Existing Environmental Management Approaches Relevant to Deep-Sea Mining

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Highlights (max 85 characters each including spaces)

-Gaps in environmental management of the deep-sea mining industry are identified

-Well-developed tools for management applicable to deep-sea mining exist

-Use lessons from other industries and science to guide deep-sea mining development

-Clear, robust and precautionary protocols and standards can be developed

Key words

Seabed mining industry; blue economy; environmental impact assessment; management systems; monitoring; mitigation

Abstract

Deep-sea mining (DSM) may become a significant stressor on the marine environment. The DSM industry should demonstrate transparently its commitment to preventing serious harm to the environment by complying with legal requirements, using environmental good practice, and minimizing environmental impacts. Here existing environmental management approaches relevant to DSM that can be used to improve performance are identified and detailed. DSM is still predominantly in the planning stage and will face some unique challenges but there is considerable environmental management experience in existing related industries. International good practice has been suggested for DSM by bodies such as the Pacific Community and the International Marine Minerals Society. The inherent uncertainty in DSM presents challenges, but it can be addressed by collection of environmental information, area-based/spatial management, the precautionary approach and adaptive management. Tools exist for regional and strategic management, which have already begun to be introduced by the International Seabed Authority, for example in the Clarion-Clipperton Zone. Project specific environmental management, through environmental impact assessment, baseline assessment, monitoring, mitigation and environmental management planning, will be critical to identify and reduce potential impacts. In addition, extractive companies' internal management may be optimised to improve performance by emphasising sustainability at a high level in the company, improving transparency and reporting and introducing environmental management systems. The DSM industry and its regulators have the potential to select and optimize recognised and documented effective practices and adapt them, greatly improving the environmental performance of this new industry.

1 Introduction

To date there has been no true commercial deep-sea mining (DSM), yet the sector already faces challenges in obtaining support and approval for developments. In some cases societal concerns have stopped or delayed planned seabed mining projects [1, 2]. The deep-sea environment, although vast, is poorly known and may be particularly sensitive to disturbance from anthropogenic activities [3]. Perceptions about the likely environmental impacts of deep-sea mining have been based on this sensitivity and concern over previous impacts caused by allied (or related) industries, such as terrestrial mining and offshore oil and gas operations [4]. The social and environmental effects of mining on land feature regularly in the media [e.g. 5], and the reputational and financial risks of environmental damage at sea are enormous, as demonstrated by the $55 billion dollar cost of the 2010 Deep Water Horizon oil spill [6]. Therefore, corporate responsibility is a key issue in sustaining a profitable business and for the DSM sector as a whole.

This demand for social license is coupled with the overarching legal requirements of the United Nations Convention on the Law of the Sea, which sets forth the environmental aim of ensuring effective protection from harmful effects of seabed mining, plus a legal obligation to avoid serious harm [7]. While definitions for these key terms are still evolving, it will be imperative for the DSM industry to transparently demonstrate its commitment to environmental sustainability in order to obtain and keep its social licence to operate [8]. It must comply with international legal requirements as well as national legislation, follow good-practice guidance, learn from the experience of allied industries and take all steps to minimize environmental impacts. To do this effectively, the industry needs to develop and maintain high standards of operations throughout the development cycle. Such management of processes is not straightforward and relies on a continuous cycle of developing, documenting, consulting, reviewing and refining activities.

Increased environmental standards are often assumed to impose significant costs on industry, impacting productivity adversely [9]. This view has been challenged by an alternative hypothesis that well-designed environmental regulations encourage innovation, potentially increasing productivity and producing greater profits [10]. The benefits of establishing regulations and binding recommendations include: 1) increased efficiency in the use of resources, 2) greater corporate awareness, 3) lower risks that investments in environmental practices will be unprofitable, 4) greater innovation, and 5) a levelling of the playing field between operators [10]. This hypothesis applies principally to productivity and market outputs, with other benefits to reputation and social license. When these benefits are considered together, evidence-based studies suggest that improved environmental requirements bring positive outcomes for industry [11]. Compelling examples of such positive outcomes on the offshore oil industry can be found in the management of routine safety and environmental activities [12]. Reductions in safety incidents and environmental hazards and their consequences have been made through advances in operational management, including regular improvements made through an iterative cycle of planning, implementation, monitoring and review [13]. Protocols for good practice in operations have been developed, tested and refined over time. Effective operations have been taken up by trade organisations and made into industry-wide standards [13]. Increasingly more rigorous legal regimes and pressures from stakeholders have enforced changes.

The DSM industry has the opportunity to learn from developments in safety and environmental management practices in other industries. DSM is still predominantly in the planning stage, offering a unique opportunity to implement good-practice approaches proactively from the outset. Although DSM will face some unique challenges, many of the key environmental management issues (e.g. environmental impact assessment (EIA), environmental management planning (EMP), baseline assessment, monitoring and mitigation) have been considered and documented in detail already by allied industries. DSM has the potential to select and optimize recognised and documented good practices and adapt them. However, DSM is different from other industries. There is a particular lack of knowledge of the environments of industry interest, and very little information on the potential effects of mining activities [14]. DSM is also unlike many other marine industries in having an international legal framework that prescribes the need to avoid serious harm [7].

A major advantage in developing good practices for DSM is that there is one principal global regulator. Unlike most deep-water industries, it is likely that a significant amount of DSM will be carried out in areas beyond national jurisdiction (the seabed that lies beyond the limits of the continental shelf is known as "the Area"). The Area and its mineral resources have been designated as the "Common Heritage of Mankind" [15]. Mining there is controlled by the International Seabed Authority (ISA), an international body composed of States party to the United Nations Convention on the Law of the Sea (UNCLOS), which is charged with managing the Area and its resources on behalf of all mankind, as a kind of trustee on behalf of present and future generations [16]. The legal status of the Area and its resources influences every aspect of the ISA regime, including the determination of an adequate balance between facilitating mining and protecting the marine environment [17]. The concept of the common heritage of mankind promotes the uniform application of the highest standards for the protection of the marine environment and the safe development of activities in the Area [17]. States encouraging DSM within their Exclusive Economic Zones must ensure that national rules and standards are "no less effective" than international rules and standards [17], thus approaches adopted by the ISA should be incorporated into national legislation and regulations.

Here existing environmental management approaches relevant to the exploitation of deep-sea minerals are identified and detailed. Environmental management will be principally guided by ISA rules, regulations, procedures and guidelines. However, the legal landscape governing DSM has been widely discussed [e.g. 18] and is outside the scope of this review. Instead, this review focuses on the mechanisms that can be used to improve the management of DSM. These include good practices adopted by allied industry (such as the offshore oil and gas sector and the marine aggregates industry) and professional organisations. Drivers for increasing sustainability are considered, followed by an assessment of management approaches that may reduce the environmental impact of operations.

2 Beyond compliance: drivers for improving environmental management of DSM

There are many reasons for improving environmental management beyond compliance with environmental regulation. All industrial activities involve a range of stakeholders that exert direct and indirect pressure on parties active in the industry; this review concentrates on drivers from those stakeholders that can exert direct legal or financial pressure on those involved in DSM activities (Figure 1).

FIGURE 1 HERE

In the case of DSM in the Area, companies need a state sponsor. The sponsor should exercise due diligence to ensure that the mining company complies with ISA rules, regulations, standards and procedures [19]. However, there is no specific guidance on meeting this requirement [20] and no examples exist of acceptable practice. All sponsoring states may need to enact and enforce new laws (for example the Singapore Deep Seabed Mining Act (2015) was enacted to enable Singapore to become a sponsoring state [21]), and implement administrative procedures and resources to regulate their enterprises, or be held liable for damage to the marine environment [22].

Many DSM operations will require external funding from large organisations, including international financial organisations and institutional investors. Increasingly, financial backing for companies or projects is dependent upon meeting key environmental criteria or performance standards. Rules and advice are given by the World Bank [23] and the International Finance Corporation [24] on criteria that should be used when considering projects for finance and the performance standards that must be achieved. Projects for the World Bank are assessed on whether they are likely to have significant adverse environmental impacts and whether the ecosystems they affect are sensitive or particularly diverse [23]. If the project is unprecedented, such as in the case of DSM, consideration might be given to the degree to which potential environmental effects are poorly known [23, 25].

The Equator Principles have been adopted by approximately 70% of organisations providing project finance for any industry across 36 countries [26]. This group of 81 Equator Principles Financial Institutions has agreed that for a company to receive investment or finance it must demonstrate that it meets eight Environmental and Social Performance Standards developed by the International Finance Corporation [24]. The Performance Standards provide guidance on how to identify risks and impacts, and are designed to help avoid, mitigate, and manage risks and impacts as a way of doing business in a sustainable way [24]. Of key relevance is Performance Standard 6 on biodiversity conservation and sustainable management of living natural resources [27]. Appropriate mitigation, following the mitigation hierarchy is emphasised particularly for avoiding biodiversity loss [28]. These appraisals take into account the level of stakeholder engagement and participation in decision taking [29].

Although the effect on DSM may be minor, there is evidence that an increasing number of individual investors are using environmental considerations to inform their investment decisions [30]. These ethical investment funds invest in companies based on objective environmental performance criteria. As a result, an increasing percentage of the ownership of a public company may be concerned with corporate sustainability and the share price may be partially driven by environmental performance. While a mining company may only directly benefit from this as part of an initial public offering, managers are usually shareholders and benefit from a high share price. Furthermore, the market for eventual mineral products of DSM may be driven in part by social or environmental considerations.

2.1.1 International good practice guidance

National and international policy has been augmented substantially by developments in international good practice guidance. A good example of such guidance was developed to guide the development of Pacific Island States Exclusive Economic Zones (EEZ) through a joint programme of work at the Secretariat of the Pacific Community (SPC; now the Pacific Community), supported by funding from the European Commission. They have developed a Regional Legislative and Regulatory Framework (RLRF) [31], a Regional Environmental Management Framework (REMP) [32] and Regional Scientific Research Guidelines [33] for Deep-Sea Mineral Exploration and Exploitation. In assessing the impact of DSM activities and any associated activities, the SPC reports recommend an “ecosystem services” approach in all its guidance, recognizing that ecosystems provide a wider variety of services than just resources.

For DSM in the Area, the ISA is considering issues of corporate social responsibility as part of its development of a framework for the exploitation of deep-sea minerals [34]. This may become a particularly important issue owing to the participation of many developing nations in the ISA, several of which will have faced social and environmental issues from mining activities on land.

2.1.2 Industry bodies

A Voluntary Code for the Environmental Management of Marine Mining has been created through the International Marine Mining Society (IMMS) [35], and the ISA has encouraged its contractors to apply the code (ISA, 2011, Section VII B, page 12) [36]. As the ISA notes (ISBA/16/LTC/2, section I, 1) [37]:

The Code provides a framework and benchmarks for development and implementation of an environmental programme for a marine exploration or extraction site by marine mining companies and for stakeholders in Governments, non-governmental organizations and communities in evaluating actual and proposed applications of environmental programmes at marine mining sites. The Code also assists in meeting the marine mining industry's requirement for regulatory predictability and risk minimization and in facilitating financial and operational planning.

The emerging exploitation regulations can be expected to cover many of the same elements as the Code, making them mandatory. The Code can also help to guide business practices within national waters until regulatory systems catch up.
Companies adopting the IMMS Code commit themselves to a number of high level management actions: to observe all laws and regulations, apply good practice and fit-for-purpose procedures, observe the Precautionary Approach, consult with stakeholders, facilitate community partnerships on environmental matters, maintain a quality review programme, and transparent reporting [35]. The Code also contains guidance on responsible and sustainable development, company ethics, partnerships, environmental risk management, environmental rehabilitation, decommissioning, the collection, exchange and archiving of data, and the setting of performance targets, reporting procedures and compliance reviews.

The IMMS Code foresees the need for companies to develop environmentally responsible ethics by showing management commitment, implementing environmental management systems, and providing time and resources to demonstrate environmental commitment by employees, contractors and suppliers of equipment, goods and services [35]. Specific recommendations are made on reviewing, improving and updating environmental policies and standards, as well as communicating these at business and scientific meetings [35]. Companies are encouraged to evaluate their environmental performance regularly using a team of qualified, externally-accredited environmental auditors [35].

3 Addressing uncertainty

Deep-sea mining is planned to occur in areas that are generally poorly known, especially with regard to their ecology and sensitivities [7]. This leads to great uncertainty in the estimation of impacts [14] and hence for establishing management activities. Managers and regulators need ways to address and reduce this uncertainty. The first approach is to reduce uncertainty through baseline data collection, experimentation and monitoring of activities. This is important, but will take a long time, particularly because of the difficulties of sampling in remote deep-sea environments but also because effects must be measured over large timescales in order to capture the long response times in many deep-water systems [38]. Area based management tools (ABMT or spatial management) are a second important approach. By protecting a proportion of an area representative of the environment suitable for deep-sea mining, it is likely that many of its key attributes, such as structure, biodiversity and functioning, are also being protected, particularly if all available information is taken into account in a systematic approach [39, 40]. ABMTs are often set up at a broad scale in regional environmental management planning and at a finer scale in EMPs. Two other important approaches for dealing with uncertainty are applying the precautionary approach and adaptive management.

The precautionary approach is widely adopted in a range of international policy [41]. The precautionary approach is to be implemented when an activity raises threats of harm to human health or the environment, and calls for precautionary measures to be taken even if some cause and effect relationships are not fully established scientifically [41]. It is a crucial tool to address the environmental protection challenges posed by deep seabed mining, both at a regulatory level and for management by the contractor [18]. The precautionary approach is applicable to all decisions relevant to DSM, including assessments of the environmental risks and impacts, the effectiveness and proportionality of potential protective measures as well as any potential counter-effects of these measures [18, 42]. Precautionary decision-making includes consideration of scientific knowledge and the identification and examination of uncertainties [18]. The precautionary approach is valuable in many stages of both the preparation and evaluation of EIA and EMPs [18, 43]. The RLRF and REMP developed by the SPC address the application of the Precautionary Approach by stressing the need to avoid the occurrence of irreversible damage. Seeking out alternatives to the proposed action as well as ongoing monitoring and research are also essential components of the precautionary approach. Where there is a possibility of an adverse effect, the provision of evidence that the nature or extent of this will be acceptable will rest with the operator.

For environmental management in projects of high uncertainty, adaptive management has been suggested as a suitable approach [44]. In DSM, uncertainty exists in a wide range of aspects particularly the impacts of mining and their effects on the environment. This results in uncertainty about the efficacy of mitigation measures proposed in an EMP. Adaptive management is a form of structured decision-making that addresses this uncertainty by monitoring the effects of the management plan and assessing the results of the monitoring with the intention to learn from the results and incorporate findings into revised models for management actions [21]. The SPC considers the application of adaptive management in its RLRF and REMP [31, 32]; adaptive management techniques are recommended to allow some activities to proceed despite uncertainty provided appropriate checks and risk-minimising controls are in place. The application of adaptive management is complicated in the Area as a result of the vulnerability of most deep-sea environments to serious and irreversible impacts from commercial scale DSM, combined with requirement to avoid serious harm [7]. Adaptive management could be applied both by the regulator, in setting of regulations, policies and guidelines, and by the contractor, in improving their environmental management activities throughout the project. While widely acknowledged as a useful management tool [45, 46], it is not clear how adaptive management approaches will be incorporated by the ISA into regulations or implemented for DSM in the Area [21, 47]. However, adaptive management has been applied successfully by a regulator to manage chemosynthetic deep-sea communities associated with SMS deposits in national jurisdictions [48]. Adaptive management should form part of the contractors’ environmental management planning and based on the results of careful monitoring, activities may be adjusted as information improves.

4 Broad scale environmental management

Although DSM will likely occur in different geographic, ecological and geological settings, such as the Clarion-Clipperton Zone (CCZ) in the equatorial eastern Pacific, at mid ocean ridge systems and at a few selected seamounts [49], there are many environmental issues that are common to DSM development in all of these areas that would benefit from harmonizing environmental management measures [21]. For example, potential environmental risks may extend beyond the boundary of a single mining site, while others may result in cumulative impacts from multiple mine sites within a region and from interactions with other uses of marine space (such as deep-water fisheries). Environmental risks may need to be considered at a broad (regional) scale and environmental management procedures may need to be tailored to the resources and ecosystems under pressure [21], and require coordination with other stakeholders and regulatory bodies. As a result, it is important to develop approaches for environmental management at a more strategic level, for example within a region [50].

The broad scales of planned mining activities and potential impacts highlight the need to manage the marine environment across business sectors and at broader scales than any one activity. Management at scales greater than individual projects is usually termed strategic or regional management. The generally accepted processes for this are Regional Environmental Assessment (REA) and Strategic Environmental Assessment (SEA) [51, 52]. Both SEA and REA are assessments, and as such, a process. The outcome of this process is typically twofold: a report that documents the process and a management plan (e.g. a regional environmental management plan; REMP) that describes the implementation of the management approach. The ISA has already begun setting high-level strategies [53], which include protecting the marine environment and encouraging scientific research. However, their focus for detailed assessment appears to be at the regional level [21] and some elements of a regional environmental management plan already exist for the CCZ, focussed on area-based management [54]. The ISA has also held workshops with a view to develop REMPs for Mid-Atlantic Ridges and North Pacific Seamount areas. As a result, this paper focuses on regional environmental assessment, which refers to an evaluation the wider regional context within which multiple and different activities are set. REA can be viewed as a subset of SEA

[55, 56]. These processes are an early management action that allows biodiversity and other environmental considerations to be included in the development of new programmes [51]. A REA for DSM might include an assessment of the probability, duration, frequency and reversibility of environmental impacts, the cumulative and transboundary impacts, the magnitude and spatial extent of the effects, the value and vulnerability of the area likely to be affected including those with protection status and the extent of uncertainty in any of the above [56]. These approaches represent the need for a transparent [57] broad, or strategic, planning view. Such assessments and resulting documents therefore are ideally formulated at an early stage, but are ongoing and should be adapted with time. For example, REAs may include provisions for representative networks of systems of Marine Protected Areas (MPAs) before specific activities commence, and for adjustments in MPA provisions with time. This may be already challenging for DSM when contractor exploration areas are defined and exploration activities have begun [40].

Regional or strategic assessments have guided a number of similar industries to DSM and how they operate, particularly as a result of the EU SEA Directive [51]. SEA has been undertaken for the offshore oil and gas exploration and production sector for several years [58]. Not all industries follow explicitly, but have adapted the SEA approach to meet their particular needs, for example ‘Zonal Environmental Appraisal’ (ZEA) for the UK East Anglia Offshore Wind Farm development [59, 60] and REA for the UK Marine Aggregate Regional Environmental Assessments [MAREA; e.g. 61]. Both ZEAs and REAs consider cumulative impacts; in the former case taking into account the effects of multiple wind turbine structures and in the latter case numerous and repeated dredging operations. In the case of dredging, the impacts of existing claim areas up for renewal are considered with applications developing new areas.

The ISA has begun strategic planning [17]. It has adopted a regional environmental management plan in the CCZ in the equatorial Eastern Pacific Ocean [36]. The CCZ EMP incorporates some of the aspects of an REA process for polymetallic nodule mining. The CCZ EMP was adopted in 2012 to set aside c. 1.5 million km^2 of seabed of a total of approximately 6 million km^2 [50] in order to protect the full range of habitats and biodiversity across the CCZ. The EMP adopts a holistic approach to the environmental management of the CCZ in its entirety, including, where appropriate, consideration of cumulative impacts, and incorporating EIAs of new and developing technologies. The CCZ EMP aims 1) to maintain regional biodiversity, ecosystem structure and ecosystem function across the CCZ, 2) manage the CCZ consistent with the principles of integrated ecosystem-based management and 3) enable the preservation of representative and unique marine ecosystems. For this purpose, the CCZ EMP establishes, on a provisional basis, an initial set of nine “Areas of Particular Environmental Interest” (APEI) as no-mining areas based on expert recommendations [39, 50], which has been recommended to be expanded [62]. The CCZ EMP does not include any APEIs within the central section, with the highest nodule concentrations and greatest mining interest, primarily because exploration contracts had been issued prior to the APEIs being established [21]. The CCZ EMP has left some flexibility as the boundaries may be modified based on improved scientific information about the location of mining activity, measurements of actual impacts from mining operations, and more biological data if equivalent protection can be achieved. The EMP should be subject to periodic external review by the ISA LTC at least every five years [36].

In 2013, the United Nations General Assembly invited the LTC to prioritize the development of EMPs for other regions of mining interest, and development of further regional environmental management plans is now a priority for the ISA [21]. This will build on the ISA’s experience with the establishment of the environmental management plan for the CCZ.

5 Project-specific environmental management

Environmental management at a project level involves detailed management of a clearly defined project location and activities within known environmental conditions, with the aim of minimizing impacts according to strategic environmental objectives. Most industries have accepted processes for the incorporation of environmental management into the planning and execution of projects, with defined project phases and associated deliverables, and roles and responsibilities for involved parties [63]; such a process has been suggested as part of the IMMS Code [35] and detailed for DSM [45]. Project-specific environmental assessments, an important component of management, are common for most major developments; internationally-approved approaches involve environmental impact and risk assessment to identify, avoid, mitigate and, potentially compensate for environmental impacts [63].

Environmental impact assessment is a key aspect of the planning and environmental management of a project [43]. EIA is a process that is documented in a report (EIA report or Environmental Impact Statement: EIS). EIA aims to describe the major impacts of an activity on the environment in terms of its nature, extent, intensity and persistence [64]; a plan can be developed to mitigate the impacts [28] using this assessment, and an overall decision can be made as to whether the project should take place [45] and what conditions should be observed if it does (for example mitigation actions, monitoring and reporting). EIA addresses the sensitivity and/or vulnerability of all habitats and species that may be affected and the ability of those habitats to recover from harm, including cumulative effects. Cumulative effects may occur from a number of repeated impacts, the sum of different impacts, and/or the combined effects of human impacts and natural events. Environmental assessments should include characteristics of the ecosystems that may warrant extra protection [65-67]. The ISA draft exploitation regulations require a site-specific EIA to be completed and an environmental management plan for DSM to be developed prior to the commencement of mining operations [68]. A draft template for environmental impact statements for exploration has also been developed by the ISA [69]. An ideal EIA process has recently been detailed for DSM [43, 45]. EIA should be a transparent process that involves independent experts and encourages public participation [70].

EIA is typically divided into stages, which are directly applicable to DSM [43]. Screening is the process by which a project is assessed to determine whether or not the production of a statutory EIA Report is required [43]. It is expected that most DSM activities will require an EIA [43]. The scoping phase should determine the content or scope, extent of the issues to be covered, the level of detail required in the EIA and identify actions to be taken to compile the required information [71]. Scoping is an important part of the EIA process in most jurisdictions and formal scoping opinions are important in clarifying the focus and direction of the EIA process [72]. Scoping studies may include a project description, project location with mapping, a list of receptors expected to be affected at each stage and by each activity, the identification of potential environmental impacts (including likelihood and magnitude) and information on how assessment will be carried out, data availability and gaps, as well as suitable survey, research and assessment methodologies [73, 74]. Scoping studies are also required to consider transboundary effects [57].

EIAs generally include an environmental baseline against which the effects of the project can be assessed [75]. The baseline study describes the physical, chemical, biological, geological and human-related environmental conditions that will prevail in the absence of the project, together with interactions between elements of them. Typically, the baseline study will identify the pre-project conditions, and highlight habitats and species that may be vulnerable to the impacts of the planned project. The study will describe and quantify environmental characteristics and may provide predictive modelling of some aspects to inform judgements about the quality, importance, and sensitivity of environmental variables to the impacts identified during the scoping process. Although it has been challenging to implement [76], the European Marine Strategy Framework Directive (2008/56/EC) uses the concept of good environmental status, with multiple descriptors to define the baseline and thresholds for significant effects. All DSM projects are expected to acquire new baseline data specific to the project prior to test operations and full-scale mining [77]. The baseline study will form the basis for subsequent monitoring of environmental impact during mining.

The ISA has issued guidance to contractors on the elements required in an environmental baseline study [77, 78] covering all three main mineral resource types: polymetallic nodules, sulphides and cobalt-rich crusts. To ensure a degree of standardization and quality, the guidance on baseline study elements includes the definition of biological, chemical, geological and physical measurements to be made, the methods and procedures to be followed, and location of measurement such as the sea-surface, in mid-water and on the seabed. Scientists have made further suggestions on parameters to include [43, 45]. These data are required to document the natural conditions that exist prior to mining activities, to determine natural processes and their rates, and to make accurate environmental impact predictions.

Baseline survey for DSM may have some specific characteristics that differentiate it from other industries [75]. There is very little knowledge of potential effects of large-scale mining activities and the ecology of the areas likely to be impacted by mining is likewise poorly known [14]. As a result, baseline surveys will necessarily have to target a wider range of investigations. Building the knowledge-base of how ecosystems respond to mining disturbance is also critical and measures of initial impacts, ecosystem effects and the rate of recovery of faunal communities and ecosystem function will be important. Residual uncertainty will be high, at least in the EIA phase, and statistical and probability analyses will be important to assess the likelihood of occurrence of a particular outcome [79]. A comparison of the mining site and reference areas to wider knowledge of biological communities in the region should be made. Area based or spatial management options are likely to be an important component of managing residual impacts [21, 79].

The guiding principle for environmental management is to prevent or mitigate adverse impacts on the environment [28]. The tiered “Mitigation Hierarchy” is becoming an accepted tool for operationalizing this principle [28] and is integral to the International Finance Corporation’s Performance Standards [24]. The first two tiers of the hierarchy, avoidance and minimisation, prevent the impacts from occurring and thus deserve particular emphasis. Indeed, these principles are referred to throughout guidance for DSM. The last tiers of the hierarchy, restoration and offsetting, are remediative, as they seek to repair and compensate for unavoidable damage to biodiversity. These stages have been little explored in the case of DSM [see 80] and are expected to be costly and have uncertain outcomes [28, 43, 81, 82].

An EIA Report brings together all the information generated from environmental baseline studies, the planned industrial activities, the EIA, and proposals for mitigation of impacts. The details of the planned industrial activities should include a description of the proposed development, its objectives and potential benefits, compliance with legislation, regulation and guidelines, stakeholder consultations and closure plans [83]. The EIA Report contains a set of commitments to avoid, and to minimise or reduce the environmental impacts of a project to an acceptable level (and in some instances to offset or compensate for the effects). While an EIA Report is generally specific to one project it may have to take into account other activities, environmental planning provisions and business sectors in the region and the possible cumulative impacts of the proposed activity with these other operations. It may also have to take into account effects of any reasonably foreseeable future impacts (e.g. climate change and ocean acidification). Guidance for the preparation of EIA reports for DSM in the exploration phase has been provided by the ISA [68, 69] and further elaborations are to be expected as part of the exploitation regulations and associated documents.

An initial guide on EIA for prospective developers planning mineral exploitation activities [68, 84] has now been refined by guidelines for EIAs relating to offshore mining and drilling in New Zealand waters [79]. These guides highlighted some concerns specific to DSM, in particularly the high levels of uncertainty associated with DSM. Sources of uncertainty, such as uncertainties in environmental conditions, mining plans, impacts of activities or efficacy of mitigation actions, should be identified and mitigation should be precautionary. Uncertainty may be addressed in part with the use of predictive models, which should be described, validated, reviewed and tested against other models [79] as was done in some existing EIAs for DSM [84].

Every plan of work for marine minerals must include a plan for management and monitoring, the EMP (Environmental Management Plan, also known as an Environmental Management and Monitoring Plan, EMMP). The aim of the EMP is to ensure that harmful effects are minimized, no serious harm is caused to the marine environment and the more specific requirements of ISA rules, regulations and standards as well as the environmental goals of the actions planned in the EIA are achieved. The EIA Report should contain at least a provisional EMP or a framework for one [e.g. 85]. Both the EIA Report and the final EMP are generally required to obtain regulatory approval to begin and continue operations; the ISA has provided some instructions for the content of an EMP for DSM [68].

An EMP is a project-specific plan developed to ensure that all necessary measures are identified and implemented in order to ensure effective protection of the marine environment, monitor the impacts of a project and to comply with ISA environmental rules, regulations and procedures as well as relevant national legislation [85, 86]. Such plans should clearly detail how environmental management and monitoring activities will be accomplished through the elaboration of specific objectives, components and activities, inputs (human, physical, financial) and outputs [85, 87] . The EMP must include monitoring before, during and after testing and commercial use of collecting systems and equipment. This will require the development of relevant indicators, thresholds and responses in order to trigger timely action to prevent serious harm. Monitoring will demonstrate whether the predictions made in the EIA are broadly correct, show that mitigation is working as planned, address any uncertainties, demonstrate compliance with the approval conditions, allow the early identification of unexpected or unforeseen effects, and supports the principle of 'adaptive management'. A clear budget and schedule for implementation is also required, with identification of the agencies responsible for financing, supervision and implementation, and other relevant stakeholders' interests, roles and responsibilities [86]. The monitoring plan should allow for impacts to be evaluated and compared with the scale(s) of variation expected from natural change, which should be assessed in the baseline study [87].

Within site management and monitoring plans provide the opportunity for specifying more local area-based management approaches. For example, it looks likely that exploitation monitoring will require establishment of impact reference zones (IRZ) and preservation reference zones (PRZ) in keeping with the ISA exploration regulations [88, 89]. Dedicated protected areas within a claim area (potentially including the PRZ), either based on criteria of representativity or importance, may help meet management objectives by mitigating impacts, at least at the scale of the claim area. Environmental management plans also offer the opportunity for even finer-scale mitigation options, such as leaving protected recolonization networks or including technological approaches to reducing the impact.

Nautilus Minerals Inc. have engaged in advance planning for SMS mining in the Exclusive Economic Zone of Papua New Guinea at the 'Solwara 1' site [84]. The approach taken by Nautilus Minerals is similar to that outlined here for other related industries. Nautilus Minerals collected environmental data to inform the EIA and improve management. Their environmental plan allows for mitigation strategies to assist the recovery of benthic ecosystems, although it is not clear if these strategies will be carried out. Mitigation strategies include the preservation of similar communities, in terms of species, abundance, biomass, diversity and community structure, at a locality within 2 km upstream [84] to allow monitored natural recolonisation of the mined area. They also include potential active restoration through the translocation of faunal groups from areas about to be mined to those areas where mining is complete [80]. A monitoring plan is to be submitted by Nautilus to PNG as part of an EMP before mining begins [84]. They will monitor and report on compliance with regulatory permits and licenses, including the validation of predicted impacts, the documentation of any unanticipated events and the introduction of additional management measures. Such a project is inevitably controversial [90], but has received authorisation to proceed from the PNG government.

Environmental impact assessment has been carried out for other mining-related projects. Some details of the EIS are available for a SMS project in either Okinawa Trough or Izu-Bonin Arc in Japan's national waters [91]. This work focusses on the environmental baseline data for the sites. There have also been two recent EIS produced for a nodule collector test in two claim areas of the Clarion-Clipperton Zone. These provide detail on small-scale tests (covering approximately 0.1 km^2 of seabed) in the German Federal Institute for Geosciences and Natural Resources (BGR) and Belgian Global Sea Mineral Resources NV (GSR) claims as part of the Joint Programming Initiative-Oceans science and industry project MiningImpact [92, 93]. The responses to these documents is as yet unknown.

6 Corporate tools for environmental management

A key characteristic of a modern sustainable business is a clear focus on sustainability in the corporate strategy. To achieve this focus, the senior management team of an organisation must include environmental considerations in all aspects of the business and create policies that embody broad sustainability principles. Clear management responsibilities and commitment at the highest level are vital to integrate environmentally responsible and sustainable management practices into all operations within a company, from exploration, through design and construction to operations (e.g. mining, minerals processing, waste disposal, mine site rehabilitation and decommissioning). Staff dedicated to environmental responsibilities report directly to senior management [94, 95], and environmental goals are embedded in the job descriptions of all managers. As recommended by the IMMS code [35], a senior executive environmental manager should be appointed to monitor the company's marine mining activities, products or services, as well as monitoring internal environmental performance targets and communicating these to employees and sub-contractors. Both internal initiatives and external advice can be used for development, implementation and refinement of sustainability strategies actions and indicators. An environmental management structure that formalises reporting is used in industries similar to DSM to improve sustainability across operations [95]. This is particularly critical as companies become larger and environmental initiatives need to be maintained across multiple projects or divisions.

Corporate transparency is important in improving sustainability, both within and outside the company [96] particularly for DSM [8]. An increase in anticipated or real scrutiny provides the business case for sustainability and enhances innovation. This is vital for public companies that are obliged to report to investors and disclose material aspects (i.e. information important in making an investment decision). Integrated reporting is becoming more common, in which sustainability metrics are included in annual financial reports. The International Integrated Reporting Framework [97] sets out guidelines for this. Reports and performance metrics should encourage sustainability and efforts should be made to quantify and monitor environmental impacts [97]. Reporting initiatives such as the Global Reporting Initiative [98], the Sustainability Accounting Standards Board [99] and the Shared Value Initiative [100] should be encouraged. A long-term focus is also important for sustainability and reporting and metrics that focus on the short term should be avoided, for example quarterly profit reports [97]. It is recommended that during periodic review key areas for improvement and specific actions should be identified and defined to increase sustainability. This may be done through function or issue-related policies, which are disseminated internally (through training, corporate communication or inclusion in staff evaluations) and externally (through sustainability reporting or marketing). Sustainability policies should be regularly reviewed and updated [97]

Larger companies may adopt an operational management system (OMS), which is a framework aimed at helping it to manage risks in its operating activities. The OMS brings together a company’s needs and internal standards on a range of matters such as health and safety, security, environment, social responsibility and operational reliability. OMS are commonplace in the oil and gas industry, where there are established guidelines for the creation and improvement of OMS [101].

Environmental Management System (EMS) are thought to have an important role in improving overall corporate environmental performance [102], particularly if clearly linked to environmental management planning [86]. EMS is a formal and standardised (for example ISA 14001 [103] and the European Eco-Management and Audit Scheme [104]) approach to integrate procedures and processes for the training of personnel, monitoring, summarizing, and reporting of specialized environmental performance information to internal and external stakeholders of the company [105]. In other industries EMS is often a component of an overarching Health, Safety and Environmental (HSE) management system that governs all of its activities [106, 107]. Aspects of an EMS are encouraged by the IMMS Code [35] and implemented by companies involved in DSM [108, 109], but no detailed EMSs have yet been presented for DSM. Evidence suggests that having a formalized and certified EMS in place increases the impact of environmental activities on corporate performance, more so than informal and uncertified systems [105].

7 Recommendations

Several important areas for development of protocols and standards have been identified in this review. These represent current gaps that key stakeholders for deep-sea mining could consider targeting as a priority. These have been generally grouped into approaches for environmental management, environmental assessment and mitigation.

Environmental management standards and guidelines for deep-sea mining are in their infancy. Some progress has been made for EIA and the contents of EIS, but further detail is required, particularly as deep-sea mining assessments have already begun. REA is likely an important process for broad-scale management and has already started for the CCZ. Unifying the approach for REA across regions and optimising the development of REMPs will improve management and provide further guidance for EIA. Operational decision making, particularly by the ISA, is currently untested as no developments have started but will become necessary once exploitation is closer. It is not clear what the process for this will be but clear approaches, timeliness and consistency may be important. Efficient management also requires access to quality information and data and is improved by transparency. Further to this, companies may want to develop improved approaches for their internal management of DSM projects, such as EMS.

Effective environmental management needs good information, particularly to predict and assess mining-related impacts. In the deep-sea much of this information is currently unknown. However, the scientific tools and expertise are available, in the majority, to collect appropriate information. Optimising data collection during baseline assessment and monitoring is important to ensure cost-effective yet robust assessment of impacts. This optimisation requires improvements in survey approaches and sampling designs, using the latest data collection and analysis tools. Quantitative prediction approaches, including modelling (for example plume modelling), are likely to be important. This prediction and effective monitoring will rely on the establishment of robust specific environmental indicators, determining what represents good environmental status and establishing appropriate thresholds for impact. Clear guidance for EMP would help ensure impacts can be detected if they occur and facilitate broad-scale data analysis by making datasets more comparable between projects. Approaches for estimating cumulative impacts also need to be developed.

Effective management relies on appropriate mitigation approaches. The general approaches for mitigation, as outlined in the mitigation hierarchy, are well known. Developing specific approaches for reducing the potential negative impacts of deep-sea mining on the environment is a priority as potential mitigation actions are untested and may not correspond with those appropriate for other environments [82].

8 Conclusions

It is clear that there is a pressing need for environmental management of the DSM industry. There is already much international and national legislation in place that stipulates key environmental management principles and requirements. There is also substantial pressure from both direct and indirect stakeholders for procedures to be put in place that reduce the magnitude and likelihood of environmental risks. In many cases the regulator for DSM activities is clearly identified. The ISA and many national regulators have implemented some environmental procedures, which are being further developed and updated regularly.

There is a well-developed set of tools for reducing industrial environmental impacts that can be applied to DSM. In some cases these have been tested, for example the Solwara 1 development has already undertaken an EIA. In other cases it is not clear how some tools, for example strategic environmental assessment, will be implemented in the case of DSM. Currently the DSM industry is small and facing much international scrutiny. As a result, environmental impacts and the sustainability of the industry will be high on the corporate agenda. As the industry develops and becomes larger, potentially with companies managing multiple projects across the world, environmental management may become more difficult and critical. Incorporating lessons from the offshore oil and gas industry in creating systems for both organizational and environmental management of DSM will help reduce environmental impacts and risks. It is important to act now in developing and reviewing the guidance for this fledgling industry because standards and protocols set at the outset quickly become precedents. Lessons learned from other marine policy and industries can be applied to DSM, while considering the higher level environmental obligations of UNCLOS. This can result in clear, robust and precautionary protocols and standards to guide the DSM industry as it develops.

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Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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