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A procedural framework for robust environmental management of deep-sea mining projects using a conceptual model

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ABSTRACT

Robust environmental management of deep-sea mining projects must be integrated into the planning and execution of mining operations, and developed concurrently. It should follow a framework indicating the environmental management-related activities necessary at each project phase, and their interrelationships. An environmental management framework with this purpose is presented in this paper; it facilitates the development of environmental information and decision-making throughout the phases of a mining project. It is based environmental management frameworks used in allied industries, but adjusted for unique characteristics of deep-sea mining. It defines the gathering and synthesis of information and its use in decision-making, and employs a conceptual model as a growing repository of claim-specific information. The environmental management activities at each phase have been designed to enable the implementation of the precautionary approach in decision making, while facilitating review of adaptive management measures to improve environmental management as the quantity and quality of data increases and technologies are honed. This framework will ensure fairness and uniformity in the application of environmental standards, assist the regulator in its requirements to protect the environment, and benefit contractors and financiers by reducing uncertainty in the process.

1. Introduction

Although there is currently no exploitation of deep-sea mining minerals in international waters, action by this emergent industry appears impending. The International Seabed Authority (ISA), which has regulatory authority for the seabed and its mineral resources in areas beyond national jurisdiction, has awarded 28 exploration contracts for polymetallic nodules, seabed massive sulphides and cobalt-rich ferromanganese crusts by public and private entities (hereafter 'contractors'; 1). In addition, plans for mining in areas under national jurisdiction are also being implemented, with mining licenses awarded for seabed massive sulphides in Papua New Guinea and metal-rich sediments of the Red Sea. Of these, mining at the Solwara-1 site off Papua New Guinea [2] may be the first test case, both in terms of economic and environmental outcomes. Terrestrial mining has not had a good environmental track record, and the social acceptance of other offshore industry activities has decreased following recent disasters (e.g. Deepwater Horizon; 3). Expectations for environmental protection associated with a ‘social license’ for exploitation influence the regulatory and political processes governing operations [4], and are an important factor for the offshore oil and gas industry. Thus, the success of the deep-sea mining (DSM) industry depends, in part, on securing and maintaining a social license to operate through effective environmental management [5].

The ISA is legally required to adopt the necessary measures to ensure effective protection of the marine environment from harmful effects that may arise from DSM activities [6, Article 145; 7]. Furthermore, the ISA is tasked with the regulation, coordination, and the

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management of multiple mining activities in space and time, accounting for the impacts of one activity on another [8], and any cumulative impacts, over the region and long timescales. A holistic approach that considers the whole ecosystem, including each project and the strategic environmental management of the region, is necessary to achieve these aims [9]. At a regional scale, an Environmental Management Plan for polymetallic nodule mining in the Clarion-Clipperton Zone was developed [10,11], which established mining-free areas outside the existing exploration claims. The Legal and Technical Commission (LTC) of the ISA, which is tasked with drafting the environmental rules, regulations and procedures for adoption by the ISA Council, recommended the plan following advice from experts [12], and it was adopted by the ISA Council in 2012 [11]. Whether the plan is binding on contractors, in particular those with exploration contracts predating the decision, is somewhat unclear [13]. Furthermore, while spatial management has been considered in this plan, it does not include temporal considerations.

At the level of individual mining claims, the ISA has gradually developed regulations for contractors as needed with each new phase of mining. As such, the ISA has adopted regulations for prospecting and exploration [14–16], and is currently developing regulations for exploitation activities. This has occurred without the context of transparent environmental strategies, at global, regional or project scales [17]. Existing recommendations to guide contractors in undertaking environmental impact assessments [18] relate primarily to baseline studies and environmental data collection during the exploration phase, but do not yet indicate how this information is to be linked for test mining, exploitation, monitoring or other future activities within a project, or for regional assessments.

Robust ecosystem assessment should include the ‘formal synthesis and quantitative analysis of information on relevant natural and socioeconomic factors, in relation to specified ecosystem management objectives’ [19], and should be updated during the project as more information becomes available, increasing the knowledge base and improving management approaches. Thus, environmental management at the project scale must be integrated into the planning and execution of mining operations, and developed concurrently. To facilitate this process, environmental management activities should follow a framework that considers linkages between project phases, and their interrelationships. Such a framework has been recommended by the International Marine Minerals Society [20] as a voluntary measure, by industry [21], alluded to by the World Bank as important to financing [22], and may also be included in a Mining Code [10]. However, such a framework has not yet been developed.

As several exploration contracts have recently expired and subsequently entered their first extension period, and draft exploitation regulations are being developed, guidance for a holistic environmental management framework is a timely task. Ideally, such a framework would be introduced before exploitation contracts and further exploration contracts are granted, as it would be difficult to implement environmental controls and ensure fairness between contractors after exploitation begins [13]. Similar concerns regarding timing apply to the establishment of protected areas [12,23]. Industry has also acknowledged that the presence of guidance governs their action; concerns over legal risks of operating in the international seabed ‘Area’ related to the lack of defined regulations has resulted in increased focus on prospecting in EEZs [24].

The adoption of a project-scale environmental management framework (EMF) by the ISA and national regulators for DSM would have four main benefits:

1. An EMF would promote the timely development and adoption of appropriate environmental management measures in parallel and integrated with project decision-making.
2. Technical aspects of the process would assist the ISA in operationalising its obligation to protect the marine environment from impacts of mining, both with respect to managing impacts from an individual project, and the cumulative impacts of multiple projects. It would also be of benefit to national regulators.
3. Implementation of a standard process would benefit contractors by reducing uncertainty in planning, application, and undertaking of exploitation activities, and the collection and reporting of environmental information, while providing some certainty of process to financiers, and reducing disparity in action and reporting to the regulator.
4. An EMF would ensure fairness and uniformity in the application of environmental standards, in conformity with the principle of the common heritage of mankind [6, Article 136] and taking into account the responsibility and liability of contractors and sponsoring states.

2. Principles and scope of framework design

This article provides a good practice framework to guide the environmental management of DSM activities, including recommendations on regulatory oversight and review. This EMF is provided on a project-specific basis, but assumes the integration by individual projects of regional and strategic management objectives and plans. The scope is limited to the environmental management of the planning and execution of DSM exploration, extraction and rehabilitation activities, and does not include transportation, port-based, on-shore or land-based activities.

While informed by practices of other extractive industries, principles for the framework are specific to the DSM context, including environmental, socioeconomic and legal/governance factors. These principles are described in detail below, with reference to key literature:

1) The EMF meets the standards of the United Nations Convention on the Law of the Sea [UNCLOS; 6, articles 136, 145, 162, 165 and 192], including the principles of the common heritage of mankind, protection and preservation of the marine environment, and prevention of damage to marine flora and fauna. It builds on environmental management practices in other established related industries with similar types of activities, work in similar environments, or with similar environmental risks, and more well-developed environmental management schemes; these include terrestrial mining [25], onshore and offshore oil and gas exploration and extraction [26–29], and the shallow marine UK aggregate industry [30], but adapted for the unique conditions of DSM.
2) The EMF is designed to be applicable to all types of DSM in international and national jurisdictions (polymetallic nodules, seabed massive sulphides, cobalt-rich crusts, and others).
3) The design of the EMF considers the existing environmental management conditions imposed by the ISA [14–16], to ensure its compatibility. Any recommendations for changes to these to ensure robust environmental management are justified and highlighted.
4) The EMF is designed to ensure that project-based environmental management follows and facilitates the objectives and policies of the strategic and regional environmental management plans, by suggesting points in the process at which to relay information between these management documents.
5) The EMF is designed to facilitate integrated ecosystem assessment by ensuring that all data are formally synthesized and related to the management objectives and regulations to inform decision-making as a project progresses. Relevant data include all current and previous environmental data, up-to-date information on the project scope and plan, and the best available technology (BAT) for both mining and environmental monitoring. The EMF reflects the incremental nature of the development of the project. In facilitating formal quantitative synthesis and review at project intervals, the EMF supports ecosystem-based management, including the assessment and management of cumulative impacts, and interactions among components [as suggested by 19].

6) The EMF structure is designed to allow the precautionary approach to be implemented at all stages of the project, not least to compensate for the paucity of environmental data and development information related to DSM. See below for more detail.
7) The mitigation of impacts should be planned, executed and evaluated according to a prioritised hierarchy. The EMF incorporates environmental management early in project planning, and should include sufficient planning for, and execution and evaluation of the implementation of this mitigation hierarchy. More detail is provided below.
8) The EMF is designed to provide for adaptation of a project, by including adaptive management (active and passive) at appropriate points in the project process to address changes to baseline knowledge, methods, regulations, techniques, practices and technology for both mining and environmental monitoring and assessment, and improvements in the understanding of ecological processes and alterations to stakeholder perspectives that are likely to occur over time. See below for further detail.
9) Explicit roles and responsibilities for the regulator, contractor and stakeholders are set out in the EMF, including required deliverables.

The EMF focuses on environmental management, but management of socio-economic/cultural impacts, and health and safety are commonly combined into the same management structure as the environmental management, and incorporated into the milestones, licenses, permitting, and reporting and data submission requirements [12].

2.1. The precautionary approach

The precautionary approach requires addressing and preventing environmental risks at an early stage, even if uncertainties remain [31]. It requires the identification and communication of uncertainties, to ensure these can be addressed through management actions. The precautionary approach has been identified as a tenet of the environmental management of DSM, because it helps to compensate for the paucity of standardised environmental data that is needed for robust decision-making within ‘reasonable time frames’ [10,32]. As such, the application of the precautionary approach has been endorsed by scientists [7,9] to protect both the environment and the common heritage of mankind. Applying the precautionary approach at the project level could involve incentives for reducing uncertainty, minimizing ecological impacts, and creating management mechanisms to halt production in cases of risk of serious harm [8,33]. For example, the development of the no-mining areas in the Clarion Clipperton Zone [34] contribute to a precautionary approach for the spatial environmental management of the region.

At a project scale, the EMF for environmental management is designed to ensure that there is sufficient review of the project at appropriate intervals to facilitate the identification of uncertainties and decision-making on whether/how to proceed following the precautionary approach. Robust collection of baseline and monitoring data; full, transparent, and peer-reviewed environmental impact assessments (EIAs); and staged reviews and assessments of detected impacts during test mining and commercial operations, all provide opportunities to adapt practices and management to ensure that precaution is prioritised. Decision-making involving risk-benefit or cost-effectiveness tests for future actions, compared with alternatives, is recommended as a means to avoid potential harm [24,35], rather than simply assessing whether a “reasonable likelihood” of serious or irreversible harm exists [20].

2.2. Mitigation of environmental impacts

The mitigation of environmental impacts is a key goal of environmental management. Mitigation opportunities should be identified during the planning phase, as part of EIA, and implemented throughout the project through adaptive management. A hierarchy of mitigation measures (Fig. 1) supports the precautionary approach, visualising how measures can be implemented in terms of their relative importance. This hierarchy prioritises the prevention or avoidance of impacts, followed by reduction of residual impacts, restoration and finally offsetting or compensation for the impacts. Following this hierarchy is widely regarded as good practice and is required by law in some jurisdictions [36], but practical application of the rehabilitation and offset elements of the hierarchy to deep-sea ecosystems following commercial mining activities have recently been called into question.

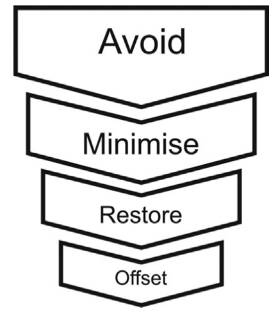

Fig. 1. Actions prioritised in the mitigation hierarchy.

The ultimate goal of mitigation measures is to ensure no net loss of key environmental parameters [see Performance Standard 6 in 37]. In DSM there is likely to be emphasis on the avoidance and minimisation phases of the hierarchy, although restoration has been considered [38]. This is reflected in the environmental impact assessment report for Solwara-1, which proposes spatial management measures to reduce the impact of the development, such as set-aside areas, and potential translocation of animals from the mined area [2].

The importance of applying the precautionary approach to preventing and minimizing the impacts of DSM is emphasised in a recent report by the World Bank [22], highlighting its application to the financial evaluation of DSM projects. To the extent that elements of the mitigation hierarchy are applicable to the deep sea, they should be included into the environmental management process of DSM at the project level, together with additional conservation actions. To facilitate decision making based on the mitigation hierarchy, the following key considerations are built into the EMF: 1) to ensure that environmental management is considered in the early planning stages of the project; and 2) that sufficient reviews of the planning, exploration, exploitation and monitoring activities are performed to ensure that avoidance and minimisation of impacts are applied in decision-making in each phase, and to evaluate the effectiveness of the chosen mitigation and conservation actions taken.

2.3. Adaptation and adaptive management

Successful environmental management of a DSM project will involve adaptation during the project to allow for industrial, scientific and policy developments to be incorporated into management strategy as they are acquired. This is particularly important in DSM, where a substantial increase in available environmental data is anticipated (e.g. baseline study results, environmental conditions, faunal response to mining activities, etc.; 39), regulations are still incomplete [17], and mining technologies are under development [40,41]. ‘Adaptive management’ involves the periodic re-evaluation and alteration of a project to accommodate current knowledge and techniques [42], and is thus an iterative process of deliberation [43]. It is employed to reduce uncertainty and improve the long-term management of a project. However, adaptive management can be unsuitable for activities that quickly cause very serious or irreversible harm, where impacts must be measured on long-term scales [44], or where endangered species are critical to a complex and poorly understood community [45], concerns for DSM. Peel [46, p. 154] cautions that “used indiscriminately or inappropriately, adaptive management mechanisms can operate to water down regulatory requirements, reduce public scrutiny of planning and development approval processes and accord preferential treatment to favoured industries, thus substantially detracting from any precautionary role they might serve in addressing uncertainty."

Effective adaptive management is integrated into the project at all phases to allow modest and reversible adjustments of a process, including environmental management. As a procedural tool, it must be integrated into the decision-making framework [13]. With each cycle of decision-making, monitoring, and assessment of the results, management decisions can be improved and uncertainty may be reduced [43,47]. The feedback from the evaluation to decision-making is key, as confidence in the alternatives evolves and appropriate actions change over time. Adaptive management considers the aims, alternatives to be evaluated, models to be used in evaluation (e.g. forecasting, cost/benefit), and stakeholder consultation, in addition to the planned evaluation, decision-making and compliance mechanisms [47,48].

In DSM, the adaptive management approach could be used to address a number of uncertainties. Anticipated developments should be evaluated, with the possibility of altering activities during a project to accommodate them. Anticipated developments include: 1) improvements to the understanding of the environment and impacts to it from mining, as well as changes to the mining plan at the project claim (arguably simply 'good management' practices); 2) improvements to the understanding of the environment, mining technologies and impacts at a greater spatial scale than the project (such as affecting other claims or the region); 3) altered environmental goals through the development and evolution of strategic and regional environmental management plans; 4) advances in the BAT; 5) updates to DSM environmental policy and regulations; and, 6) active experimentation, for example to test new technologies or to research mitigation options through a well-designed trial. Many of these aspects should be proposed by the contractor and agreed with the regulator during the EIA preparation, with the monitoring plans and adaptive actions agreed by both parties prior to proceeding with exploitation. Aspects 2-5 above may be imposed by the regulator. Each of these adaptive management 'loops' requires tangible goal setting, and both monitoring and review at an appropriate time scale, so the EMF is designed to include sufficient points for such planning and review. Additionally, the EMF is designed to include opportunities for adaptive management to be incorporated into decision-making point in the project.

3. The Environmental Management Framework

3.1. Introduction

The EMF follows the main phases of a DSM project, from project conception, through exploration and exploitation to closure, with environmental management activities at each phase (Fig. 2). If a staged mining approach is adopted, where different mining phases occur at one claim, then several aspects of the EMF may run in parallel (e.g. exploitation in one area, and closure at another area). Fig. 3 provides detail on each of these phases. Descriptions of the components are provided below, but detailed guidance for these components will be presented in companion papers, together with standards and methods for analysis. Distinct roles and responsibilities for the main parties involved are presented. Consideration for the establishment and maintenance of a repository for the environmental information generated during a project is also given below, as a conceptual model.

3.2. Roles and responsibilities

The contractor proposes, plans and undertakes exploratory and/or extractive activities. The contractor is responsible for ensuring that it and its subcontractors comply with all regulations and the conditions of the contracts/licenses and permits [14, Regulation 14; 15 and 16, Regulation 15]. It is responsible for the development of the project-specific mining and environmental management plans and their documentation, collection of environmental data within the claim area, submission of reports and data, and engagement with the regulator and stakeholders. For DSM in the Area, the contractor is sponsored by a State [6, Article 153(2)]. The State also carries responsibilities and liabilities [6, Article 139; 49], a discussion of which is beyond the scope of this paper; the collective environmental responsibilities of the State and contractor are listed here for the 'contractor'.

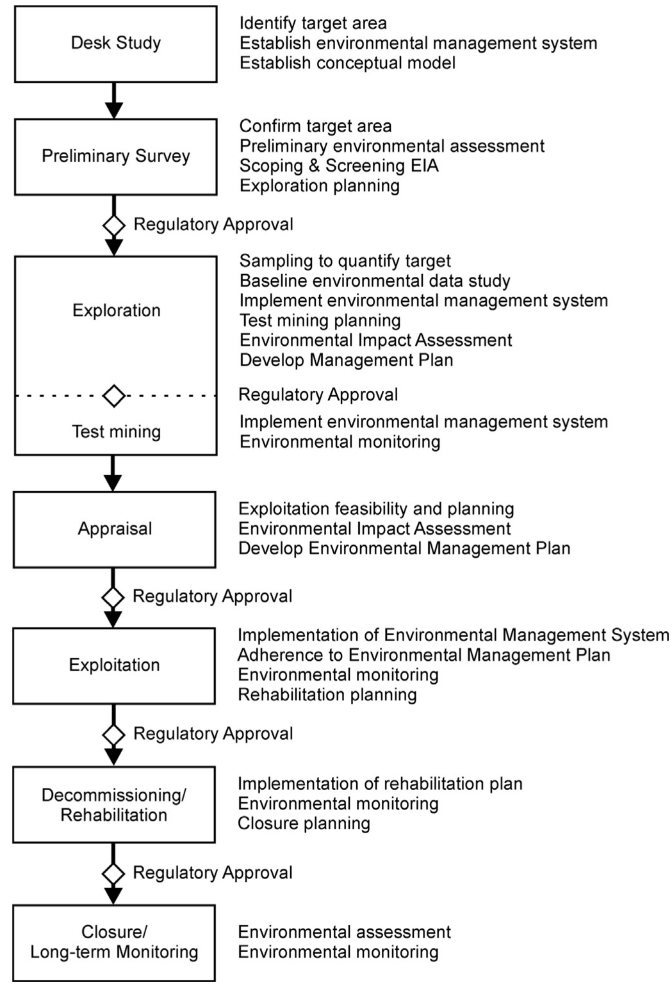

Fig. 2. A flowchart depicting the basic phases of a deep-sea mining project, including ideal environmental management steps.

From a project perspective, the roles of the regulator are of supervision and enforcement. It should provide independent oversight of DSM projects, to evaluate and manage their impacts to the environment, and to enforce legal obligations. Additionally, the regulator should coordinate and manage activities by individual and multiple mining contractors, and manage mining within the context of conflicting ocean uses [19]. This includes environmental management at multiple spatial scales, including development and maintenance of strategic and regional environmental management plans. The regulator should be responsible for acquiring the necessary data for project-based and regional management; assessing applications for mining contracts, review such applications and provide adjustments or regulatory approval (where appropriate); setting performance targets; and enforcing targets, policies, regulations and adherence to license conditions by auditing contractors' activities, reviewing reports and data provided by contractors. The regulator will receive all reports from the contractors and use the information therein to inform and update the regional assessment iteratively.

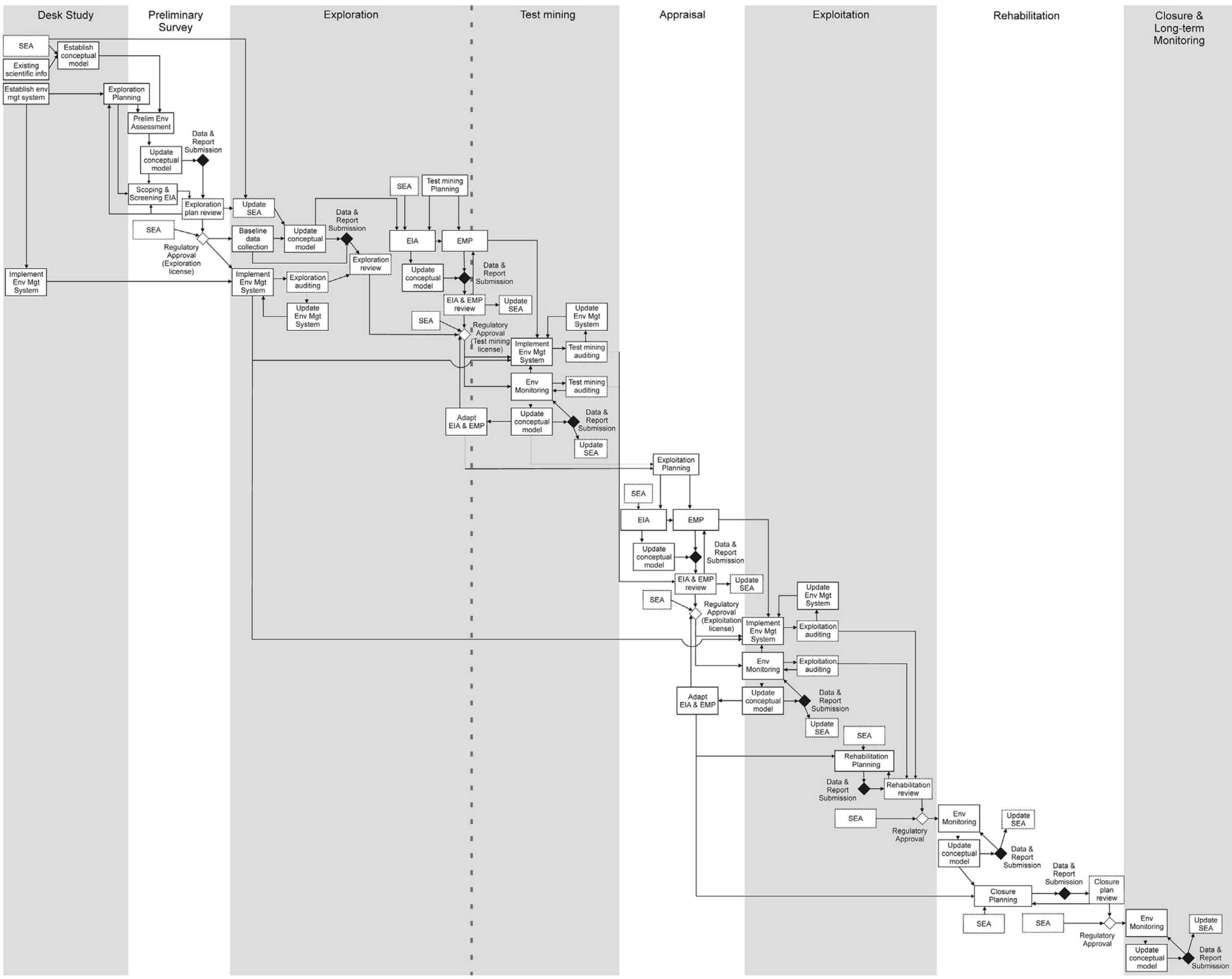

Fig. 3. A detailed flowchart depicting the sequence and data interrelationships between phases of environmental management associated with deep-sea mining activities. Tasks outlined in black are the contractors' responsibility, and those outlined with a dashed line involve regulator (and stakeholder) input. 'Test mining' is shown as a separate phase within 'Exploration', since current exploration contracts include test mining. 'SEA' denotes the regional (and/or strategic) environmental assessment and plan(s).

Stakeholders should be invited to provide input to the environmental management process, particularly at decision-making junctures, such as in the EIA scoping stage, the review of EIAs, and outcomes of environmental monitoring programs. Interests related to DSM are diverse, and come from a wide range of stakeholders, including the regulator, State Parties to UNCLOS, other claim holders and contractors, shareholders, employees, legal experts, mining experts, scientific experts, local communities, non-governmental organisations, and the public [12,20].

3.3. The conceptual model

Conceptual models are used in the environmental management of other industrial activities, particularly in the management of industrial contaminated sites in the United States [50] and Europe [51], and the idea has been adapted here for DSM. As the name suggests, it is a concept of the current understanding of the environmental conditions related to a project location, and as such includes both a repository of information and an interpretation/synthesis of this data. The conceptual model for a project contains all information necessary for decision-making related to the mining project and its environmental management, including environmental data and syntheses, the mine plan, past and present mining activities and equipment, and previous decisions (Table 1).

The main benefit of the conceptual model is to have all available data and interpretations at hand as an evidence base for decision-making. It also facilitates ensuring that outcomes of previous decisions are adequately addressed, thus avoiding the repetition or propagation of errors. In a phased or staged mining scenario, the conceptual model becomes central to managing activities in different phases at different locations within a claim (most likely for seabed massive sulphide mining). A conceptual model for a project is developed and maintained by the contractor, and the up-to-date conceptual model for a project is provided to the regulator to inform its management of the wider region (which may, in turn, maintain its own conceptual model of the region).

The conceptual model is thus a growing repository of claim-specific information supported by transparent data. It must be updated regularly, at least before each decision-making point (Fig. 3), and it iteratively increases in content. During an update of the conceptual model, new data are added and evaluated in the context of all existing data and decisions, and previous syntheses are re-evaluated. The conceptual model must be presented and stored in an accessible format, including 2-dimensional graphics and/or 3-dimensional renderings, in addition to text describing detailed conditions and interpretations. A

Table 1
The conceptual model should contain up-to-date information on the environmental conditions, all historical data and syntheses, and information on proposed activities. The types of contents are listed below, and have been expanded from those suggested by others [26,58,59]. For each item, the size/magnitude (spatial and temporal), rates and magnitudes of variation, and periodicity should be considered. Sources of information should include environmental data collected at the claim, information from the regulator, previous studies at the claim or analogous locations, historical environmental assessments at other claims, scientific literature and other sources of applicable data (e.g. Census of Marine Life, Census of the Diversity of Abyssal Marine Life) [10].

Type of information	Parameters
Location and size of project area	Location, size
Bathymetry	Depth, notable features
Climatic conditions and air quality	Physical, chemical, biological
Pelagic conditions	Physical, chemical, biological
Midwater conditions	Physical, chemical, biological
Benthic conditions	Physical, chemical, biological
Surface and subsurface geology	Physical, chemical, biological
Interactions between geological, benthic, midwater, and pelagic conditions	Physical, chemical, biological
Hazards (potential and historical)	Natural and anthropogenic, scale of and impact to physical, chemical and biological conditions, timeline of/for impact
Project areas within the claim	Locations, size, purpose
Protected areas within and without claim areas	Locations, size, purpose
Details of planned, current and historical mining exploration or extraction activities	Scope, type, details of design and operation, timeline, environmental risks or results
Transport corridors	Location, size, usage type, frequency of use
Areas of potential conflict with other claims, contractors and/or industries	Location, size, frequency, nature of conflict, other parties involved
Risks and risk management activities (including emergencies, release and exposure characteristics; may include computer models/results)	Details and rationale of risk assessments
Planned mitigation/rehabilitation work	Location, type, size, anticipated result, details of monitoring to measure results, possible negative effects, rationale
Identified current, potential and historical risks and impacts	Type, spatial size, estimated or actual duration, risk receptors, anticipated or measured combined and cumulative effects
Plan for potential emergencies (e.g. process-related, natural disasters, war/sabotage), nature of emergency and consequences, combined incidents	Type of emergency, size and timeline of emergency and recovery, consequences, anticipated impacts, type and scope of mitigative actions
Results of current and previous monitoring programs	Aims, scope, results, implications; for all information types
Results of current and previous regulatory reviews and audits, and details of any penalties	Aims, scope, findings
Adherence to current regulations	Information of actions to adhere to current regulations, and records of any contraventions (including penalties and consequences)
Implementation of BAT	Details of technology (e.g. purpose, application, design, operation), details of implementation (e.g. purpose, rationale, result)
Stakeholder inputs, current and past	Formal and informal; identity, nature and detail of input, response to stakeholder input, how input addressed, rationale
The current and previous syntheses of all data at a given point (i.e. what is the story?)	Synthesis of all information above, including rationale for interpretation
Summaries of previous decisions made regarding the project	
Uncertainties, and items requiring further investigation	Scale and relationship to above types of information (qualitative and quantitative), information and timeline required for certainty

component of computer modelling is likely to be included. Consistency in nomenclature, including symbology, is essential, with nomenclature being prescribed by the regulator.

3.4. EMF Components

Environmental management must be integrated into all phases of a project (Fig. 3), which are detailed below.

3.4.1. Phases 1 & 2: Desk study and preliminary assessment

These phases involve: consulting the strategic environmental assessment and plan (if available; to be developed by the regulator) to incorporate regional strategic actions and environmental understanding; and preparing a review and synthesis of existing information on the environmental conditions of the project area to anticipate risks of mining and to plan the baseline sampling program during exploration. During these phases, the initial plan for mining is also developed, including a preliminary resource assessment and initial development of the design specifications for the mining vehicle and other platforms. The conceptual model is established at this stage using this information, which will provide an evidence base from which to evaluate impacts at a later stage. The contractor's environmental management policy should be established a manner that is consistent with environmental goals and objectives of the regulator, including responsibilities, procedures, resources, internal policies, objectives, targets with periodic assessment, and consistently applied throughout the project. Robust environmental management policies comply with ISO 14001 [52] as well as all requirements by the regulator.

Prior to the commencement of exploration activities, the conceptual model should be submitted to the regulator for review. A detailed plan for exploration, including sampling and analytical protocols required for the baseline study, should also be presented. Stakeholders should be engaged, and plans revised if necessary, to secure regulatory approval to proceed [53].

3.4.2. Phase 3: Exploration and baseline surveys (and test mining)

The aim of exploration is to reduce uncertainty about the resource and the environmental conditions, in advance of the EIAs for test mining and exploitation. The agreed environmental baseline survey [current requirements in 14–16], and monitoring during exploration activities should undertaken during this phase, with the results being used to update the conceptual model to inform the EIA. The contractor's environmental management plan should be implemented in exploration activities, and the regulator audits these activities to ensure compliance with the regulations [e.g. to prevent, reduce and control pollution, and to report on any effects; 14–16].

Test mining has been included as a separate phase, as it may include activities that may harm the environment, and as such should require its own EIA and environmental management (and monitoring) plan (EMP; also sometimes denoted as 'EMMP' by others; see below for details). However, mechanisms for preparing, evaluating and approving a test mining-specific EIA, and its content, have not been developed yet. Results of previous scientific studies of test mining-type activities [54–57] could be used to inform the EIA for a test mining phase. These results suggest that substantial impacts to biotic communities may be sustained by test mining, thus test mining activities need planning and an EIA. Monitoring during test mining will collect vital data on the scale and intensity of impacts that can inform the EIA for the commercial mining phase.

3.4.3. Phase 4: Appraisal

The preparation of the EIA is likely the most well known aspect of project-scale environmental management, and currently required by the ISA. The ISA has developed a draft template for the EIA report [58], so details are not presented here. In brief, the EIA report should include the exploitation plan; results of the baseline assessment completed during exploration work [14–16]; an assessment of risks to the environment, their probability of occurrence and consequences [20]; and the designation of protected areas within a claim [e.g. impact and preservation reference zones; 14, Regulation 31(6); 15 and 16, Regulation 33(6)].

The project-specific EMP details how exploitation operations will proceed [existing guidance in 58], and the risks identified in the EIA should be mitigated according to the hierarchy. Again, the conceptual model should underpin the EMP. Here the precautionary approach and adaptive management may be revisited, and their application may be particularly important [20]. Plans to conduct environmentally responsible operations should be detailed, including the environmental management system with a quality review program [20], use of BAT for both mining and environmental assessment and monitoring activities, environmental assessment and monitoring at suitable spatial and temporal scales, regulatory reporting, emergency response plans, and an initial plan for rehabilitation and closure following exploitation.

The stakeholder and regulatory reviews of the EIA (for both test and commercial mining) and EMP may involve iterative adaptation of both until all parties are satisfied. It should include the consideration of previous environmental performance during exploration and test mining. Regulatory approval for exploitation will include explicit minimum requirements for the EMP, monitoring, and reporting. The regulator should audit or make provision for the independent auditing of exploitation and monitoring activities, as well as publish reports on the results of these activities, to demonstrate compliance and to show that where any non-compliances have occurred, corrective actions have been put in place.

3.4.4. Phase 5: Exploitation

In this phase, the contractor must implement its up-to-date EMP during exploitation activities, complete required monitoring, and provide reports on its environmental management and adherence to performance targets to the regulator. The conceptual model should be updated with monitoring results, and be used in revising rehabilitation and closure plans. The regulator audits the exploitation and monitoring activities to ensure compliance with the regulations and performance targets, and uses information from the conceptual model to update its regional assessment.

Following exploitation activities, the environmental conditions should be assessed as in the baseline study to determine the extent of rehabilitation required. Rehabilitation planning should be revised and reapproved based on updated environmental information, and any newly-imposed regulatory requirements. Compensation for damage may also be required by the regulator [20].

3.4.5. Phases 6 and 7: Rehabilitation and closure/long-term monitoring

In this phase, the rehabilitation plan is implemented, and the closure plan is determined. Long-term monitoring may be required to assess rehabilitation success; it will inform risk assessments for future projects. All information gained in the rehabilitation and closure phases should be reported to the regulator and reviewed by an environmental science advisory group, which should use the information to update the regional assessment.

4. Discussion

The EMF for DSM described here provides a platform for robust environmental management of a DSM project, regardless of the type of mining involved. Numerous exploration contracts have already been issued by the ISA, with work beginning at Phase 3 (as described above); the opportunity to integrate environmental management into the early phases of the project (i.e. the desk study, preliminary study and exploration phases), and decision-making therein, may have already been lost [59]. In these cases, the EMF would be implemented from the appraisal phase, and the initial conceptual model should be based on existing information. Consideration of environmental management early in project planning encourages the development of environmental management systems that can be implemented throughout the project. In addition, early adoption of the EMF allows risks to the environment to be identified earlier, and associated avoidance and minimisation practices to be considered and planned as part of the financial investment.

Application of a robust EMF for the environmental management of a DSM project requires substantial effort by the contractor and the regulator, with frequent communication between the two (often weekly to monthly in other industries, depending on the phase of a project; Durden and Murphy, *pers. comm.*). The magnitude of such efforts may not be fully appreciated by the ISA, the LTC, or current contractors [59]. The ISA requires annual progress reports from contractors [annex IV, section 10 in each of 14–16] and that these reports be judged for comprehensiveness and quality of information [10], but this is only one component of contractor engagement. In allied industries and other jurisdictions, regulators employ dedicated staff to engage with contractors, facilitate the environmental management process, provide the necessary oversight, consult with stakeholders and manage regional interests (e.g. United State Environmental Protection Agency, Alberta Environment and Parks in Canada, United Kingdom Environment Agency). This is often accomplished by establishing an independent environmental management body composed of qualified environmental scientists, with the power to approve and restrict contractors' activities through the determination and enforcement of the license/contract terms. For DSM activities in national jurisdiction, it is likely that a similar approach would be adopted to that for management of oil and gas activities. Another model is based on the regulator having sectoral expertise in-house, which is supplemented by an independent adviser to provide peer review whose role is paid by the contractor. Inspection and enforcement, logistics, emergency response, and training institutions and standards associations are other important resources that the regulator must provide to ensure environmental protection [26]. DSM presents additional regulatory challenges, particularly where management of large and remote areas such as the CCZ is required [12]. For example, auditing and enforcement of requirements at a claim site are difficult to complete when mining activities occur thousands of kilometres from shore and several kilometres below the surface of the ocean. Remote monitoring tools and technologies will be essential, and their use will need to be integrated into any enforcement requirements.

While this EMF provides information on the process, including data collection, analysis, decision-making and review, it does not address enforcement. Appropriate legal and financial instruments are needed to provide incentive for all parties to participate and comply fully. As currently envisaged, exploitation contracts will be difficult to modify and are incompatible with adaptive management, unless there are effective mechanisms for updated environmental standards and requirements to be incorporated into an existing project [13,60]. Some opportunities for adaptations of existing legal tools employed by the ISA in the application of aspects of our EMF have already been explored [13]. It is unclear how exploitation contracts could provide the same level of oversight and flexibility as for other industries that operate under license from a regulator, rather than through contracts. The licenses enable periodic review, adjustments to the project, interim enforcement actions, periodic licensing fees, and other desirable regulatory functions. The draft exploitation regulations from the ISA envisage a five year review cycle, much less than the annual review cycle enforced in industries such as oil and gas.

Key to both the conceptual model approach and to successful adaptive management is the availability of information. The information contained in the conceptual model must be submitted to the regulator and be accessible to all parties. If information is withheld, poor management decisions are the likely result, because decision-making is improved by up-to-date and comprehensive information on the environment and impact of the project upon it. Thus, the data management strategy of the ISA must be improved to cope with the volumes of data and requests for access [as highlighted by 10,59].

An important consideration in the environmental management of DSM projects is time, an aspect deliberately omitted from the EMF presented here. The appraisal phase is a bottleneck in project progression; this phase often requires years of work prior to the commencement of test mining or commercial extractive activities (e.g. 7 years for the preparation, consultation and evaluation of the Trans Tasman iron ore EIA; 61). Robust environmental management is dependent on the ability to recognise and act on threats to the ecosystem. Temporal scales and the timing of baseline and monitoring data collection must be scientifically relevant. Given the long timescales of some processes in the deep sea (years to decades, and longer; 7), timelines for detecting and monitoring the impacts on such processes may conflict with timelines for project progression. Such mismatches in timescales must be considered by the contractor, regulator and stakeholders when developing regulations, assessing impacts, planning monitoring and mitigation actions, and determining whether active adaptive management is appropriate and, if so, how best to apply it.

5. Conclusion

The EMF and conceptual model are designed to facilitate the environmental management of a DSM project, integrating and expanding on existing guidance provided by the ISA. Experts found them to be useful tools to guide environmental management, and that they provided facility for the precautionary approach, mitigation hierarchy, and adaptive management to be integrated into the process [59].

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