space and time of pelagic ecosystem functioning to the introduction of physical structures at the seabed?*

3.4. *What is the response in space and time of benthic ecosystem structure to the introduction of physical structures at the seabed?*

3.5. *What is the response in space and time of benthic ecosystem functioning to the introduction of physical structures at the seabed?*

3.1.8. Resilience

Societal concern: Benthic and pelagic communities will not tolerate or recover from deep-seabed mining impacts (see previous societal concerns).

Overarching & *operational* questions:

Operational questions for assessing the tolerance of pelagic and benthic communities are defined in line with the various societal concerns and overarching questions above. The priority operational questions hence are covered by the foregoing.

1. What is the change in pelagic and benthic ecosystem structure and functioning after being exposed to deep-seabed mining impacts? (answered by preceding operational questions for the different individual pressures)

2. What is the recovery rate of pelagic and benthic communities after having been impacted by deep-seabed mining activities?

   2.1. *What is the differential speed at which various descriptors of ecosystem structure and functioning are recovered after damage due to deep-seabed mining activities?*

   2.2. *Do environmental conditions influence natural recovery rates of pelagic and benthic communities?*

   2.3. *How does geographical distance to undisturbed pelagic and benthic communities, such as those in the (waters overlying the) APEIs, relate to recovery rates?*

3.1.9. Cumulative pressures and impacts

Societal concern: There will be cumulative impacts of cumulative pressures on benthic and pelagic ecosystem structure and functioning of impacts (a) of multiple pressures from a single mining operation (*e.g.*, sediment deposition, noise, habitat disturbance,..) and (b) of multiple (simultaneous) mining activities in an area, while the deep sea is already, and increasingly, facing multiple stressors from anthropogenic activities such as pollution, and climate change and related impacts such as acidification, warming, oxygen depletion and reduced nutrient supply from surface waters.

Overarching & *operational* questions:

1. How do pelagic and benthic ecosystem structure and functioning respond to multiple pressures of a single mining operation in space and time?

   1.2. *What is the response in space and time of pelagic and benthic ecosystem structure to multiple pressures of a mining operation?*

   1.2. *What is the response in space and time of pelagic and benthic ecosystem functioning to multiple pressures of a mining operation?*

2. How many mining operations can take place simultaneously without a change in pelagic and benthic ecosystem structure and functioning at the regional scale?

   2.1. *What is the response of pelagic and benthic ecosystem structure in space and time to increased intensity of simultaneous mining operations?*

   2.2. *What is the response in space and time of pelagic and benthic ecosystem* *functioning to increased intensity of simultaneous mining operations?*

3. How much mining can take place in combination with other predicted stressors without a change in pelagic and benthic ecosystem structure and functioning at the regional scale?

3.1. What are the predicted and observed effects of climate change and other anthropogenic pressures in the pelagic and benthic environment on a regional scale?

3.2. Concerns about the effectiveness of potential strategies to mitigate environmental impacts

The mitigation hierarchy is a well-established framework for managing risks and potential impacts concerning biodiversity and ecosystem services during the planning and execution of operations on land or in coastal waters (Ekstrom *et al*. 2015). In addition to the above formulated concerns about potential environmental pressures and impacts, some of the consulted round table participants and external scientific experts expressed concerns about the feasibility and effectiveness of different options for the mitigation of these environmental impacts at all levels of the mitigation hierarchy (*i.e.*, avoidance, minimization, restoration / rehabilitation and offsetting). This last societal concern deals with the lack of data needed to inform if and which mitigation strategies can be effective and thus stands out from the preceding concerns. Note that to be able to adequately answer these questions, one first needs to understand completely the spatial and temporal extent of impacts on the benthic and pelagic environment.

Societal concern: Options for mitigating impacts following the mitigation hierarchy, do not balance the environmental impacts of deep-seabed mining.

Overarching & *operational* questions:

Impact avoidance and minimization options may include technical solutions to minimize adverse pressures of deep-seabed mining activities. The effectiveness of technical solutions to reduce pressures are engineering challenges and are hence not covered by the current report focusing on the understanding of how pressures from deep-seabed mining activities impact deep-sea communities. Another avoidance and/or minimization strategy, which is covered here, is establishing set-aside areas representative of and ecologically connected to the mining areas.

1. What active rehabilitation actions can be taken to speed up recovery after negative effects have occurred on biological ecosystem structure and/or functioning?

1.1. Can artificial substrates (e.g., artificial nodules physically resembling poly-metallic nodules) be developed and deposited at the seafloor and at what cost?

1.2. Does habitat rehabilitation by the introduction of artificial substrates after removal of the polymetallic nodules attract the original seabed community structure and functioning?

1.3. Can we rehabilitate the soft sediments in- and outside the tracks to promote recolonization by benthic fauna?

2. What other mitigation measures can be taken?

2.1. Does the establishment of strictly protecting areas beyond the mining site (APEIs) have the potential to successfully guarantee the protection of representative biodiversity and ecosystem functions as a way to mitigate for the biodiversity loss at the mining sites?

4. Conclusions and recommendations

One of the main objectives of the Belgian roundtable process, *i.e.*, to get the participants, who represented different deep-seabed mining stakeholders with different views on deep-seabed mining, around the table and have them engage in a constructive dialogue, was met. The process generated a safe environment for the presentation and discussion of societal concerns about environmental impacts of deep-seabed mining pressures by all stakeholders. Hence, the round table process outlined in this report could serve as an example and a proof-of-concept for similar discussions in other countries and preferably at the international level. In fact, when questioned regarding the prospective means through which various stakeholder factions might cooperate to tackle shared knowledge and data deficiencies linked to deep-seabed mining, as part of a stakeholder consultation initiative initiated by the British Geological Survey (Lusty *et al*. 2021), the importance of fostering a constructive and transparent dialogue among deep-seabed mining stakeholders was emphasized.

Many stakeholders, including scientists, have denounced the present lack of data and information on deep-sea ecosystems targeted for potential, future deep-seabed mining (Amon *et al*. 2022a; Rabone *et al*. 2023). The initiative presented in this chapter is the first step in a process leading to the identification of what research, or what data and information, is still needed to address the many societal concerns. To be able to quantify the currently lacking data and information, a follow-up initiative could aim at determining to what extent (1) information is readily available, (2) data is available but awaiting analysis to provide the necessary information, and (3) data is not available yet, and needs collecting; this for the list of operational questions. Based on such categorization, it can be determined what type of data collection and scientific research is still outstanding and thus could potentially be prioritized in the coming years. Note that, besides data and information availability, the different societal concerns raised could also be categorized on the basis of the magnitude and likelihood of environmental pressures and impacts of deep-seabed mining, through a dedicated Environmental Risk Assessment (ERA). Furthermore, an additional potentially useful categorization could be based on the feasibility of the studies needed to answer the operational questions (*i.e.*, the possibility to answer the operational question with "reasonable" effort/cost/time). Whether (both of) these or other additional categorization steps are possible or desirable for potential prioritization among operational questions, could be discussed during future deep-seabed mining stakeholder initiatives.

Nevertheless, similar to much better studied shallow-water areas, decisions on human activities in the deep sea may have to be taken without absolute certainty, resulting in a situation where a more precautionary approach will have to be applied until a sufficient level of certainty can be achieved – in line with the precautionary principle. If prioritization of operational questions would be feasible, we would be able to better focus research efforts to the most critical knowledge gaps and hence maximally reduce uncertainty where needed the most.

As mentioned in the introduction of this chapter, the focus of the present round table meetings was on the offshore ecological impacts of deep-seabed mining for polymetallic nodules. Nevertheless, at the start of the round table meetings, the present stakeholders expressed other societal concerns (see Appendix 3 for the complete overview of societal concerns expressed by the stakeholders consulted during the round table meetings in an anonymized manner), such as those related to:

- Environmental impacts associated with on-land transportation and processing of the extracted mineral resources;

- Offshore environmental impacts of mining of other deep-sea mineral resources such as seafloor massive sulfides and
- Governance and management of the deep sea and deep-seabed mining.

These other societal concerns could be the focus of future round table meetings or other initiatives at the national, regional and/or international level.

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Appendix 1

Glossary (terms listed in alphabetical order). CCZ = Clarion Clipperton Fracture Zone.

Term	Definition and examples (if applicable)
APEI	Area of Particular Environmental Interest. The network of currently 13 APEIs is a crucial component of the regional environmental management plan for the CCZ, which are (1) thought to be representative of the full range of habitats, biodiversity and ecosystem structure and function within the management area (2) to be closed to potential mining activities to protect and preserve the marine environment. (ISBA/17/LTC/7 (ISA, 2011) and ISBA/26/C/43 (ISA, 2021b))
Area (Beyond National Jurisdiction)	The seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (UNCLOS, Art. 1 (1))
Benthic	Associated with or occurring at the seabed. Includes the suprabenthos (Frutos *et al*. 2017), which comprise all swimming bottom-dependent animals (mainly small peracarid crustaceans) living in the water layer just above the seabed and which perform, with varying amplitude, intensity, and regularity, seasonal or daily vertical migrations above the seafloor.
Collector plume	Sediment plume generated by the nodule collector vehicle caused by movement on the seabed and the initial separation of nodules from the sediments.
Ecoregion	Area with relatively homogeneous ecosystem structure, clearly distinct from adjacent systems. Ecosystem structure is likely to be determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining the ecoregions vary from location to location but may include nutrient inputs, sediment composition, currents, polymetallic nodule abundance and bathymetric complexity (definition adapted from Spalding *et al*. 2007) who developed a classification system for coastal and shelf seas). When we refer to *regional scale*, we mean within an ecoregion.

Term	Definition and examples (if applicable)
Ecosystem functioning	All processes and functions in an ecosystem. Examples for the CCZ, including the overlying water column, are primary and secondary production and nutrient cycling.
Ecosystem structure	Taxonomic and functional composition, diversity, abundance and biomass within an ecosystem.
Mining Code	Comprehensive set of rules, regulations and procedures issued by the International Seabed Authority to regulate prospection, exploration and exploitation of marine minerals in the Area. See: https://www.isa.org.jm/the-mining-code/
Pelagic	Associated with or occurring in the water column, including the interface between the seawater surface and the air (Lawrence 1999). Including all swimming animals that have no interaction with the seafloor and seabirds.
Regional scale	Within an ecoregion. See *Ecoregion*.
Rehabilitation / restoration	Rehabilitation or restoration measures are those taken to reinstate a degraded site following exposure to impacts that could not be completely avoided or minimized. Within this level, a second hierarchy exists: (a) Restoration to return an area to the original ecosystem that existed before impacts; (b) Rehabilitation to restore basic ecological functions and/or ecosystem services. (ISBA/27/C/4**,** (ISA 2022))
Resilience	The ability of an ecosystem to maintain its overall identity, *i.e.* the same function and structure, in the face of internal change and external perturbations (Gollner *et al*. 2017)
Return plume	Plume comprising water and sediment discharged from a surface operation vessel, comprising water and sediment brought up with the nodules, nodule fines, and water used to clean the nodules aboard the vessel. May in theory be discharged at any water depth (at the surface, in the water column or near the seafloor).

Appendix 2

Round table participants including stakeholders consulted during the round table meetings.

List of the round table participants, in alphabetical order, and their affiliations. Those marked with an asterisk were consulted. Government representatives participated but did not actively engage in the discussions. Facilitators of the round table meetings are underlined.

Last name, first name	**Affiliation**	**Stakeholder category**
Degraer, Steven	Institute of Natural Sciences	Scientist
Fordeyn, Jan*	Jan De Nul	Industry
Govaert, Patrick	FPS Foreign affairs	Government representative
Lambrechts, Ann*	Greenpeace	NGO
Meeus, Kim	Cabinet North Sea	Government representative
Pape, Ellen	Ghent University	Scientist
Patel, Tasnim	Institute of Natural Sciences	Scientist
Schotte, Patrik	FPS Economy	Government representative
Tak, Paulus*	Pew Charitable Trusts	NGO
Vandenborre, Steven	FPS Environment	Government representative
Vanden Eede, Sarah*	WWF	NGO
Van Nijen, Kris*	DEME-GSR	Industry
Vanreusel, Ann	Ghent University	Scientist

Appendix 3

List of all societal concerns expressed by the consulted stakeholders.

In the following paragraphs the societal concerns raised by the stakeholders consulted during the round table meetings, are listed. Concerns that were not addressed in this report to keep the scope focused, are written in *italics*. These may be further addressed in future stakeholder initiatives.

1.1. Consulted stakeholder n°1

Consulted stakeholder n°1 expressed their concerns about gaps in environmental baseline data for the CCZ and other regions, which would need to be collected to address the societal concerns about ecological impacts listed in this chapter, and about governance. Their list of concerns was accompanied with a list of bibliographical references, which has been included.

1.1.1. Scientific knowledge gaps for the CCZ and other regions

- In this region, knowledge gaps for evidence-based management remain dominate for every biologic environmental baseline category examined by Diva Amon *et al.* (2022) including species taxonomy, life history, trophic relationships, spatial and temporal variability, connectivity, and ecosystem functions and services.
    - Species Taxonomy (identification and classification of species)
        - In areas where sampling has been highest (central-eastern region of CCZ), models predict 25–75% of total species have yet to be discovered [2].
        - From a recent CCZ benthic study, 65% of known benthic species have only been recorded from a single location, and 36.5% have only been recorded one time [3].
        - Ecological baselines for midwater ecosystems in areas likely to be impacted do not exist, owing largely to severe under sampling and sampling focus on benthic communities. [4]
        - Conservation areas (Areas of Particular Environmental Interest) are severely under-sampled. It is unclear whether they adequately represent biological communities in contractor areas and will therefore contribute to maintaining ecosystem integrity in lieu of mining impacts. [2]
    - Life History (i.e., species rate of growth, age of maturity, frequency of reproduction, number of offspring produced, longevity)
        - We are not aware of any studies that have investigated life history traits in the CCZ.
    - Trophic Relationships (Food Webs)
        - The lack of data on species abundance, distribution, and diets continues to be a significant limitation for understanding food webs. [5]
        - We do know that removal of polymetallic nodules will lead to a loss of food-web integrity, as ~50% of known fauna are facultatively or obligatorily associated with nodules; however, the consequences of this to regional or global biodiversity remain unknown. [6]
    - Spatial and Temporal Variability [2,7]
        - Most known fauna have in the CCZ have only been observed over a relatively small range (< 200 km), but it remains unclear whether these species in fact have a small range or if this is simply due to severe under sampling.

    - Biological time-series measurements in the CCZ are for the most part unavailable, making baseline temporal variability impossible to assess.
  - Connectivity (species dispersal mechanisms, source and sink populations) [8]
    - There is a severe lack of knowledge of deep-sea larval dispersal mechanisms.
    - One study of larval patterns suggests a short dispersal range for many CCZ species, which would increase the risk of spatial fragmentation of species population from mining.
  - Ecosystem Functions and Services [2, 9–10]
    - We know nodule regions contribute to ecosystem services, such as carbon sequestration, nutrient regeneration, and high biodiversity, however there is a very poor understanding of the mechanics behind it and how those mechanics might be disrupted.
- *For other habitats targeted for mining (i.e., active and inactive hydrothermal vents, seamounts) the knowledge gaps are more extensive.*
- Without information above important scientific questions necessary to manage this industry effectively and ensure the effective protection of the marine environment (benthic and mid-water) cannot be answered:
  - What species are present, how abundant are they, are they unique to any one Contractor site, are they represented in conservation areas, such as Contractor Preservation Reference Zones or in Regional Areas of Particular environmental interest?
  - What do we know about the life histories of species and are we able to determine if species are capable of repopulating after disturbance and what is needed to constitute a minimum viable population?
  - Do we know how species at mine sites are interlinked in food webs, either on the ocean floor or in the broader ocean ecosystem? How many nodules can be removed before food-web integrity and ecosystem functions are significantly disrupted?
  - Can we distinguish mining impacts from natural seasonal or annual variability at the contractor and regional scale?
  - What are the environmentally acceptable thresholds these communities can tolerate from mining impacts: resource/habitat removal, collector vehicle and midwater plumes, noise, vibration, and light and cumulative impacts of multiple mining operations?

1.1.2. Governance Gaps

- *Robust Stakeholder Engagement [11]*
  - *The ISA provides only a patchwork of stakeholder engagement in its policy-setting and decision-making. It must develop a clear process for proactively identifying and communicating with stakeholders, justifying its decision in response to comments received, and providing recourse where stakeholder concerns are not addressed.*
- *Inspectorate with monitoring and enforcement capabilities [12–14]*
  - *The ISA must establish and ensure that the inspectorate is capable of monitoring mining operations in real-time and can identify environmental non-compliance and take action against it when it occurs, including terminating operations where necessary.*

- *Liability [15]*
  - *The draft Regulations affirms that contractors are liable for damage, however they do not elaborate on the meanings of 'actual amount', 'damage', 'wrongful acts,' and 'omissions' or mention the legal and administrative mechanisms that would assign responsibility and enforce compensation or remediation.*
- *Corporate Accountability [16]*
  - *Sponsoring States must maintain "effective control" over entities mining under their flag. The ISA accepts corporate control as "effective," meaning that the mining entity must be incorporated in the jurisdiction of its sponsorship. Accountability would be better served with an economic control test, requiring that the ultimate beneficial owners of a mining entity be based in the jurisdiction of its sponsorship.*
- *Institutional Accountability*
  - *The ISA has insufficient measures to ensure its own accountability to stakeholders.*
  - *It must implement systems for administrative review of decisions, a system of appeals, and mostly importantly, a public complaints mechanism that is independent from its existing institutional structures.*
- *Scientifically supported Environmental Standards and Thresholds [17–18]*
  - *There are presently no thresholds for environmental performance. The ISA must set binding thresholds that limit environmental disturbance to prevent unacceptable harm to the marine environment.*
- *Rigorous Scientific Data Requirements [19]*
  - *The ISA offers only non-binding guidelines regarding scientific evidence that must be collected by contractors before commencing potentially harmful activities.*
- *Regional Planning and ISA-led Monitoring [19–20]*
  - *Currently, the ISA develops regional environmental management plans on an ad hoc basis and has not established an ISA-led monitoring program.*
  - *The ISA must identify consistent requirements and objectives for all regional plans, and implement a standardized process for their development.*
- *Independent Scientific Input [20]*
  - *It will not be possible for the ISA to serve as the sole provider of expertise to evaluate potential environmental impacts.*
  - *The ISA should not only be permitted, but required to solicit this input from a roster of qualified, stakeholder-vetted experts.*
- *Careful decision-making for all mining phases [12,19]*
  - *There is presently no requirement in the ISA's rules, regulations, or procedures for it to disapprove proposed activities that may result in unacceptable harm to the marine environment.*
  - *The ISA must evaluate all proposed mining activities and make an affirmative finding that proponents have demonstrated, with scientific support and evidence, that resulting impacts – either individual or in cumulation – will be controlled in such a way so as not to breach any standards or thresholds, and will deliver overall benefits to humankind that are deemed sufficient to outweigh the negative impacts, including the environmental damage caused.*

- *Adequate Capacity*
    - *All of the elements above will require sufficient staff and expertise for implementation, as well as the funding necessary to secure them.*
    - *Ensuring that an appropriate regulatory framework is also fully implemented will require additional staff and resources, which has yet to be assessed. This is the responsibility of ISA to assess capacity and capability requirement and responsibility of mining proponents to fund those resources.*

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1.2. Consulted stakeholders n°2 & n°3

Consulted stakeholders n°2 and n°3 listed several specific concerns, formulated as questions or statements. These can be found in the below paragraphs. They also expressed concerns about impacts of deep-seabed mining on bat communities. However, since it was decided to only considered offshore ecological impacts of deep-seabed mining, this concern was not explored further during the present round table meetings, as these are terrestrial organisms.

1.2.1. Specific questions about impacts on biodiversity, nature and the environment in space and time

– The deep sea was probably at the root of the beginning of all life, and discoveries about life here offer new insights for medicine, among other things. Scientific knowledge about the deep sea is still extremely limited. Since we still have everything to learn and know so little, shouldn't we exercise extreme caution at all times, protect adequately and take sufficient time to gain adequate knowledge and prioritize our basic understanding of the deep sea?

– Is there an overview of what we do and do not know about the deep sea and ongoing research?

– The deep sea is home to an extremely large and unique biodiversity. In times of biodiversity crisis, to allow an activity such as deep-seabed mining is also to knowingly allow (more) biodiversity loss. This both by destroying life on the seafloor where mining would take place, with little prospect of recovery, and by generating plumes, light, toxins and noise that could affect both benthic and mesopelagic marine life far beyond the actual mining sites. Is there evidence that we can avoid, mitigate, compensate for, or retrospectively restore the biodiversity loss that will be caused by deep-seabed mining?

– The deep sea provides essential environmental goods and services, including a climate regulation function and long-term carbon storage. In times of climate crisis, allowing an activity such as deep-seabed mining is also risking reaching tipping points whether accelerated or not. Is there evidence that deep-seabed mining may or may not have an impact on climate change and vice versa?

– *The deep sea is characterized by very fragile and unique ecosystems, with very slow-growing organisms and structures that take a long time to recover from disturbances. Since disturbances seem to have such large-scale and irreversible effects in the deep sea, how can we assume that we can regulate deep-seabed mining in a controllable way, within acceptable environmental impact margins?*

– The deep sea is already, and increasingly, facing multiple stressors due to pollutants, plastics/ plastics and climate change and related impacts, such as acidification, warming, oxygen depletion and reduced nutrient supply from surface waters. Deep-seabed mining activities will introduce additional impacts. This will increase the overall impact on the deep sea and ocean, certainly cumulatively, both in space and time. Is there any indication of what magnitude this would assume and what the consequences might be?

– In addition, there is the cumulative impact of:
  ○ E.g., different deep-seabed mining activities starting up at the same time or in parallel.
  ○ E.g., other sectors that have activities going on at the same time or in parallel with deep sea mining activities

– The deep sea is part of the ocean. We know little about the interconnection between marine life and ecosystems in the deep sea and throughout the water column on which humans already depend.

1.2.2. Specific questions about the independence and objectivity of science and scientific findings

– *How can we ensure that more funds go to fundamental, independent scientific research on the deep sea (habitats, species, processes...)?*

– *How can the scientists involved ensure their independence from the deep-seabed mining industry if they depend on it to conduct their research (budget, vessels, logistics...)?*

– *How to ensure that environmental standards for the industry, and policy informing information are developed in an independent manner?*

- *How can one guarantee the application of the precautionary principle? This is only possible if scientists are free to report and disseminate early warnings without potential repercussions on ongoing research budgets.*
- *It is still not clear who is responsible for independent scientific monitoring (abiotic and biotic) of GSR's exploration activities. A clear and detailed overview of responsibilities on different aspects of monitoring could clarify this.*

1.2.3. Specific questions on social impact

- *In the deep sea, according to UNCLOS, both the seabed and natural resources have the status of "Common Heritage of Humankind." According to UNCLOS, activities in the area and marine scientific research should be carried out for the benefit of humanity as a whole. Is deep-seabed mining at all relevant and desirable? Is there social support among the population worldwide, and more specifically among the sponsoring states?*
- *Can we justify an activity such as deep-seabed mining to future generations? Do we take into account that we should also be good ancestors in terms of the common heritage of humankind?*
- *How is benefit sharing regulated? Do we include environmental costs?*
- *Exploration licenses for deep sea mining are mainly in the hands of governments and companies headquartered in the global north while the impact of industrial exploitation will mainly affect island states in the global south. There should be a clear and transparent framework to ensure the free, prior and informed consent of indigenous peoples and the consent of potentially affected communities.*
- *There is strong evidence that deep-seabed mining will threaten traditional fishing, on which many Pacific communities depend. This food source is critical to the survival of those communities.*
- *How will the Belgian government address the growing concerns of local communities regarding the impact of deep-sea mining on their livelihoods and quality of life and their opposition to deep-seabed mining?*

1.2.4. Specific questions on the usefulness of deep-seabed mining and extractivism

- *The United Nations 2030 Agenda for Sustainable Development calls for ocean protection and sustainable consumption and production of resources. The Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Science and Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the International Resource Panel (IRP) all call for a radical change in our use of the Earth's resources to reverse environmentally destructive and wasteful patterns of production and consumption. A more strategic global approach to the production, extraction, use and reuse of mineral resources is needed. Is deep-seabed mining at all relevant and desirable in the context of these societal aspirations and requested transitions?*
- *It is important to have a public debate about the necessity and desirability of activities with irreversible environmental impacts. To date, there is a total lack of a comprehensive and substantiated public debate on extractivism, including (deep sea) mining. It is high time that the debate is held in a democratic and participatory manner, and based on scientific knowledge.*
- *Alternative sources for responsible production and use of the minerals also found in the deep sea should be fully researched and applied, such as reduction in demand for primary minerals,*

transformation to a resource-efficient, closed-loop economy for materials, and responsible mining practices. Is deep sea mining at all (still) necessary to meet global mineral needs, if all these things are done first?

- *The European Parliament proposes material footprint reduction targets (the EEB calls for a 65% reduction by 2050). Is this being considered by the Belgian government? For example, if the European Union reduces its material footprint by 65%, will deep-seabed mining still be necessary?*
- *How can misleading and/or erroneous information in the public domain be rectified?*
  - *E.g., that deep-seabed mining would be more sustainable than land-based mining?*
  - *E.g., inadequate comparisons between terrestrial and marine ecosystems?*
  - *E.g., inadequate comparisons between economic sectors that operate independently?*
- *Can the mineral needs debate take into account scenarios other than business as usual (BAU) exponential growth curves?*
- *There are no international outlooks that include real scenarios for sustainability (sustainability scenarios), with e.g. measures to drastically reduce consumption (e.g. of cars, energy, electronics...), e.g., through the sharing economy/post-growth economy, shared mobility, longer lifespan of appliances, right to repair... How can the Belgian government change this?*
- *Are there any realistic scenarios at all that take into account the very rapid technological evolutions in the BEV (battery electric vehicle) sector?*
- *Has research been done on the impact of sustainable scenarios and policies for energy and energy storage (batteries), mobility and ICT in Belgium?*
- *What is the potential of circular economy applications regarding reduction, reuse, recycling of minerals in Belgium and in Europe?*

1.2.5. Specific questions about Belgium's position and role

- *What is the Belgian government's position on commercial deep-sea mining / deep-sea mining exploitation and officially supporting or guaranteeing this as a sponsoring state?*
- *Given the wide range of potential impacts of deep-seabed mining on the marine environment, resources such as fisheries and minerals, and even on people and property, the need for proactive monitoring of the contractor's deep-seabed mining activities, and the high degree of scientific uncertainty about the extent of damage that could occur, there is a significant risk that sponsoring states could be held liable (liability) for significant costs of damage caused by their deep-seabed mining contractor's activities. Is the Belgian government prepared to assume the obligations and responsibilities of an exploitation sponsorship?*
- *Where does the Belgian government stand on the growing demand for a moratorium on deep-seabed mining (see moratorium calls from the Deep Sea Conservation Coalition, IUCN (motion 069) and the European Parliament)?*
  - *Business Statement Supporting a Moratorium on Deep-Seabed Mining*
  - *622 scientists in support of a pause on deep-seabed mining - 25/01/2024*
  - *The growing movement for a moratorium on deep-seabed mining*

- *There is the commitment of all countries, including Belgium, to the Sustainable Development Goals (SDGs) of the United Nations Agenda 2030, specifically:*
  - *SDG 14 "Conserve and make sustainable use of oceans, seas and maritime resources," specifically Goal 14.2 to avoid significant negative impacts, including by strengthening their resilience, and take action to restore them and achieve healthy and productive oceans. As a Blue Leader, what actions is the Belgian government taking to protect the deep sea and deep-sea floor?*
  - *SDG 12 "Ensure sustainable consumption and production patterns." Has any consideration been given to how the Belgian government can incorporate the following criteria into public procurement and tenders in order to facilitate a circular transition within the carrying capacity of planetary systems?*
    - *Design reusable, circular products and components that can be repaired, replaced or completely decommissioned to their primary materials so that they can be reused or recycled again.*
    - *Subject each project to a full life cycle analysis before the project can qualify for public support.*
    - *Support initiatives and research focused on sustainable, circular design, construction, operation and decommissioning/dismantling/deconstruction.*
    - *Select required minerals from responsible and circular sources. Avoid at all times minerals extracted through irresponsible, destructive exploitation on land, in the (deep) sea or in space.*
- *There is also the COP 14 decision of the Convention on Biological Diversity (CBD), which emphasizes that integrating biodiversity into the mining sector is essential to halting biodiversity loss and achieving the goals of the SDGs and the Paris Agreement. How will the Belgian government handle sponsorship of deep-seabed mining in light of political coherence on international political and legal commitments to conserve and protect the marine environment?*

1.2.6. Specific questions on international policy and management of the deep sea

- *According to the International Resource Panel, there is no international mechanism to monitor and ensure the sustainability of metals supply and demand, including terrestrial and deep-seabed mining. How can this be resolved?*
- *There is a lack of transparency in decision-making at the International Seabed Authority (ISA, International Seabed Authority) level, e.g., LTC (Legal and Technical Committee), Council (Council).*
  - *E.g., what environmental impact is identified in the context of environmental impact assessment is secret and it is completely unclear what action should be taken to monitor, prevent or remedy these impacts*
- *One-sided composition of the LTC, with a lack of environmental expertise.*
- *UNCLOS gives the ISA a dual mandate: to protect deep-sea ecosystems and to sustainably manage the use of natural resources. The precautionary principle is central to this. The ISA unilaterally emphasizes the deep-sea exploitation part of its mandate, but pays far too little attention to deep sea protection.*
  - *E.g., the ISA has never refused an exploration permit and has even issued a permit for the Lost City (UNESCO World Heritage Site).*

- *E.g., the ISA issues exploration permits without an international framework to adequately protect the deep sea and international waters in general and uses its lobbying machine to weaken the future Biodiversity Beyond National Jurisdiction (BBNJ) agreement in favor of industrial exploitation.*
- *E.g., the refusal to establish a scientific/ environmental committee.*
- *E.g., the rush to finish the Mining Code without waiting for the BBNJ treaty (protection framework).*
- *E.g., the designation of APEIs at the edge of the contract zones in the Clarion Clipperton Fracture Zone; except 1 that was approved very recently.*

– *The ISA itself has a direct interest in deep-seabed mining revenues and may even act as a deep-seabed company itself.*

– *REMPs (Regional Environmental Management Plans) are an essential part of the strategies implemented by the ISA to protect the marine environment. REMPs should be mandatory because they are necessary to provide an appropriate level of protection to those areas, and because they facilitate the achievement of globally agreed objectives and targets, such as the Sustainable Development Goals.*

– *The ISA has no mandate to address the cumulative impact of different stressors on the deep-sea ecosystem and biodiversity and this is not taken into account in the REMPs .*

– *The ISA has no mandate to address the impact of deep-seabed mining in the water column.*

– *Assessing environmental impacts is in the hands of the companies involved, including transparency about them (see above).*

– *The ISA's requirement to demonstrate damage turns the precautionary principle on its head. The precautionary principle means that damage must be avoided, and moreover, it is unclear who would have to demonstrate what damage.*

– *ISA member states, including Belgium, have already allowed companies to speak on their behalf. Delegations are not a diplomatic channel to garner political support for the deep-seabed mining industry.*

– *The highly self-serving actions of the ISA Secretary General and his erroneous and unsubstantiated statements.*
  - *E.g., Mr. Lodge's statements during the hearing in the federal parliament as if a moratorium would not be legal and would shut down scientific research.*
  - *E.g., the assertion that the 2-year rule means that the Mining Code must be completed within 2 years.*

1.3. Consulted stakeholder n°4

Consulted stakeholder n°4 has provided the below text when asked for their societal concerns regarding deep-seabed mining. Bibliographical references are provided at the end.

1.3.1. Need to diversify supply

Minerals form a central part of today's society. Their demand is not only driven by population growth and urbanization, but they have become our most important ally in the fight against climate change.

Following the IEA's landmark reports "The role of critical minerals in clean energy transitions" (May 2021) and "The World Energy Outlook" (December 2021), it has become abundantly clear that a vast increase in primary mineral supply will be required to facilitate the transition away from fossil fuels to clean energy, including offshore wind (IEA 2021a, 2021b). With recycling expected to contribute only 10% of supply in 2040, according to the IEA, society will need 6 times more metals in 2040 compared with today to become net-zero by 2050. The figures for key battery minerals are even more alarming; lithium supply will need to expand 42-fold, graphite 25-fold, cobalt 21-fold, and nickel 19-fold.

The majority of these minerals are found in geopolitically and environmentally sensitive regions. China, Russia, Indonesia, and DRC hold dominant positions in the mining and processing of minerals such as nickel and cobalt. As raw materials are not evenly distributed geographically, and all world powers are looking for different options to diversify the supply chain.

1.3.2. Polymetallic nodules

One such option entails polymetallic nodules, found on the abyssal plains of the world's oceans. A recent paper in Nature identified that the nodules in the Clarion Clipperton Zone (CCZ) of the Pacific Ocean, located between Hawaii and Mexico, contain more nickel, cobalt, and manganese than all terrestrial reserves combined (Hein et al. 2020). The nodules also contain copper. These metals are never found together in terrestrial deposits, meaning there is good reason to believe they can be recovered from the seabed in a way that places less stress on biodiversity and ecosystem function and results in lower carbon emissions overall.

When responsibly sourced, these nodules can play a central role in diversifying supply chains and achieving energy independence and could very well have environmental and social advantages over other sources of minerals. In a recent scientific publication from the University of Ghent (Belgium), it was shown that deep-seabed mining of polymetallic nodules produces up to 40% less CO2 compared to land mining (Alvarenga et al. 2021). Furthermore, the Massachusetts Institute of Technology (MIT) has shown that the impact of the sediment plume is much less than what has been previously estimated (Muñoz-Royo et al. 2022). In addition, research shows that the waste stream is significantly lower and that while the abyssal plains host much less biomass than tropical rainforests (where nickel laterite deposits occur), the impact on abyssal plain biodiversity (made up mostly microbes and meiofauna) cannot be compared to that found in tropical rainforests (where much larger lifeforms are found) (Paulikas et al. 2022; Katona et al. 2023). In addition, deep-seabed mining avoids deforestation, which is often a consequence of terrestrial mining (Giljum et al. 2022).

1.3.3. A central authority to regulate

The International Seabed Authority (ISA) is a body established through the United Nations Convention on the Law of the Sea (UNCLOS) and its Implementing Agreement to manage seabed mineral resources in the area beyond national jurisdiction. It is also mandated to ensure the effective protection of the marine environment. The ISA is comprised of 168 Member States and the EU. To date, 17 exploration contracts have been granted in the CCZ with Sponsoring States like China, Russia, South-Korea, Japan, France, Germany, Belgium, UK and others. Today, the industry is in a research phase, including collecting important environmental data, conducting environmental impact assessments, and developing environmental management plans to allow informed decision-making.

Regulations on Exploration are in place, and Regulations on Exploitation (mining) have been in development since 2014. The Exploitation Regulations are nearing completion (July 2025), with *a key outstanding issue entailing the financial payment regime including equitable distribution of proceeds. As part of the Mining Code, ISA has established detailed guidance and [draft] standards and guidelines for environmental studies and impact assessment, with lay out requirements for environmental baseline studies, environmental impact assessments, environmental impact statements and environmental management and monitoring plans. DEME-GSR is diligently adhering to these requirements, investing in a number of long-term studies.*

1.3.4. Research & Development

DEME-GSR is one of the offshore technology leaders in this space and conducted two technology trials in 2017 and 2021. The 2021 GSR trial was accompanied by independent monitoring by the EU JPIO MiningImpact2 project, entailing 30 scientific partners to close knowledge gaps and to establish best practice environmental monitoring in the deep ocean.

1.3.5. Polarization, Misinformation and Moratorium Calls

A number of OEMs have signed a call for a moratorium on deep seabed mining organized by WWF. These include BMW, Samsung, Google, and Volkswagen. In reality, the moratorium is aligned with the regulatory approach of the ISA and leaves the door open to seabed minerals if it can be demonstrated that they can be sourced responsibly.

1.3.6. European Critical Raw Materials Act

On 16 March 2023, the European Commission proposed the European Critical Raw Materials Act (CRMA), which will be translated into EU law by the end of 2024. The purpose of the CRMA is to propose a comprehensive set of actions to ensure the EU's access to a secure, diversified, affordable and sustainable supply of critical raw materials. The Regulation sets clear benchmarks for domestic capacities along the strategic raw material supply chain and to diversify EU supply by 2030:

- *At least 10% of the EU's annual consumption for extraction,*
- *At least 40% of the EU's annual consumption for processing,*
- *At least 25% of the EU's annual consumption for recycling,*
- *Not more than 65% of the Union's annual consumption of each strategic raw material at any relevant stage of processing from a single third country.*

In a first step policy makers will attempt to reshore mining activities onto European soil, followed by establishing partnerships (Critical Raw Materials Club) with countries which have reputable mining activities to strengthen global supply chains. It goes without saying that Europe is not the only economic power that wants to secure its supply chain. For decades, Europe's energy systems have been vulnerable to geopolitical and macro-economic risk.

The transition to clean energy technologies represents a unique opportunity to buttress European security and independence. In the final text, all three institutions (Council, Commission and Parliament) agreed that deep seabed mining can play a role provided it is done responsibly: "In line with the precautionary principle the Commission cannot grant the strategic status to a deep sea mining project before the effects of deep-sea mining on the marine environment, biodiversity and human activities have been sufficiently researched, the risks are understood and technologies and operational practices are able to demonstrate that the environment is not seriously harmed."

1.3.7. BBNJ Agreement

On 4 March 2023, the world adopted an Agreement on the management of the Biodiversity Beyond National Jurisdiction. Together with the Kunming-Montreal Global Biodiversity Framework, which was adopted on 19 December 2022, the world has now agreed to set aside 30% of the ocean and 30% of Earth's lands by 2030. Whilst it will take several years for these goals to be implemented, the ISA has already set aside over 30% of the CCZ as no-mining areas.

1.3.8. Take home message

The climate and biodiversity crises are coinciding with a massive increase in global population. Decarbonizing a rapidly urbanizing planet will require huge amounts of primary metal. This in turn will add to the carbon budget and impact biodiversity. Different solutions have different implications. Society needs to confront this reality so that these metals can be sourced in the most responsible way possible, for the benefit of us all.

Our call to action for policy makers is this: support the establishment of robust ISA regulations, support European involvement in the sector, support the science and research into all mineral supply options, including deep seabed minerals, so that informed decisions can be made about how best to achieve a sustainable future.

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1.4. Consulted stakeholder n°5

1.4.1. Learning by doing

Industrial activity typically develops in steps where knowledge that is acquired in one step results in more efficient and less impacting processes and more precise regulation in the next step. The cost of acquiring this knowledge is borne by the mining operation. The argument that no activity is allowed until sufficient knowledge is available does not take into account this economic reality.

1.4.2. Comparison with terrestrial mining

The basis of all socio-economic impact assessment is the equivalent comparison of alternatives - including the zero-alternative - in order to be able to make a well-founded decision.

Comparison of deep-seabed mining with terrestrial mining activities – either existing or to be developed – is not covered in this roundtable on the basis that the value of biodiversity loss in these vastly different environments cannot be expressed on a linear scale. Yet the organisms that are studied in the deep sea mainly consist of micro- and mesofauna. There are a few studies concerning micro- and mesofauna on terrestrial mines, but these studies are not part of a mining permit procedure. If these studies are not taken into account for terrestrial mining permits, how can their presence (or the lack of data about their presence) in the CCZ then be a basis to deny a mining permit? The concern is that the evaluation of deep-seabed mining is made on grounds that are not scientifically sound.

Comparison with terrestrial mining activities – existing or to be developed - will inevitably be done on an economic basis, with the most environmentally detrimental methods (such as laterite nickel mining) pushing more expensive/less impacting methods out of business. The concern is that without a straightforward (linear) comparison between Deep-Seabed Mining and terrestrial mining, there is no mechanism that takes into account the relative benefits of Deep-Seabed Mining and that makes it possible to opt for the less impacting scenario.

1.4.3. Comparison with other marine activities

The systematic inventarisation of impacts of deep-seabed mining to local and regional communities and thresholds for their response – which are deemed required for granting mining permits – are largely absent for other existing industrial marine activities such as dredging, fishing, maritime transport, oil a gas exploitation and offshore renewables. Some of these activities require Environmental and Social Impact Assessments, including in-situ monitoring, but these are all limited in terms of scope, cost, time, nr of pages, etc. It is unclear why terminology such as "precautionary principle" and "moratorium until sufficient knowledge is acquired", is only used with reference to Deep-Seabed Mining. The concern is that the development of Deep-Seabed Mining is impeded by other than scientific considerations.

1.4.4. Access to commodities

The access to raw materials is a key concern for the European economy. It is increasingly difficult to open or to keep operational local mines in Europe for economical and environmental reasons. A country that prohibits its companies to engage in deep-seabed mining because of possible environmental impact or that imposes conditions that make exploitation technically or economically impossible makes its economy dependent on countries that already dominate the extraction of raw materials, such as Russia and China. Such a point of view will rather harm a country's (tax) income than inhibit deep-seabed mining. Companies can relocate relatively easily to less strict countries.

1.4.5. Level playing field

The countries that eventually will support deep-seabed mining in CCZ, may have different views on environmental impact and stakeholder participation. Countries that impose conditions that make exploitation much more expensive, disadvantage the companies they sponsor. The concern is that mining companies sponsored by different companies cannot compete on the same level.

1.4.6. Open requirements make a business plan impossible

Monitoring and mitigation of environmental impact will most likely represent a significant portion of operating costs. These costs form the input of the business plan that makes an investment decision possible. More important than the amount of those costs is that the scope is determined. An example of such cost is the deep-seabed mining-specific insurance for environmental damage. Even with a consensus on the cap, insurers have no reference to determine the premium in advance. The concern is that this uncertainty will favour junior companies with large appetite for risk and high probability of failure over large established companies.

CHAPTER 2

ALIGNING SOCIETAL CONCERNS ABOUT POLYMETALLIC NODULE DEEP-SEABED MINING PRESSURES AND IMPACTS WITH THE REGULATORY FRAMEWORK: POTENTIAL METHODOLOGY AND PROOF OF CONCEPT

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1. Introduction

Deep-seabed polymetallic nodule mining is a potentially emerging industry poised for initial exploitation in the Clarion-Clipperton Fracture Zone (CCZ, 4.5 million km^2) in the northeast Pacific Ocean. The CCZ lies between Mexico and Hawaii in 4000 to 6000 m water depth, between the Clarion and the Clipperton submarine fracture zones and herein exist the greatest concentration of resource-grade polymetallic nodules discovered to date (Fig. 1) (Hein *et al*. 2013; Petersen *et al*. 2016; Dutkiewicz *et al*. 2020; Verlaan & Cronan 2022).

Polymetallic nodules of the CCZ contain critical minerals including nickel, cobalt, manganese, and copper – all of which have been identified as important for the clean energy transition. As such, the commercial collection of nodules is being considered to help meet clean energy goals. As with any extractive activity, there are environmental impacts to consider, and these must be carefully balanced with any economic or societal gains.

The International Seabed Authority (ISA) is an autonomous international organization which was established under the 1982 United Nations Convention of the Law of the Sea (UNCLOS) and the 1994 Agreement (relating to the Implementation of Part XI of UNCLOS). The ISA has a dual-mandate: determining the rules and procedures for deep-sea polymetallic nodule mining, and also to ensure the effective protection of the marine environment. These duties include overseeing any harmful effects that may arise from mineral resource related activities in the Area Beyond National Jurisdiction (ISA 2024a). To date, UNCLOS has been ratified by 169 parties (168 States and the European Union). In its remit, UNCLOS legislation Part XI, Section 2, Article 136, proclaimed the deep sea and its resources as the “common heritage

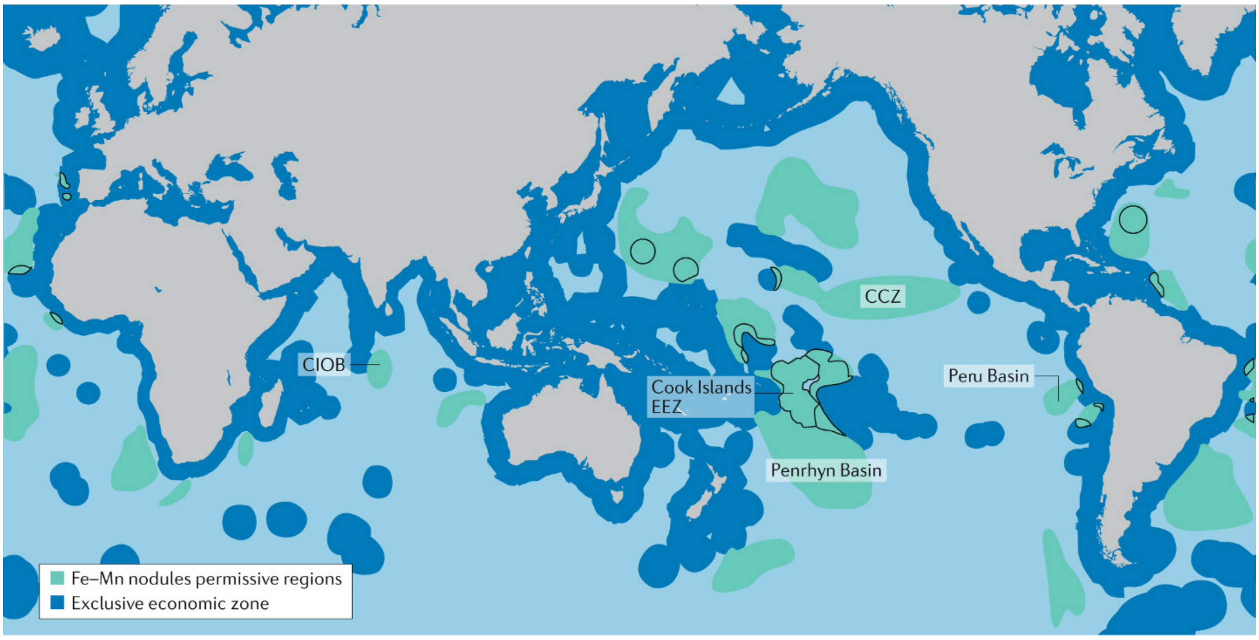

Figure 1. Global overview of ferro-manganese (Fe-Mn) polymetallic nodule provinces e.g., the Central Indian Ocean Basin (CIOB), abyssal plains of the Cook Islands exclusive economic zone (EEZ). The Clarion-Clipperton Fracture Zone (CCZ, northeast Pacific) being the largest concentration of this resource, globally. Source: Hein *et al*. 2020.

of mankind" (UNCLOS 1982). Moreover, UNCLOS set the policy context for deep-seabed resource environments (UNCLOS Articles 137, 145, 153, *inter alia*) and delegated the role of managing and regulating this sector to the ISA in consultation with stakeholders (Cormier & Londsdale 2020).

Currently, exploration for deep-seabed mineral resources, including polymetallic nodules, is ongoing by contractors in multiple regions (ISA 2024b). The ISA developed and adopted (binding) exploration regulations (ISBA/19/C/17) (ISA 2013) which stipulate, amongst others, that obligatory environmental baseline surveys be conducted. In conjunction with these exploration regulations there are recommendations for the guidance of contractors, including on the assessment of possible environmental impacts arising from exploration for marine minerals in the international seabed area (the Area) to assess possible environmental consequences (ISBA/25/LTC/6/Rev.3) (ISA 2023a).

Since 2014, the ISA began to develop regulations pertaining to the exploitation of mineral resources in the Area (ISA 2022a, 2023c; Pickens *et al*. 2024) and associated standards and guidelines which are at the time of writing still being negotiated. Together these regulations, recommendations and standards and guidelines form a comprehensive set of rules, regulations, and procedures, referred to as the "Mining Code". Even with these developments, the implementation of the exploration regulations and the ongoing negotiations of the exploitation regulations, not all societal concerns have thus far been considered, despite the ISA's strategy of stakeholder consultations (Carver *et al*. 2020; Amon *et al*. 2022; Cassotta & Goodsite 2024).

The key differences between these Mining Code documents are to what degree the information within is enforceable or legally binding. The distinction between the different document categories is as follows: (1) the "regulations" and the "standards" which are legally binding for both contractors and for the ISA and (2) the "recommendations" and "guidelines" which are recommendatory in nature and thus not legally binding (Table 1).

Please note that although all recommendations are not *per se* legally binding, the majority view is that the Contractors have agreed, by virtue of their contract with the ISA, to be guided by the recommendations, given that the (legally binding) exploration regulations mention that "…each contract shall require the contractor to gather environmental baseline data and to establish environmental baselines, taking into account any recommendations issued by the Legal and Technical Commission (LTA) (reg. 32)" (Prof. Niki Aloupi, Dr. Jennifer Walker and Prof. Klaas Willaert, personal communication).

One of the most frequently communicated societal concerns is that the areas targeted for mining and the ecosystems therein are insufficiently studied with large scientific knowledge gaps still persisting in different fields (Amon *et al*. 2022). In Chapter 1, societal concerns related to environmental pressures and impacts as expressed during a series of round-table discussions were categorised under nine thematic areas, with a tenth thematic area related to concerns about the effectiveness of mitigation of pressures and impacts. Of these ten thematic areas, twenty-nine overarching research questions and eighty operational research questions were identified. These Belgian stakeholder round-table discussions were initiated and facilitated by the federal Cabinet North Sea and took place in 2022–2024. Henceforth, the authors present a proof of concept for a potential future comparative analysis between societal concerns expressed about environmental impacts of deep-seabed mining and the ISA Mining Code.

2. Methodology and results

The proof of concept presented in this chapter although systematic, is not an exhaustive review of the current draft ISA Mining Code. A methodology was developed with which the data and information needed to answer the eighty operational questions could be compared to the information and/or data collection requests (recommended/obliged) by the ISA to eventually ascertain where there might be a complete, partial or no match.

This example pilot study aims to develop a methodology to achieve an overview of the degree of coverage of the ten thematic areas of societal concerns posited in Chapter 1 in the relevant ISA Mining Code documents. Subsequent to consultation* with subject matter experts Dr. Becky Hitchin and Dr. Samantha Smith on the most relevant documents for the current initiative, it was decided that eight draft Mining Code documents should be screened (Table 1). To check if the eighty operational research questions long-listed in Chapter 1 (which were not ranked with regard to their importance or priority, and are not exhaustive) are fully or partly covered, these questions were cross-checked against the data collection requirements or recommendations of these eight relevant Mining Code documents.

The methodology suggests following a structured approach to review the documents. At first, when it was not certain which ISA documents would be most relevant to this exercise, as a first step, keywords were systematically collated from the eighty operational research questions, *e.g.*, electromagnetic radiation, seabirds, collision, eco-toxicity/-toxicology, smothering, blanketing, and removal. Once we were certain which documents were most relevant, after the guidance of Dr. Becky Hitchin and Dr. Samantha Smith, this was followed by two rounds of full screening of the documents resulting in a stepwise hybrid approach. The last Mining Code document reviewed was dated 10th August 2022 and therefore this exercise does not include Mining Code documents released after the 27th ISA session.

A set of criteria in the form of questions were developed to see whether the data and information required to answer these

* Expert consultation occurred on 09/08/2023. After this date, the more recent ISA documents could not be included in this report for the example pilot study component of this chapter.

Table 1. An overview of the International Seabed Authority (ISA) Mining Code documents consulted in the course of this example pilot study. Documents marked with * are or will be (in case of draft versions) legally binding on contractors and the ISA. Documents related to exploitation that are intended to be binding are at the time of writing in draft form.

International Seabed Authority document number	Title and date of issue	Exploration/ exploitation
ISBA/19/C/17 (ISA 2013)*	Decision of the Council of the International Seabed Authority relating to amendments to the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area and related matters – 22nd July 2013	Exploration
ISBA/25/C/WP.1 (ISA 2019)*	Draft regulations on exploitation of mineral resources in the Area – 22nd March 2019	Exploitation
ISBA/27/C/4 (ISA 2022b)*	Draft standard and guidelines for the environmental impact assessment process. Standard for the environmental impact assessment process – 31st January 2022	Exploitation
ISBA/27/C/5 (ISA 2022c)	Draft guidelines for the preparation of environmental impact statements – 31st January 2022	Exploitation
ISBA/27/C/6 (ISA 2022d)	Draft guidelines for the preparation of Environmental Management and Monitoring Plans (wherein paragraphs 2, 25 and 72 have a *corrigendum*) – 31 January 2022	Exploitation
ISBA/27/C/6/Corr.1 (ISA 2022e)	Draft guidelines for the preparation of Environmental Management and Monitoring Plans. – 15th March 2022	Exploitation
ISBA/27/C/11 (ISA 2022f)	Draft guidelines for the establishment of baseline environmental data – 31st January 2022	Exploitation
ISBA/27/C/37 (ISA 2022g)	Guidance to facilitate the development of regional environmental management plans – 10th August 2022	Exploitation
ISBA/25/LTC/6/Rev.3 (ISA 2023a)	Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area – third revision – 4th August 2023	Exploration

questions were sufficiently covered by the current version of the draft Mining Code. Information relating to temporal and spatial scale was noted, *e.g.*, “large-scale”, “regional”, “vertical”, and “long-term”.

The following six criteria were used to screen the ISA documents:

(1) Is the response variable in the operational question covered by one of the ISA Mining Code documents, and how?
(2) Is spatial scale (both in relation to water depth and geography) mentioned in relation to the response variable, and how?
(3) Is temporal scale mentioned in relation to the response variable, and how?
(4) Is the explanatory variable in the operational question covered by one of the ISA Mining Code documents, and how?
(5) Is spatial scale (both in relation to water depth and geography) mentioned in relation to the explanatory variable, and how?
(6) Is temporal scale mentioned in relation to the explanatory variable, and how?

For each thematic area, we outlined both a “response” and an “explanatory” variable. For example in operational question 2.2, defined under the thematic area related to return sediment plumes: “What is the response of benthic ecosystem functioning in space and time to increased suspended sediment load?”, the explanatory variable here is “suspended sediment load” and the response variable here is “ecosystem functioning”. Hence, for this example we screened for “suspended sediment load” or “suspended sediment concentration” for the explanatory variable, and for the response variable we screened for “ecosystem function”, “ecosystem functioning” and/or any variables that are representative of ecosystem functions (*e.g.*, productivity, nutrient cycling).

The Mining Code documents were again screened but during this iteration, comparisons were stringent and only where all six criteria were fulfilled by the Mining Code, did our methodology consider this as a match. For example, where “water column” was mentioned, this was noted, along with any terminology relating to scale and temporal resolution, *e.g.*, bathypelagic zone, photic zone for the former and long-term, lasting, immediate for the latter. In screenings where one or more of the criteria were fulfilled, this was considered as a “partial” match and where none of the six criteria were fulfilled by the Mining Code documentation, we denoted “no” match. To ascertain whether spatial and temporal context criteria were fulfilled, units of space and time, *i.e.*, SI unit of distance and qualitative descriptors, *i.e.*, “short-/long-term, water column, regional” were considered as a match. An example of what such a comparative analysis could look like is presented in Fig. 2.

It is important to note that Fig. 2 is only intended for use as a proof of concept. The analytical results presented here are not to be considered as finalised. However, the methodology as preliminarily applied in this proof of concept would allow for an eventual deduction of statistics such as the percentage of “full”, “partial” or of “no” match between the operational research questions and the draft ISA Mining Code documents.

3. Discussion and conclusions

A key issue that still needs to be defined prior to commercial mining operations or exploitation is to clarify how exactly ISA member states can meet their duties as stipulated in UNCLOS Article 145 (UNCLOS 1982), *i.e.*, to effectively protect the marine environment from harmful effects that may arise from deep-seabed polymetallic nodule mining. The primary way to reach this goal (in addition to baseline studies) is via the development of robust exploitation regulations and standards and guidelines that would facilitate on an international scale the effective protection of the marine environment. Thus, one of the intentions of this exercise was to provide information on how the societal concerns should inform what the EIA/EIS should cover and manage.

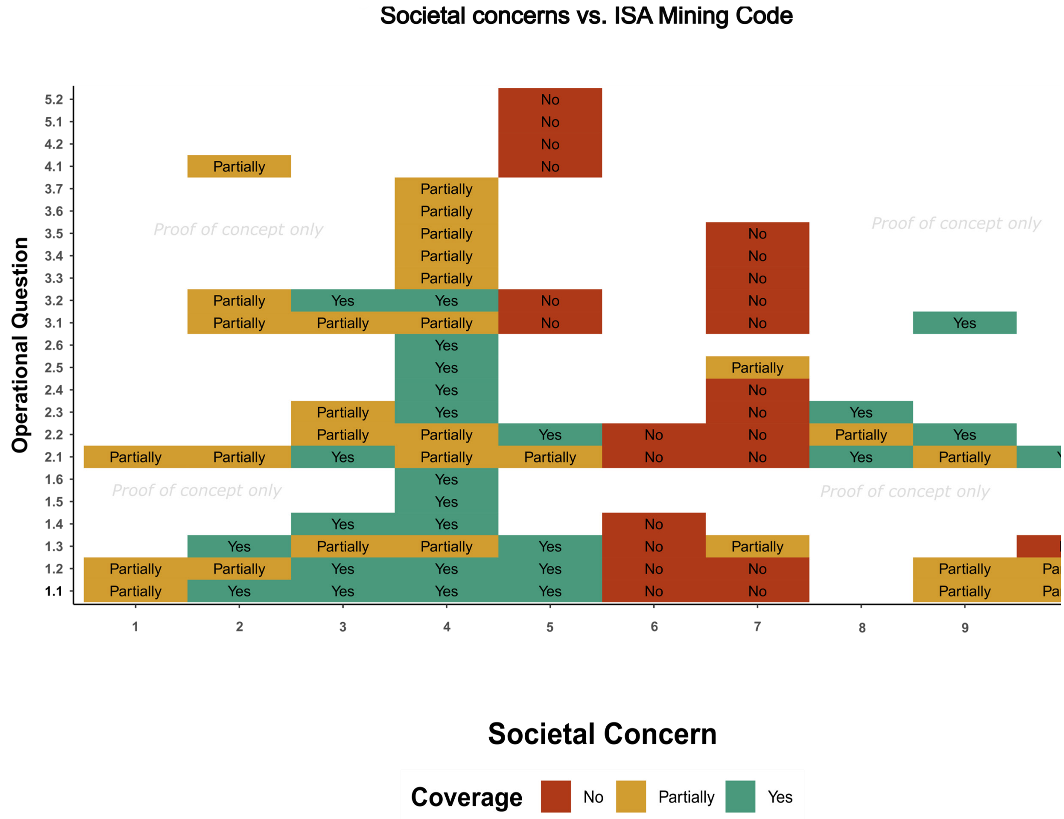

Figure 2. A preliminary prototype of the proof of concept of the ten thematic areas of societal concerns, the operational research questions and outcome of the comparison exercise in the Mining Code documentation. The comparisons were constrained using a set of six questions whereby a complete correlation of 6/6 was considered as "yes", a match of 1–5/6 was considered as a "partial" match and 0/6 was considered "no" match found. *y*-axis = Operational question number, *x*-axis = societal concerns titled as follows: 1: Removal of resources and sediment disturbance in nodule collector tracks, 2: Collector sediment plumes, 3: Return sediment plumes, 4: Contaminant release and toxicity, 5: Anthropogenic noise and turbulence, vibrations, electromagnetic radiation and light, 6: Introduction of invasive species, 7: Presence of physical structures, 8: Resilience, 9: Cumulative pressures and impacts, 10: Mitigation. **Not** to be disseminated as peer-reviewed, finalised results.

It is important to note that a potential lack of match between the operational research questions and the Mining Code does not necessarily imply that the latter is missing a request for data or information. In some instances, these operational questions may be answered by other relevant marine legislation such as the International Convention for the Prevention of Pollution from Ships (MARPOL 1973). However, this exercise was constrained to the information found within the Mining Code and not compared to the legislation/regulations/standards of other industries. Another reason for a lack of correlation may be that the concern is potentially not well-grounded, or it is not high-risk. Hence, as already stated in Chapter 1, it would be useful to examine these aspects prior to the comparison. Nevertheless, the results of this example pilot study indicate that the methodology should allow for the identification of the match between societal concerns and operational research questions.

The proof of concept presented in Fig. 2 should not be considered as finalised. A prototype such as Figure 2 provides a clear overview of what thematic areas are most covered and which are covered to the least extent. Discrete categories may be assigned, as in this example, or, a gradient may also be added to generate a heat map. Whilst the methodology developed is credible, the analytical results are pending a thorough cross-check of the criteria and terminology via peer review. For instance, during this initiative we assessed whether spatial and temporal scale of the variables in our operational research questions were mentioned in the ISA Mining Code documents, but we did not evaluate whether these were sufficient to answer the operational questions. This could be considered in a follow-up initiative. Furthermore, this chapter does not remark on the wider implications of these missing data or on the current status of policy. The authors have started this exercise with an overall goal to develop a methodology that could help to determine whether the statement that we do not know enough about these ecosystems is correct, and if so, what information are we still missing, and ultimately what scientific data and information are needed to address societal concerns about the environmental impacts of deep-seabed mining.

In sum, the proof of concept for this initiative has already been positively demonstrated at the Belgian national level for the offshore wind farms (Gill *et al*. 2020), and now forms a lynchpin with which future research strategies may be streamlined. At a mature stage, it is envisaged that the approach and preliminary results of such a study may be used as a foundation for future deep-seabed mining stakeholder engagement initiatives.

4. Outlook and recommendations

At the time of writing the ISA released a statement on the status of the draft regulations on exploitation of mineral resources in the Area (ISBA/28/C/INF/2) (ISA 2023b). The Council is currently (re-)considering the draft regulations on the exploitation of mineral resources in the Area (ISBA/25/C/WP.1) (ISA 2019). These were initially prepared by the LTA and submitted to the Council in 2019 following an iterative process of development and consultation that began in 2011. Five rounds of open stakeholder consultations were undertaken between 2014–2019.

The LTA also prepared drafts of ten standards and guidelines to support the implementation of the future regulations. These draft standards and guidelines have been through two stakeholder consultations during 2020 and 2021. Suggestions for normative environmental thresholds are in the process of being developed by the nominated intersessional expert groups (IEG) for each of the three main environmental pressures (1) underwater noise and light pollution, (2) turbidity and settling of resuspended sediments, and (3) toxicity (please refer to ISBA/28/C/5) (ISA 2023c).

On the 21st of July 2023, the Council adopted a decision on a timeline and modalities for the work of the Council until July 2024 and endorsed a new roadmap (ISBA/28/C/24) (ISA 2023d). Thus, at the time of writing there are no finalised legally binding standards for deep-seabed polymetallic nodule mining or exploitation.

Deep-seabed resource mining is a nascent industry and as such, the breadth of knowledge gathered during previous mining impact and environmental baseline studies (e.g., Gollner *et al*. 2017; Jones *et al*. 2017; Washburn *et al*. 2021) should be used as a scientific basis for the assessment of potential future exploitation activities. The methodology of this chapter may be opened up to the international audience, the resulting data from which may inform the decision-making, environmental policy, and legislation in the next ISA Council meetings. The procedure presented both in this report and when scaled-up in future initiatives could together sufficiently address the scientific knowledge gaps ultimately providing scientifically sound support to ocean governance.

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