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Ecosystem-based Management through the lenses of International Seabed Authority stakeholders: current status, implications, and opportunities for the deep-sea mining regime in the Area

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The ocean is threatened by human activities, which undermine the health of its ecosystems. To overcome this scenario, there is a converging understanding that a more encompassing approach, such as Ecosystem-based Management (EBM), is essential to manage human activities. EBM implementation in scenarios of limited knowledge and potentially irreversible impacts, such as deep-sea mining (DSM), is thus highly appropriate, although the translation of this approach into practice is not intuitive and rather challenging. The International Seabed Authority (ISA), the organization with the mandate to award exploration and exploitation contracts for minerals on the international seabed, has recognized the need to incorporate EBM in its instruments but has not specified how to implement it. Through an online survey and in-depth interviews, ISA stakeholders have been inquired about their perception of the understanding, current status, implications, and opportunities of EBM for the deep-sea mining regime. The findings reveal that stakeholders perceive EBM as more related to ecological and impact aspects and less with participation, socio-ecological systems interlinks, and other forms of knowledge that are not scientific. Few respondents recognize EBM within the ISA, reporting its reflection in management instruments such as Regional Environmental Management Plans and Environmental Impact Assessments. No common definition exists, regarded as an obstacle to decision-making and EBM operationalization. According to them, opportunities to improve EBM implementation include collaboration with organizations already familiar with EBM, capacity development activities, workshops, and dedicated side events focusing on the issue. Finally, most of them recognize that a lack of consensus regarding EBM can impact decision-

making and EBM operationalization, thus compromising ISA's mandate. In this context, the clarification on what EBM entails for the seabed mining regime should be a matter of major interest to the ISA and all its stakeholders, as the mineral resources found in the seabed beyond the limits of national jurisdictions (the Area) are the common heritage of humankind, and therefore, its maintenance and benefits must be ensured to future generations.

KEYWORDS

ecosystem-based management, seabed mining, the Area, common heritage of humankind, stakeholder perception

1 Introduction

The ocean presently faces many threats from human activities and climate change, which undermines the health of its ecosystems. As recently cautioned by the UN Secretary-General, the levels of threats faced by the ocean are unprecedented (Lisbon, 2022). Indeed, the closely interconnected nature of the ocean and its problems and the need to consider them as a whole have been recognized decades ago in the Preamble of the UN Convention on the Law of the Sea 1982 (UNCLOS). Being the “constitution for the ocean,” UNCLOS plays an important role in ocean governance through the protection of the marine environment and its intricate ecosystems.

Over the years, national and international agendas for the ocean have frequently stressed the importance of adopting an ecosystem approach in line with more holistic and integrative management practices (Gelcich et al., 2018; Warner, 2020), in opposition to managing single species or a specific sector. Ecosystem-based Management (EBM) is advocated in recent global commitments, such as the Agenda 2030 for Sustainable Development (UNGA, United Nations General Assembly, 2015; Diz, 2019). The Agenda 2030, in particular the Sustainable Development Goal 14 - focused on the ocean - should be reconciled among all marine sectors, including emerging industries such as deep-sea mining outside jurisdictional waters, also known as areas beyond national jurisdiction (ABNJ) (ISA, International Seabed Authority, 2018; Singh, 2021a).

EBM focuses on interactions among ecological and social systems, including stakeholder groups and communities interested in maintaining the health of coastal and marine areas (Leslie and McLeod, 2007). EBM practices require redefining the “roles of humans in nature”, in which human activities and uses should be harmonized with natural ecosystems' spatial and temporal scales (Grumbine, 1994; De Lucia, 2015; Stephenson et al., 2021). Nevertheless, obstacles remain in implementing EBM, primarily due to the different scopes (i.e., time, space, sector) in which its application is required, the diversity of nomenclatures and definitions attributed to it, and due to several challenges encompassing its operationalization.

Several EBM-related nomenclatures exist, including the ecosystem approach, ecosystem approach for management, ecosystem-based management, ecosystem-based management

approach, and ecosystem-based approach, among others¹. Such terminology is usually used interchangeably (Stephenson et al., 2021); however, some authors have argued that there is a consistent conceptual divergence between them and, therefore, these should not be used as synonyms (Kirkfeldt, 2019).

EBM definitions found in the literature hold some commonalities (Delacámara et al., 2020), and a rough general understanding exists among scientists (ICES, International Council for the Exploration of the Sea, 2016; Marshak et al., 2017) (e.g., an integrative, non-siloed, holistic approach). More frequently, it is defined by a set of principles (CBD, Convention on Biological Diversity, 2000; Long et al., 2015; Long et al., 2017; Delacámara et al., 2020), which can vary depending on the context and scale of implementation (Link and Browman, 2014; Delacámara et al., 2020). In contrast, divergences seem to be centered on the consideration of the human dimension as an intrinsic component of ecosystems (ICES, International Council for the Exploration of the Sea, 2016; Delacámara et al., 2020), as under the logic of socio-ecological systems (Piet et al., 2020). In addition to challenges surrounding a standard definition, a comprehensive ecosystem overview is demanded by EBM, which can be added as a challenge to its implementation. Due to that, the approach can be perceived as aspirational, utopic, or even as a

¹ Other existent terminologies are more focused on a sectoral approach to fisheries and include: ecosystem-based fisheries, ecosystem-based fisheries management and ecosystem approach to fisheries.

² For the present study, we followed a broad EBM definition proposed by Long et al. (2015), which includes: “Ecosystem-based management is an interdisciplinary approach that balances ecological, social and governance principals at appropriate temporal and spatial scales in a distinct geographical area to achieve sustainable resource use. Scientific knowledge and effective monitoring are used to acknowledge connections, integrity and biodiversity within an ecosystem along with its dynamic nature and associated uncertainties. EBM recognizes coupled socio-ecological systems with stakeholders involved in an integrated and adaptive management process where decisions reflect societal choice”

“wicked solution for wicked problems” (Berkes, 2012; Defries and Nagendra, 2017; O’Higgins et al., 2020; Piet et al., 2020). Finally, issues related to EBM operationalization seem to be less related to a lack of mandate (Link et al., 2019; Dickey-Collas et al., 2022) than to the way it is interpreted and implemented for a given set of variable conditions across various jurisdictions (Enright and Boteler, 2020; Link et al., 2019).²

Despite the existence of distinct terminologies, EBM holds the adoption of cross-sectoral approaches at its core (Christiansen et al., 2022). More specifically, cross-sectoral approaches acknowledge and integrate distinct needs, expectations, interventions, trade-offs, and impacts arising from different ocean space sectors and users as part of decision-making (Burt et al., 2017). As an intrinsic component of EBM, cross-sectoral considerations aim to harmonize the broad spectrum of human activities and uses with management and conservation objectives in a determined context.

EBM has been advocated in instruments such as UNCLOS and the United Nations Fishing Stocks Agreement (De Lucia, 2018; Diz, 2019; Guilhon et al., 2020). Moreover, EBM is explicitly mentioned in the recently agreed final text of the future legally binding instrument on marine biodiversity beyond national jurisdiction (BBNJ) and in the regulatory framework for the deep-sea mining (DSM) regime in seabed areas beyond national jurisdiction (known as “the Area”) administered by the International Seabed Authority (ISA), both under the framework of UNCLOS. Established under Article 156 of UNCLOS, the ISA is responsible for the development, implementation, and management of a regime for DSM in the Area, including the establishment of an equitable mechanism for benefit sharing, while ensuring the effective protection of the marine environment from the harmful effects of such operations.

The organizational structure of the ISA comprises several key organs: the Legal and Technical Commission (LTC), the Council, the Assembly, and the Secretariat. The LTC, a subsidiary organ of the Council currently comprising 42 individual experts, is established to provide recommendations to the Council (UNCLOS, 1982 - Articles 163 and 165) and attend to its instructions. The Council is the executive organ of the ISA, comprising 36 member States elected for four-year terms among Assembly members (UNCLOS, 1982 - Articles 161.3 and 162.1; Agreement Relating to the Implementation of Part XI of UNCLOS, 1994 - Section 3.15). Consisting of all State parties to UNCLOS, the Assembly is the supreme organ of the ISA (UNCLOS, 1982 - Articles 160.1 and 156.2) that provides the final approval of recommendations provided by the LTC and regulations approved provisionally by the Council (UNCLOS, 1982 - Article 162.2.o.ii). The Secretariat comprises the Secretary-General and staff (UNCLOS, 1982 - Article 166.3) and fulfills administrative roles at the ISA. Among others, the function of the Secretariat includes producing reports that facilitate deliberation and decision-making, producing publications, organizing meetings, seminars, and workshops, and ensuring compliance with plans of work for exploration and exploitation.³ Moreover, other groups play an important role as ISA observers, influencing the decision-making

processes. These include contractors, scientists, NGO members, legal and political experts, civil society members, and members of intergovernmental organizations, among others (Levin et al., 2020).

The regulations that will govern the future commercial extraction of seabed mineral resources in the Area are currently under discussion at the ISA through an instrument called the Draft Regulations for Exploitation (DRE). Preparatory work for the DRE has been conducted by the LTC with the support of the Secretariat since 2014, and an advanced version was presented to the Council in 2019 for negotiations. The Council established several working groups in February 2020 to advance the negotiations of the DRE, namely, on the protection and preservation of the marine environment, inspection, compliance and enforcement, and institutional matters. Due to the Covid-19 pandemic, negotiations at the Council abruptly halted shortly after that. As a result of the invocation of a treaty provision known as the “two-year rule” by the Republic of Nauru in late June 2021, imposing a so-called deadline on the Council to complete the elaboration and adoption of the DRE by July 2023, post-pandemic negotiations at the Council have resumed at an accelerated pace. The deadline expired, and the Authority is now in a new phase fraught with legal uncertainty and political controversy. Following the deadline expiration, an application for exploitation activities can directly be submitted to the Authority for consideration – and can be provisionally approved by the Council – in the absence of the very regulations intended to govern their conduct and ensure compliance (Singh, 2023). Indeed, it has been noted that many key outstanding matters remain unresolved in the negotiation process at the ISA, both within and beyond the DRE, with respect to establishing and implementing a robust and effective exploitation regime for the Area (Singh, 2021b).

While negotiations on the text of the DRE are still ongoing at the Council, exploration activities in the Area have been carried out for over two decades. Up to July 2023, the ISA has granted some 30 exploration approvals to contractors (including private companies sponsored by UNCLOS Member States) to conduct exploratory activities (ISA, International Seabed Authority, 2010; ISA, International Seabed Authority, 2012a; ISA, International Seabed Authority, 2013). Most awarded contracts are for polymetallic nodule fields concentrated in the abyssal plain area of the Clarion-Clipperton Zone (CCZ) on the Northeast Pacific Ocean. Exploration contracts for other mineral resources, such as polymetallic sulfides and cobalt-rich crusts, respectively, have been issued in areas of hydrothermal vents and seamounts ecosystems in the Atlantic and Indian Ocean Basins and the Pacific, respectively (Levin et al., 2020).

An explicit reference to EBM is observed in two different instruments of the ISA regulatory framework. In 2012, the term “ecosystem-based management” first appeared as one of the environmental goals of the Regional Environmental Management Plan (REMP) for the CCZ. According to the document, among other goals, the CCZ-REMP will “Manage the Clarion-Clipperton Zone consistent with the principles of integrated ecosystem-based management” (ISA, 2011 - para. 35.d). The “application of an ecosystem approach” was later described as a sound principle to be applied for “the effective protection of the marine environment from the harmful effects which may arise from Exploitation” in the

³ <https://isa.org/jm/secretariat>

DRE (ISA, 2019). Although there has been an increasingly visible recognition of EBM principles in the developing seabed mining regulatory framework over time (Guilhon et al., 2020; Warner, 2020), there are as yet no steps toward operationalizing EBM as an integrated concept. Such conduct may restrict wording to empty scientific jargon, compromising an efficient translation and communication to decision-makers (Amon et al., 2022) and resulting in non-existing or failed implementation.

The development of a pathway to clarify what EBM entails and how it can be implemented under the ISA regime could benefit from understanding how stakeholders involved in the process perceive EBM and its influence to effectively manage ecosystems in the Area and the mineral resources therein. The present study was motivated by the assumption that different perceptions may result in conflicting decision-making and frustrated compliance, particularly when several economic and political interests are at stake. More specifically, this article addresses key aspects of stakeholders' perceptions regarding the ISA regime on (i) what is the importance of EBM for DSM in the Area and how stakeholders define it (Section 3.1 and Section 4.1); (ii) if and where stakeholders perceive EBM implementation at the ISA regime (Section 3.2 and 4.2); (iii) the impacts that a possible lack of a clear definition may have in decision-making and EBM operationalization (Section 3.3 and 4.3) and (iv) what are the opportunities to improve EBM incorporation in the regime including who should lead such changes (Section 3.4 and 4.4). Finally, concluding remarks are provided, evidencing that ecological and impact aspects are EBM's most commonly relatable attributes, while participants poorly acknowledged socio-economic elements.

2 Methods

2.1 Data gathering

To fulfill its objectives, the study adopted complementary approaches for data collection. An online survey was widely circulated among networks of deep-sea experts to obtain more general impressions. Following this, an interview script was developed and applied to representatives of different stakeholder groups. The latter had the objective of supplementing the information obtained through the online survey and deepening discussions on EBM for the ISA regime. To avoid misinterpretation on which methodological approach resulted in each set of data, we convened to call participants from the online questionnaire "respondents" and in-depth interviews "interviewees." In both cases, participants were ensured anonymity. An overview of the general objectives (addressed by four sections), questions, and methodology applied for obtaining data are represented in Figure 1.

Before the data gathering, a multidisciplinary expert committee comprised of social, political, economic, legal, and natural sciences from the Research Institute for Sustainability – Helmholtz Centre Potsdam reviewed and discussed the outline for the online survey and in-depth interview script, providing feedback and recommendations on the documents' structure and content. In addition, the research proposal was evaluated and approved by an ethical committee (please refer to the Ethics Statement section).

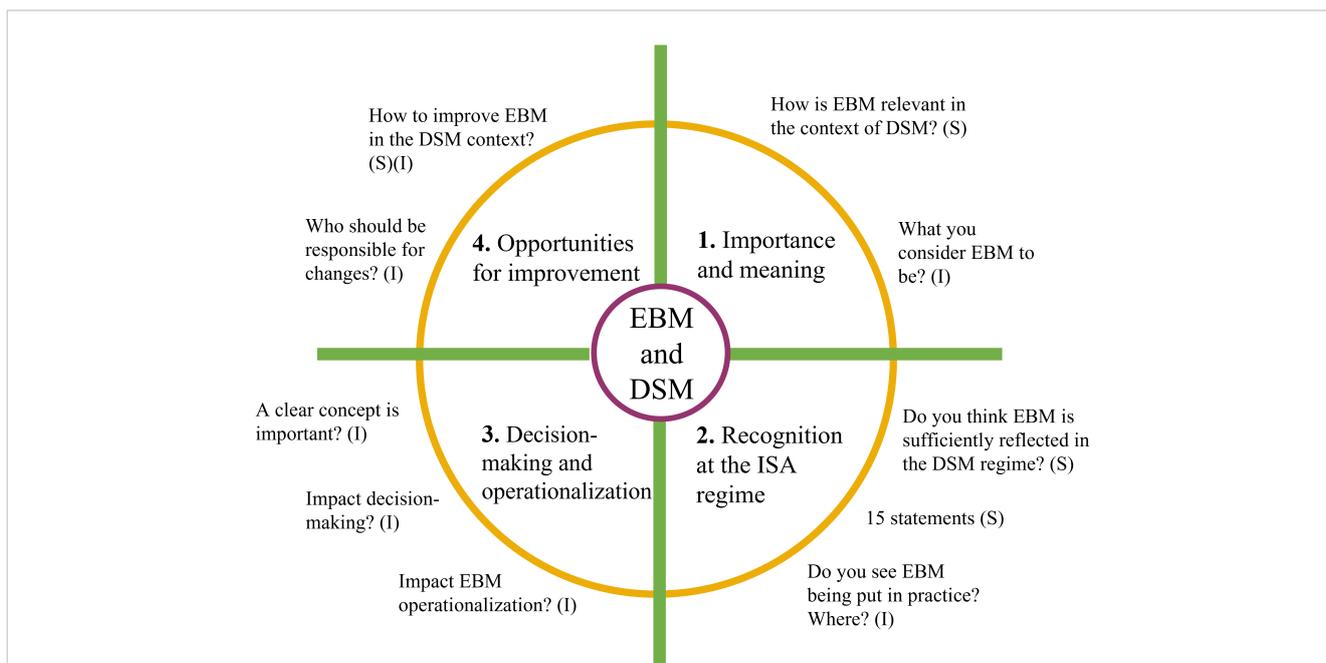


FIGURE 1
 Graphic representation of the strategy adopted by the present study. The center circle represents the study's main objective, which refers to the evaluation of ISA stakeholders' perception of Ecosystem-based Management (EBM) for the deep-sea mining (DSM) regime administered by the International Seabed Authority (ISA). For that, four aspects were explored through an online survey (S) and in-depth interviews (I): 1) identification of EBM importance and meaning for the DSM regime administered by the ISA; 2) perception regarding current EBM implementation; 3) if a lack of consensus on EBM at the ISA regime could impact decision-making and the operationalization of the approach, and 4) what are opportunities to improve EBM and who should take part on such changes. The respective guiding questions for each aspect are presented externally to the figure. Questions presented at the online survey are accompanied by (S), and inquiries performed during the in-depth interviews are represented by (I).

2.1.1 Online survey

A survey and a general description of the study were widely distributed by mail to a deep-sea network of specialists and mail lists comprising natural and social scientists, law experts, decision-makers, and other stakeholders involved in the deep-sea science-policy interface. The survey consisted of three sections:

1. Self-identification.
2. Four open-ended questions covering respondents' perception of the importance of EBM for DSM in the Area, reflection of EBM in the regime, opportunities for improvement, and general thoughts about the research.
3. Fifteen statements addressing if and where respondents perceive EBM in the DSM regime, attached to a five-point Likert scale (categories ranging from strongly disagree to strongly agree). The option "I don't know" was also available.

The first section included categories to be selected with respect to general area of expertise (e.g. natural scientist, law expert, policy expert, etc.) and examples of roles or work positions that they may self-identify with (e.g. NGO representative, international organization representative, advisory role, etc.). The second section collected general perceptions and previous understanding of EBM and ISA structure. The third was used to refine perceptions assessment. Statements were developed considering the relation between EBM principles described by Long et al. (2015) and the ISA regime. Participants were exposed to the same information (statements) and were able to express their opinions on a specific aspect of the ISA regime independently of their previous knowledge or familiarity with EBM. Using Likert-scale statements provides a valuable opportunity to ensure that potential divergences in stakeholders' perceptions are captured based on the same assumption (Bryman, 2012).

Thirty-five respondents (35) completed the online survey (Table 1). Natural scientists and legal experts comprised 77% of the total respondents. The low participation of social scientists and

economists was expected, as these professionals remain underrepresented in the context of DSM discussions. Six participants self-identified as policy experts, whereas only one indicated being a "policy expert" as its primary role. Only one participant self-identified primarily as a "diplomat." Four respondents self-identified as members of the Council, three as members of the Assembly (two of which also self-identified as Council), two as members of the LTC, and an additional two as ISA observers. Based on these numbers, the views of members of the ISA (Assembly, Council, LTC, and Secretariat) may be underrepresented in the survey findings. Therefore, the survey results should be carefully examined as they represent a limited view of participants from the organization responsible for regulating and managing DSM activities. As part of the category "others," two participants have self-identified as "expert" and "environmental consultant." No participant self-identifies as a student, ISA Secretariat member, or contractor.

2.1.2 In-depth interviews

The interviews aimed to complement the online survey and deepen the information regarding the perceptions of what EBM is, its current implementation, its potential impact on decision-making under the ISA, and recommendations for improvement. An interview guideline was prepared to provide the individual interviewees with roughly the same structure while simultaneously opening the conversation for diverging narratives and customized queries. Each interview was recorded, transcribed, and sent back to the interviewee as a register of their participation.

Interviewees were selected based on a list of experts from distinct groups deeply involved with DSM discussions and negotiations at ISA. The list was compiled with the authors' previous contacts and indications from selected experts (snowballing), aiming at a balanced number of representatives from distinct groups.

Sixteen (16) interviewees participated in the research, including representatives from contracting parties with interests in mining ("contractors"), decision-makers (members of Council and Assembly), the technical and scientific body of the ISA (the Legal and Technical Commission), representatives of civil society with influence powers ("observers"), independent consultant parties, and members recognized by their extensive scientific production and engagement with ISA discussions (natural scientists and legal experts). Members of the ISA Secretariat were also invited to participate in the interviews, but there was no response to our contact.

2.2 Data analysis

Given its exploratory nature and the intent to delve deep into participants' perspectives, this study adopted a mixed-method approach to data analysis with a focus on qualitative approaches. Such focus is justified by the lack of conceptual consensus on EBM, the inherent complexity of working with perceptions from different

TABLE 1 Stakeholders' category (left column) and number of participants per category (right column) based on participants' self-identification from the online survey.

Stakeholder category	Number of participants
Natural scientist	14
Legal expert	13
Policy expert	2
Economist	2
Social scientist	1
Diplomat	1
Others	2
Total	35

The numbers indicated in the table reflect the primary type filled in by respondents, without considering other categories related to occupation also present in the survey (e.g., delegates of the Assembly, Council, LTC, ISA Observers, NGO members, international organization representatives, contractors) were not accounted in the table.

stakeholder groups, and the diversity of subgroups within the participant groups.

2.2.1 Open-ended questions

Responses from questions regarding the definition and importance of EBM for DSM were subjected to content analysis and categorized into groups reflecting EBM principles as proposed by Guilhon et al. (2020) (Section 3.3.1): core, ecological, impacts, knowledge, management, participation, socio-economic, and scales (Table 2). Examples of how categories of responses were established based on the content analysis are available as Supplementary Material. The qualitative approach was applied to enable an in-depth examination of participants' insights and interpretations of the study. It was complemented with quantitative elements

TABLE 2 The twenty-six Ecosystem-Based Management (EBM) principles recognized in a literature survey promoted by Long et al. (2015) are represented in the right column.

General Groups	EBM Principles
Core	Sustainability
Ecological	Account for Dynamic Nature of Ecosystems
	Consider Ecosystem Connections
	Consider Ecological Integrity and Biodiversity
Impacts	Acknowledge Ecosystem Resilience
	Consider Cumulative Impacts
	Consider Effects on Adjacent Ecosystems
Knowledge	Acknowledge Uncertainty
	Apply the Precautionary Approach
	Consider Interdisciplinarity
	Use of All Forms of Knowledge
	Use of Scientific Knowledge
Management	Implement Adaptive Management
	Conduct Appropriate Monitoring
	Develop Long Term Objectives
	Explicitly Acknowledge Trade-Offs
	Integrated Management
Participation	Decision Reflecting Societal Choice
	Promote Organizational Change
	Promote Stakeholder Involvement
Social-economic	Commit to Principles of Equity
	Consider Economic Context
	Recognize Coupled Social-Ecological Systems
	Use of Incentives
Spatial and Temporal Scales	Consider Appropriate Spatial and Temporal Scale
	Recognize Distinct Boundaries

The principles have been divided into general categories (left column) in a previous analysis of the Mining Code proposed by Guilhon et al. (2020).

describing the number of occurrences and distribution of qualitative categories. Commonalities arising from responses to other open-ended questions originated general categories that were grouped and discussed based on a minimum of two answers on the same topic, also considering the number of occurrences. To incorporate as many views as possible on the subject, both the online questionnaire and the interview structure contained a question on the perception of respondents concerning potential pathways to improve EBM incorporation in the ISA regime. These were only discussed qualitatively to avoid possible double counting from respondents who participated in the online survey (anonymous) and in-depth interviews.

2.2.2 Likert-scale

Responses to Likert scale statements are presented as percentages to support the qualitative discussion of respondents' perceptions of EBM implementation in the ISA regime. Whenever available, comments related to respondents' reasoning for the ranking were also considered to discuss the data.

3 Results

3.1 EBM importance and definition for DSM in the area

When asked why EBM is important in managing DSM in the Area, fourteen general categories resulted from respondents (n=35) (Figure 2A). In contrast, nine categories were obtained from interviewees (n=16) on how they would describe EBM (Figure 2B).

Answers regarding the importance and definition of EBM provided by respondents and interviewees, respectively, included all categories of EBM principles but participation. Interviewees' responses also lacked mention of knowledge, scales, and sustainability (Core) principles.

Both respondents and interviewees mainly referred to ecological and impact-related principles as justification for the importance of EBM for DSM in the Area and components that take part of EBM definition. Among respondents, the holistic nature and the acknowledgment of cumulative impacts (11 responses each) are the main aspects that explain EBM's importance in the DSM context. Regarding a definition, interviewees mainly highlighted that EBM recognizes and integrates existing ecosystem interconnections (8 responses) and acknowledges cumulative impacts (6 responses).

When taking into consideration the number of participants for each methodological approach, interviewed experts proportionally referred more to "Ecosystem management," "Human dimension," "Interconnections," "Cumulative Impacts," "Broad Impacts," and "Collaboration" than survey respondents. Interconnections between and within ecosystem components, including in relation to adjacent systems or units (both vertically and horizontally), was proportionally the most cited aspect associated with EBM definition or importance, as referred by 50% of the interviewees. Other EBM aspects, such as science-based considerations, the acknowledgment of knowledge gaps (uncertainties), sustainability goals (Core), and scales, were left out by interviewees.

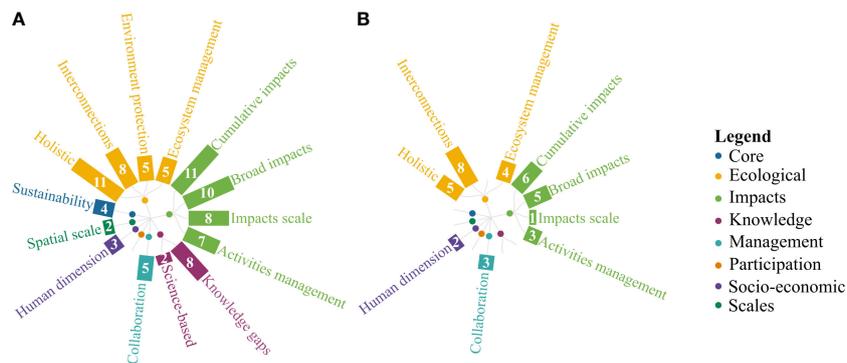


FIGURE 2
 Responses obtained by participants based on qualitative (categories) and quantitative (number of mentions) analysis of answers provided by respondents from the online survey (N=35) and interviewees (N = 16) on why Ecosystem-based Management (EBM) is important in the context of deep-sea mining (DSM) (A) and what they understand EBM to be (B). The qualitative and quantitative information obtained were classified on EBM principles following Guilhon et al. (2020).

3.2 Recognition of EBM within the ISA regime

Survey respondents expressed their perceptions regarding the recognition of EBM at the ISA regime through an open-ended question and 14 Likert-scale statements. Approximately 83% of respondents did not perceive EBM as sufficiently reflected in the ISA regime. Further justification for such answers included: a lack of definition and clarification on the application of the term (9); issues with environmental requirements (7) - including standards and guidelines; the absence of a plan to assess ecosystem-level responses, insufficient mention of cumulative impacts, absent mention to ecosystem services and inadequate consideration of water column processes; lack of coordination with other institutions/bodies (4); lack of requirements during the exploration stage (4); issues with EIA, REMPs and transparency (3 for each); and others more punctually mentioned (5). The latter included the lack of requirements by UNCLOS, an insufficient application of the precautionary approach, a lack of a final mechanism that reflects the common heritage of humankind, and the rush for exploitation activities to start. Lastly, a participant pointed out that EBM as a requirement may never be sufficiently reflected.

Respondents mostly disagreed that current ISA practices are consistent with EBM. More specifically, more than 60% of respondents disagree that the ISA currently provides clear guidance on how to intend to apply, enforce, and comply with EBM (as provided by the General statement). Following that, disagreement rates above 50% were observed for Ecological, Impacts, Knowledge (Use All Forms of Knowledge), Management (Implement Adaptive Management), Socio-economic, Scales, and Transparency (General). Among those who disagree, respondents appear not to be so convinced about the statements “Acknowledge Uncertainties” and “Consider Interdisciplinarity,” which presented higher rates of “somewhat disagree” than “totally disagree.” Statements with higher agreement rates were observed for the EBM categories concerning Knowledge (Acknowledge Uncertainties – 42,9%; Consider Interdisciplinarity – 34,3%) and

Management (Integrated Management – 37,1%). None of the respondents strongly agreed with “Use all Forms of Knowledge.” Approximately 20% of respondents did not know how to answer a statement about “Transparency” (Figure 3).

Whenever asked if they think that EBM is sufficiently reflected in the current regime administered by the ISA, close to 83% of the survey respondents answered “no,” while 8,6% answered “yes,” and 8,6% did not know or did not respond to it. According to two of those who responded affirmatively, the ISA has been implementing adequate guidelines and environmental requirements, such as the practice of Environmental Impact Assessment (EIA) and Environmental Management and Monitoring Plans (EMMP). A third respondent did not provide any example. The respondent who answered “I don’t know” highlighted that it was too early to speak about EBM and exploitation as no standards or guidelines have been agreed upon.

Interviewees were asked to provide a few examples of where they have seen EBM incorporated into the regime. Most participants related EBM at the ISA regime to developing Regional Environmental Management Plans - REMPs (9). Although perceiving REMP as a management approach compatible with EBM, most of those who mentioned REMPs recognized that it is “not really in practice,” “not enough,” “only partially,” or “not appropriate.” Others situated parts of planning and developing REMPs as evidence that EBM is “behind the thinking.” More specific examples under the REMP process included the development of regional environmental assessments - including aspects of ecosystem functioning and exercises to identify cumulative impacts performed during workshops organized by the ISA. Further, requirements under the ISA regulations, such as assessing impact during test-mining activities and submitting Environmental Plans (EIS, EMMP, and Closure Plans) as part of the application to obtain an exploitation license, have been raised. On this matter, a participant highlighted that the development of Environmental Plans requires the recognition of other uses, a primary step in assessing cumulative impacts. Other two perceived that requirements for EIA/EIS (including for presenting ecosystem services and connectivity aspects, according

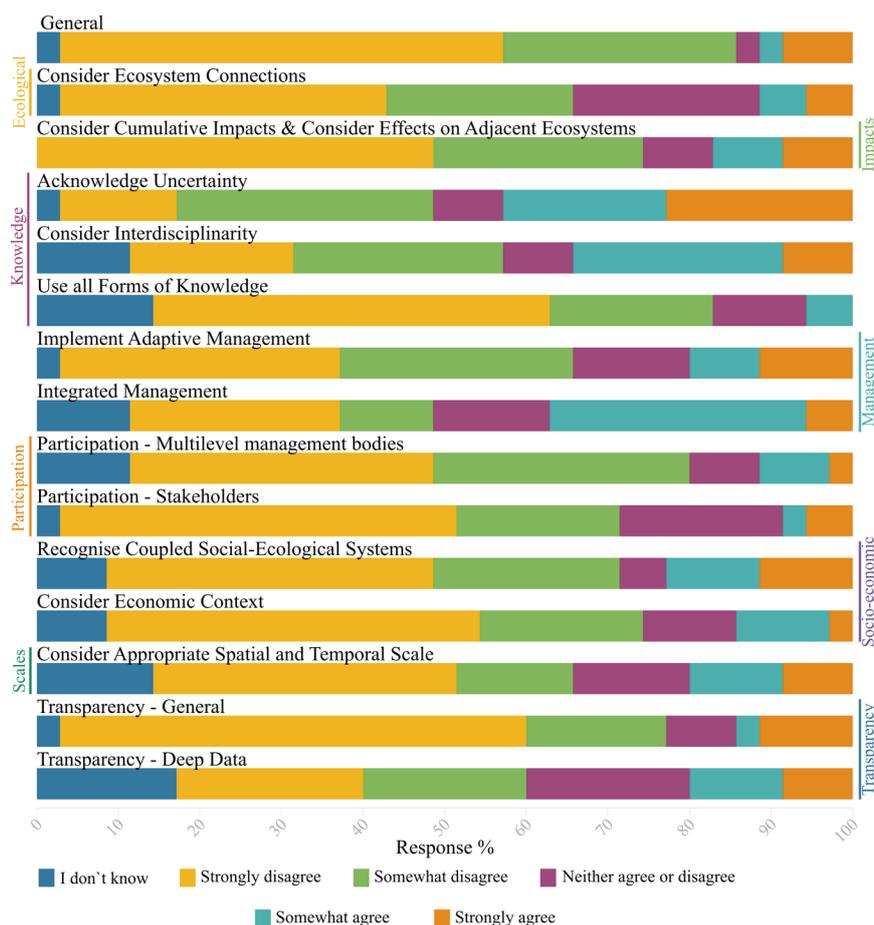


FIGURE 3 Results (percentage) were obtained for the fifteen statements included in the online survey, which aimed to provide a shared background to evaluate to what extent respondents recognize Ecosystem-based Management (EBM) as contained in the current International Seabed Authority regime. Each statement is related to one or more EBM principles, as indicated at the top of each bar. As shown in the figure legend, respondents were presented with five Likert-scale categories of response ranging from “strongly agree” to “strongly disagree.” Respondents were also presented with the option “I don’t know.” EBM general groups, following Guilhon et al. (2020), are described perpendicularly to the respective statements they represent. The content of each statement is available in the [Supplementary Material](#).

to one) could be *per se* understood as acknowledging EBM. Extensive requirements for baseline studies during the exploration phase - including data beyond the seafloor - were also raised as measures in accordance with EBM. In this aspect, two other participants acknowledged an “expansion” in baseline data requirements as actions toward EBM.

Finally, three interviewees responded that they did not recognize EBM as being put into practice by the ISA.

3.3 Decision-making and operationalization under the ISA

Seventy-five percent (75%) of interviewees perceived a lack of consensus regarding EBM as a factor that can impact decision-making. According to them, a lack of common understanding can lead to different interpretations, preventing the setting of standards and leaving room for gaps in compliance. The existence of economic and political interests was also given as a reason for the

importance of clarifying an EBM mandate for the deep-sea mining regime. Among those who do not see a lack of EBM consensus to impact decision-making (12,5%), some stated that there is already a general understanding of EBM within the ISA but argued that an alignment between delegations could be beneficial. Others highlighted that the foreseen standards to be adopted should allow to align expectations regarding EBM implementation. The remaining 12,5% did not know how to answer this question.

About two-thirds of interviewees (64%) perceived a lack of consensus potentially impacting EBM operationalization under the ISA regime, and 29% believed there was no impact. According to those who do not foresee an impact, EBM should not be compromised if the necessary expertise is enrolled in the development of the regulatory framework (including standards) and with the elaboration of baseline studies and EIA/EIS. Nevertheless, all participants agreed that it would be important to agree on a definition and scope of EBM under the ISA regime. Among those who do not perceive a lack of understanding as impacting decision-making, they perceive that as long as there is a

common understanding within the LTC and between the LTC and Secretary-General, alignment and convergences with Member States can be obtained through side events and/or development of policy-briefs. Other than that, a participant perceived that future exploitation guidelines issued by the LTC should align potential divergences in understanding among stakeholders.

According to respondents, the lack of a common understanding may lead to different interpretations, which can impact the negotiations and EBM operationalization. Among responses, participants considered a challenge to approach aspects other than those related to the natural environment (i.e., social, economic, cultural), especially considering the political and economic stakes intrinsic to the negotiation processes. Other than that, respondents perceived that different understandings might impact the monitoring of compliance and enforcement.

3.4 Opportunities for improvement

The highest number of responses from respondents and interviewees included aspects related to (a) the importance of clarifying an EBM mandate under the ISA and (b) increasing discussions on the subject. According to participants, more clarity is needed from the ISA in terms of what are the elements that encompass EBM, as well as concerning what is expected in terms of compliance with EBM. Among those who perceive the need for further discussions on the topic, capacity development activities, the development of policy briefs, and side events with delegations were raised as possible ways forward. Yet generally, respondents referred to the need for better integration between the ISA and other sectors and organizations (e.g., OSPAR), including the consideration of criteria for identifying areas in need of protection (e.g., EBSAs); improvement in transparency, involvement of stakeholders, incorporation of independent and external science and a better acknowledgment and reduction of uncertainties.

Concerning more specific recommendations, the results were more oriented towards the improvement of management instruments and data collection. The improvement of REMPs substance and procedure was the aspect more frequently mentioned. Additionally, including clearer and comprehensive templates for EIA/EIS/EMMPs and the need for standardization of technologies, data analysis, and dissemination were also mentioned as aspects requiring further attention. The need for data that allows for EBM was also expressly mentioned among interviewees. According to respondents who raised issues with data, the consideration of interconnections with water column ecosystems, acknowledgment of ecosystem functions and services, and the establishment of thresholds and tipping points were referred to as aspects playing a significant role in enabling EBM.

Whenever asked whom they consider the responsible parties in improving EBM implementation in the ISA, most respondents (62%) perceived that such change should be led by the State parties of the ISA, in other words, the signatories' parties of UNCLOS. Respondents also mentioned the importance of involving the "community" related to and affected by deep-sea mining discussions, including through national population

hearings, input from scientists, and conversations with other organizations and actors enrolled in ocean management, such as those involved in discussions taking place under the negotiations of a legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ). Nonetheless, less frequently, the Secretariat and the LTC were also mentioned as parties potentially playing a role in improving EBM implementation. Finally, two respondents perceived the ISA as in the right direction for implementing EBM.

4 Discussion

4.1 EBM definition and its importance for DSM in the area

The findings follow the evidence of other investigations concerning stakeholders' perceptions of EBM. Views from both respondents and interviewees were mainly related to Ecological and Impacts principles and less focused on social sciences aspects. A similar pattern was observed among participants from an Atlantic Ocean Research Alliance workshop concerning EBM (ICES, International Council for the Exploration of the Sea, 2016; Dickey-Collas et al., 2022). In the present study, participants made references to the Ecological principles of EBM, which included "to take a holistic approach to the ecosystem," "the consideration of the marine environment as a whole," and "consider interactions within an ecosystem." In relation to Impacts principles, mentions mainly included the acknowledgment and consideration of cumulative impacts, together with a broader consideration of impacts both in terms of effects and scale. The consideration of the ecosystem as a whole is part of the paradigm shift represented by EBM, which included the recognition of humans and non-humans alike as entities interconnected by places, processes, individuals, and communities (De Lucia, 2015).

Albeit discreetly, the recognition of a human dimension as an aspect of EBM figured among responses and encompassed the importance of factoring human elements (economic, social, and cultural) as part of management, as similarly observed by Dickey-Collas et al. (2022). As reflected by the lack of mention of Participation principles, it seems that stakeholders generally do not factor it as an intrinsic component of EBM. In that sense, a trend in transitioning from an eco-centric to a more anthropocentric approach regarding EBM (Aas et al., 2020) seems to be restrained to concepts such as ecosystem services (De Lucia, 2015), in which humans are placed as direct or indirect beneficiaries from natural ecosystems, without acknowledging and factoring societal values or shared responsibilities that are linked to participation. These, nevertheless, are already recognized as EBM components in the related literature (Long et al., 2015; O'Higgins et al., 2020; Sardà et al., 2014). Based on the assumption that humans are an integral part of ecosystems – not only by influencing ecosystem dynamics and processes but also as beneficiaries of ecosystem services – the existent diversity of values and voices should be acknowledged as part of management and governance processes.

The lack, insufficiency, or inefficiency of participatory mechanisms by the ISA have been discussed elsewhere. Shortcomings in participation include lack of consultation with a wide diversity of stakeholders, including indigenous peoples and coastal communities (Tilot et al., 2021), acknowledgment and response of stakeholder submissions (e.g., EIA – Guilhon et al., 2022) and engagement of stakeholders when implementing decisions (Ardron et al., 2023). Ignoring such participatory aspects as in line with EBM may ultimately compromise the legitimacy of the process (Jaekel et al., 2023). Based on that, the importance of participation in the context of DSM in the Area is not questionable; nevertheless, participants do not seem yet to associate it with EBM.

EBM categories were diversified as more respondents participated in the online survey in comparison to the number of interviewees. Survey respondents mentioned in high numbers the existence of uncertainties related to deep-sea ecosystems and processes (lack of scientific knowledge) and the foreseen (yet uncertain) extension of impacts to be caused by future large-scale DSM activities. Conversely, only a few survey respondents spontaneously referred to the importance of scientific knowledge for decision-making, and none of the interviewees referred to scientific knowledge as a component of EBM definition. Adopting a precautionary approach and implementing science-based decision-making are cornerstones of EBM and have great relevance to the context of DSM (Jaekel, 2015; Guilhon et al., 2020; Christiansen et al., 2022). Additionally, other forms of knowledge, including those provided by indigenous peoples and local communities, should also be included in the context of DSM discussions and decision-making (Tilot et al., 2021; Amon et al., 2022; Guilhon et al., 2022), although not raised by any participant.

Respondents considered establishing collaboration mechanisms as an important EBM aspect to DSM. Political will is required for successful collaboration endeavors, as in consonance with EBM (Enright and Boteler, 2020). According to participants, collaboration efforts should be considered in light of other human activities taking place in the marine realm as well as with the mandate of other management organizations, including the forthcoming BBNJ regime. An important avenue for such collaboration lies under the mechanisms established under the approved text of the BBNJ treaty. As suggested by Christiansen et al. (2022), a contact group between ISA and BBNJ processes, a joint scientific advisory board, and a consolidated clearing house mechanism could feature among such measures.

Concerning the sustainability principle (Core), two different views of sustainability were raised by participants. One considers EBM important to “achieve sustainable use of mineral resources,” whereas others see it as relevant to the “sustainable management of natural resources.” Sustainability is the ultimate objective of adopting EBM (De Lucia, 2015), and therefore it is embedded in it (ICES, 2005). Although the terminology is usually used to relate to the importance of guaranteeing the interests of the current and future generations, especially in the context of the Area’s minerals, which are a “common heritage of humankind” (UNCLOS, 1982 - Article 136; Guilhon et al., 2020), the wording adopted may reflect different expected outcomes, which, in turn, can be primarily based

on interests. To “achieve sustainable use of mineral resources” may suggest a prioritization of an exploitation view, potentially implying that the primary objective is to guarantee that the activity (exploitation) is sustainable, ensuring that the mineral resources of the Area are not exhausted for current and future generations. Alternatively, a more conservationist view is reflected in the responses addressing the “management of natural resources” (Le Tisser, 2020), which can be interpreted as a concern focusing on the maintenance of natural resources (ecosystems) over time. In line with EBM, such conservation of marine resources should reflect the latest view and focus on maintaining ecosystem structure, functions, and services (Guilhon et al., 2020). In both scenarios, the view of sustainability is debatable, as minerals on the deep form in the scale of millions of years and considering that deep-sea mining activities are frequently associated with potentially causing irreversible impacts (Levin et al., 2020; Singh, 2021a).

4.2 Recognition of EBM within the ISA regime

Concepts such as the need for assessing and evaluating cumulative impacts and ecosystem services are often linked to EBM terminology. Under the ISA regime, the acknowledgment of cumulative impacts is contained as an express requirement in the DER (Guilhon et al., 2020); however, it remains one of the main scientific gaps in informing DSM decision-making (Amon et al., 2022). The requirement of assessing ecosystem services as part of baseline studies and as part of assessing impacts is absent in the Mining Code (Guilhon et al., 2020) and was also listed as an existing scientific gap (Amon et al., 2022). As mentioned by respondents, the interconnection of ocean ecosystems and processes, both vertically and horizontally, reflects the holistic approach that EBM stands for. Nevertheless, considering the water column aspects as part of baseline information and in assessing environmental impacts for test-mining components during exploration is limited so far⁴ (Amon et al., 2022).

The importance of better integration between the ISA regime and other organizations and instruments, e.g., the recently agreed BBNJ instrument for the conservation of biodiversity in the high seas, in light of EBM, and steps to improve the coherence between the two regimes have been discussed by Christiansen et al. (2022). Another critical aspect raised is that EBM requirements are missing

⁴ Considerations regarding the current lack of considering adjacent ecosystems (e.g. water column) in Environmental Impact Statements submitted by contractors for the performance of activities with impact to cause harm to the marine environment were also raised during stakeholder consultations, which can be found here: https://www.lbeg.niedersachsen.de/startseite/bergbau/offshore/aktuelle_projekte/aktuelle-projekte-offshore-124111.html ; <https://economie.fgov.be/en/themes/enterprises/deep-sea-mining/workshops-and-public/environmental-impact-statement>; https://www.dosi-project.org/wp-content/uploads/DOSI_Submission_MoESEIS.pdf; <https://www.pewtrusts.org/-/media/assets/2020/05/code-project-comments-regarding-eis.pdf>

for the exploration stage. That aspect raises concerns, given that the exploration stage is of utmost importance to collect, analyze, and evaluate data, including assessing impacts and monitoring during and after test-mining (Guilhon et al., 2022). Test-mining activities provide evidence that can help balance trade-offs for exploitation (Ginzky et al., 2020).

Having REMPs as a reference to EBM under the ISA regime is somewhat expected. EBM wording and implicit facets of EBM (Dickey-Collas et al., 2022) are contained within the EMP-CCZ as one of its goals (ISA, 2011 - para. 35.d), facilitating stakeholders relating to it. In the case of the current EMP-CCZ, the Areas of Particular Environmental Interest (APEIs) have a similar role to marine protected areas (MPAs), as they should represent a precautionary measure that safeguards key ecological processes within areas that are biogeographically representative of the location. In practice, APEIs are non-permanent protected areas where no exploration or exploitation activities are allowed (core areas of 200x200 km²) accompanied by buffer areas (100 km) (Wedding et al., 2013; Wedding et al., 2015). In 2012, the ISA Council approved the first network of nine APEIs distributed outside of contract areas (ISA, International Seabed Authority, 2012a; ISA, International Seabed Authority, 2012b). More recently, as a result of scientific workshops and the review process conducted by the LTC, four new APEIs were included in the network of APEIs, taking into consideration internationally accepted criteria (ISA, International Seabed Authority, 2021a).

Shortcomings of REMPs procedure and substance in reflecting EBM hamper their potential to become instruments that effectively enhance coherence for management and conservation in ABNJ (Christiansen et al., 2022). Moreover, it compromises the ISA's mandate to "ensure effective protection for the marine environment from harmful effects which may arise" from activities in the Area (UNCLOS, 1982 - Article 145). Christiansen et al. (2022) provide an extensive list of recommendations to improve REMPs-related practice, including amendments in the scope and procedure for REMPs that derived from an expert workshop, followed by a formal collective submission from Germany, the Netherlands, and Costa Rica to be appreciated by the Council of the ISA (ISA, International Seabed Authority, 2020a, ISA, International Seabed Authority, 2020b)⁵. Addressing such recommendations would ensure the REMPs are management instruments aiming for EBM under the DSM regime of the ISA.

Responses obtained for the General statement reinforce the perception that for stakeholders, the application, enforcement, and compliance with EBM are unclear under the ISA regime, standing out as an issue that requires further discussion (Guilhon et al., 2020; Guilhon et al., 2022). For instance, intersessional discussions could be carried out by a dedicated group Council working on the protection and preservation of the marine environment to specifically tackle and how provisions giving effect to EBM should feature throughout the draft regulations. Indeed, there have been recent precedents where intersessional groups have been created by the Council under the

informal working group on the protection and preservation of the marine environment to work on specific themes such as the rights and interests of coastal states as well as underwater cultural heritage, among others (Earth Negotiations Bulletin, 2023).

Regarding knowledge, the highest rates of disagreement were obtained for the statement related to the acknowledgment of traditional/local/indigenous knowledge for informing decision-making processes. There is no reference to the use of traditional knowledge as part of the Mining Code (Guilhon et al., 2020; Tilot et al., 2021), despite the evidence that coastal communities can be exposed to the effects of activities taking place in ABNJ (Popova et al., 2019). Conversely, the acknowledgment of uncertainties and consideration of interdisciplinarity as part of the ISA regulatory framework seems to remain uncertain, as observed by more balanced responses obtained among those who agree and disagree with it.

Public and stakeholder participation, which are at the core of EBM, seems to be a controversial issue among ISA stakeholders, as responses to the statements seem to reflect that there is no consensus on whether the ISA presents an adequate strategy for stakeholders' engagement and communication. Several authors have pointed out issues relating to such aspects at different stages of the DSM process (Ardron et al., 2018; ISA, International Seabed Authority, 2021b; Guilhon et al., 2022; Ardron et al., 2023). Similarly, transparency shortcomings have been reported in relation to numerous aspects of the DSM regime, including concerning plans of work, annual reports, REMPs and EIS (Guilhon et al., 2020; Tilot et al., 2021; Amon et al., 2022; Christiansen et al., 2022; Guilhon et al., 2022) and are largely addressed by the literature (Christiansen et al., 2016; Ardron et al., 2018). With respect to the platform *DeepData*⁶, to provide for transparency on the data held by the ISA, stakeholders seem to not have a very clear opinion, although the highest percentage was obtained for the category "disagree." The *DeepData* database has the potential to expand access to scarce deep-sea knowledge, as well as to address transparency issues raised with respect to the ISA regime. However, so far, the *DeepData* is not yet fully operational or interlinked with other global databases (Amon et al., 2022). In addition, some respondents have reported that the platform is not user-friendly and that there are difficulties in extracting data from it. Numerous challenges and opportunities for improvement in the use of *DeepData* have more recently been reported in the literature. (Rabone et al., 2023).

According to one, "[as exploitation is not in place] *there has been no forum where (...) an ecosystem-based management could be showcased*". This statement reinforces the perception of stakeholders who currently perceive requirements compatible with EBM as lacking in the exploration stage. Also, it underlines the view that EBM should only be enacted during the exploitation phase. We argue that EBM must be part of the process from the early stages to make sure that necessary questions are raised, efforts to fill gaps are in place, remaining uncertainties are acknowledged, and the values of those more or less directly involved with the process (and its potential impacts and effects) are appreciated.

⁵ As of August 2022, there was no reaction from the ISA regarding this submission.

⁶ Six <https://www.isa.org/jm/deepdata>

4.3 Decision-making and EBM operationalization under the ISA

Challenges remain in establishing a universal operationalization of EBM, and it is not likely nor expected from the ISA to provide a final solution to such a matter. However, as the responsibility of establishing a coherent regulatory framework for DSM falls within the remit of the ISA, determining a clear definition and scope for EBM in the context of DSM is a critical step towards its operationalization and compliance (Guilhon et al., 2020; Christiansen et al., 2022) whereas avoiding its reduction to an abstract, unspecific and jargon-limited terminology (Amon et al., 2022).

Moreover, the debate on a final text to regulate exploitation activities is a timely opportunity to include clear and assertive wording on EBM scope and expected practical implications. Importantly, to be effective, EBM should be reflected throughout the regime of the ISA, including prospecting and exploration regulations. For such, changes can be debated and accommodated during the regular reviews performed by the LTC and approved by the Council.

EBM wording should set the basis for transversal logic to be encapsulated in all procedural steps and substance for the different stages of mining. Practically, such logic should be embedded in the process of planning, elaborating, delivering, and reviewing (if applicable) plans of work, annual reports, EIS, EMMPs, Closure Plans, and REMPs (Guilhon et al., 2020; Guilhon et al., 2022). According to participants, the efforts of determining meaning for EBM under the ISA could be accomplished through different efforts, such as co-designed inter-sessional working groups, side events, and policy-briefs and be largely informed, if applicable, through a guideline document.

4.4 Opportunities for improvement

The issue of capacity development, communication, and EBM is not exclusive to the ISA context (ICES, *International Council for the Exploration of the Sea*, 2016; Marshak et al., 2017; Dickey-Collas et al., 2022). A suggestion to overcome such challenges includes engagement with other organizations and processes dealing with EBM as a mandate and learning from their expertise. For instance, the ISA could collaborate more closely with BBNJ's future discussions, which also account for EBM as one of its guiding principles and approaches (BBNJ, 2023). Further, the ISA could exchange (e.g., through workshops) and collaborate with other institutions (e.g., CBD, OSPAR, FAO, NOAA) as reflected in the Strategic Plan 2019-2023 (ISA, *International Seabed Authority*, 2018; Jaeckel, 2020). Such efforts could increase coherence among international treaties and instruments (Christiansen et al., 2022), which is desirable under the UN Decade of Ocean Science for Sustainable Development, a commitment formalized by the ISA⁷.

⁷ <https://www.isa.org/jm/un-ocean-science-decade/>

Issues related to the improvement of transparency and consideration of inputs from external science by the ISA have mainly been acknowledged and discussed in the literature (Ardron et al., 2018; ISA, *International Seabed Authority*, 2021b; Christiansen et al., 2016; Markus and Singh, 2016; Ginzky et al., 2020; Guilhon et al., 2020; Willaert, 2020; Craik and Gu, 2021; ISA, *International Seabed Authority*, 2021b; Amon et al., 2022; Guilhon et al., 2022).

5 Final remarks

Different EBM views exist between ISA stakeholders, reflecting other findings in the literature. More prominently, principles associated with Ecological and Impacts aspects were more frequently perceived as in association with EBM. The narrative of considering the ecosystem holistically does not account for human spheres beyond the concern of impacts resulting from DSM activities and their effects on marine ecosystems. As seen in other studies, the perception of human aspects, such as the inclusion of cultural or social values and knowledge in management objectives and humans as part of one integrated system, as part of EBM, remains limited.

Considering the complexity that permeates EBM structural discussions, it is not expected of the ISA to provide a solution for this entangled question. However, as the regime assigns the concept as part of its regulatory framework, it is expected that the ISA provides enough elements to reach an understanding between stakeholders and the possibility of compliance by contractors. As a recommendation, establishing a task force can be a valuable contribution to boosting discussions on the theme. Such efforts could be optimized, for instance, by establishing closer collaboration and exchange with other international entities and experts with experience in the topic. Based on these inputs, Member States, the LTC, Observers, independent scientists, and other stakeholders can put their values and interests on the table and, together, reach a consensus among the actors on how EBM should be understood and applied within the ISA. Creating spaces to broaden this discussion, such as initiatives on capacity development, workshops, policy briefs, and side events, will ensure that all the interested stakeholders will get sufficiently familiarized with EBM to reflect their expectations when a final text on the topic is discussed at the ISA.

A translation of EBM towards what it encompasses for the seabed mining regime should be a matter of significant interest to the ISA and all stakeholders, especially as the mineral resources found in the Area are the common heritage of humankind, and therefore, its maintenance must be ensured to future generations. For that, we argue that EBM must be part of the process from the early stages to make sure that necessary questions are raised, efforts to fill gaps are in place, remaining uncertainties are acknowledged, and the values of those more or less directly involved with the process (and its potential impacts and effects) are appreciated. Despite requiring complex and often tricky conversations (Dickey-Collas et al., 2022), we echo Delacámara et al. (2020) that there is a need to start somewhere.

Data availability statement

The raw data supporting the conclusions of this article are interviews transcriptions and will only be made available upon individual request.

Ethics statement

This study was approved by Brazilian Ethics Committee Plataforma Brasil (Proc. 50513021.8.0000.5464). The study was conducted in accordance with the local legislation and institutional requirements. Participants provided their written informed consent to participate in this study.

Author contributions

All authors contributed to conception and design of the study. MG and LP developed the survey and questionnaire's frameworks. LYX, PS, SC, and AT reviewed and further collaborate refining the proposed methodological approaches. MG and LYX performed the analysis and developed the figures of the article. MG wrote the first draft of the manuscript. LYX, LP, PS, and AT reviewed and refined the final text. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

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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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2023.1139396/full#supplementary-material>

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