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Evaluating the quality of environmental baselines for deep seabed mining

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Generating environmental baseline knowledge is a prerequisite for evaluating and predicting the effects of future deep seabed mining on the seafloor and in the water column. Without baselines, we lack the information against which to assess impacts and therefore cannot decide whether or not they pose an acceptable risk to the marine environment. At present, the International Seabed Authority (ISA), which is the international regulator for seabed mining, requires contractors engaged in mineral exploration to establish geological and environmental baselines for their respective contract areas. However, there are no criteria for evaluating what a robust baseline entails. This paper seeks to address this gap by not only analyzing the role and importance of baselines for environmental management but also suggesting criteria for evaluating the quality of baselines. Such criteria (which we present in tabular format) should include at least a minimum amount of technical information, based on best available scientific information and process, in standardized format to enable comparison between contractors and regional synthesis. These criteria should also allow baselines to be used for before-after comparisons through the choice of appropriate zones for comparison of impacts, and to prepare and test a suite of monitoring indicators and their metrics. Baseline studies should identify uncertainties, vulnerable species and habitats, and include transparent reporting as well as exchange with independent scientists and other stakeholders. The quality criteria suggested in this paper build on the ISA's existing Mining Code and seek to support the development of a more standardized catalogue of requirements for environmental baselines. This will allow states, mining operators, the ISA, and the public to gain a better understanding of the environmental impacts of seabed mining and available mitigation measures.

KEYWORDS

deep ocean, environmental baseline, governance, International Seabed Authority (ISA), mining impact, scientific knowledge, seabed mining

Introduction

Deep seabed mining (DSM), if it were to become reality, would yield metals, such as copper, manganese, nickel, and cobalt from some of the least understood places on Earth, in the deep ocean. Knowledge about deep ocean ecosystems remains largely rudimentary and uncertainties remain about the role of the deep ocean in carbon capture, climate regulation, food provision, and other "ecosystem services" (Amon et al., 2022). Importantly, deep ocean species, their life histories and functional relationships remain largely unknown. These uncertainties currently make it almost impossible to predict the precise environmental effects of DSM.

Environmental baselines are the foundation for assessing and managing the environmental effects of DSM, as well as for regulating and permitting seabed mining (Johnson and Ferreira, 2015; Clark, 2019). Baselines document the past and present natural conditions at a future mine site including physical conditions and ecology and help to understand the environment in which DSM might take place. Baselines identify key species and their tolerance for stresses, such as pollution, which can then serve as indicators for measuring and managing the impact of DSM.

Any DSM in the Area[1] is controlled by the International Seabed Authority (ISA) and will require a prior environmental impact assessment (EIA). This, in turn, requires knowledge of the current state of the environment. Thus, the purpose of baselines is to identify scientific questions (such as what level of noise pollution is tolerated by key species at a mine site) and the methodology for answering them.

This paper suggests broad criteria for evaluating the quality of an environmental baseline for DSM as summarized in Table 3. This discussion is warranted not least after an ISA mining contractor submitted an EIA without site-specific baseline data in 2021 (NORI, 2021), which was only rectified (NORI, 2022b) after stakeholder feedback (DOSI, 2021; Pew Charitable Trusts, 2021; NORI, 2022a).

The importance of baselines is undisputed (Johnson and Ferreira, 2015; Clark, 2019, page 458). As the ISA's Mining Code itself states, 'baseline data documenting natural conditions prior to test-mining or testing of mining components are *essential* in order to monitor changes resulting from these activities and to predict impacts of commercial mining activities'[2]. Nonetheless, the ISA has been 'operating in a data-deficient environment, particularly as regards resource data and environmental data' for some time[3]. While data submission by contractors may have improved[4], '[t]here remain, however, ongoing questions about whether enough was being done for the baseline studies, across a range of environmental aspects'[5]. A lack of transparency around data submission, and DSM governance more generally, is compounding the problem (Ardron, 2018; Ardron, 2020; Amon et al., 2022).

This paper discusses the role of, and requirements for, baselines from a scientific and environmental management perspective, while also offering thoughts on how baselines can be legally integrated into the ISA regime. However, the paper does not purport to exhaustively discuss governance questions around baselines. Our aim is to articulate what a robust environmental baseline for DSM would need to entail in order to reflect Best Environmental Practice[6]. Moreover, while acknowledging that geological data are also required for DSM, this paper focuses largely on environmental baselines as these remain subject to significant scientific uncertainty. While the paper focuses on polymetallic nodules, for which mining technology is most advanced, much of the discussion is equally relevant to polymetallic sulphides and ferromanganese crusts.

International legal and policy framework for environmental baselines

Overview

All DSM in the Area is regulated and managed by the ISA on behalf of humankind as a whole[7]. The relevant legal framework

1 Area is a legal term to describe 'the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction'. See United Nations Convention on the Law of the Sea, 1982, article 1(1)(1) (UNCLOS).

2 ISA, Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area, ISBA/25/LTC/6/Rev.1, 30 March 2020, para. 14 (emphasis added).

3 ISA, Developing a Regulatory Framework for Mineral Exploitation in the Area: Report to Members of the Authority and All Stakeholders, ISBA/Cons/2015/1, 2015, https://www.isa.org.jm/files/documents/EN//Survey/Report-2015.pdf, p. 41.

4 ISA, Review of the Implementation of the Environmental Management Plan for the Clarion-Clipperton Zone, ISBA/16/C/43, 1 June 2021.

5 ISA, Report of the Chair of the Legal and Technical Commission on the work of the Commission at the second part of its twenty-sixth session, ISBA/26/C/12/Add.1, 25 September 2020, para. 13.

6 The latest ISA draft exploitation regulations define Best Environmental Practice as follows: '"Best Environmental Practices" means the application of the most appropriate combination of environmental control measures and strategies, that will change with time in the light of improved knowledge, understanding or technology, as well as the incorporation of the relevant traditional knowledge of Indigenous Peoples and local communities, taking into account the applicable Standards and Guidelines.' ISA, Facilitator's Revised Draft Regulations on Exploitation of Mineral Resources in the Area: Parts IV and VI and related Annexes. ISBA/27/C/IWG/ENV/CRP.1/Rev.1, June 2022, Schedule.

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consists of the United National Convention on the Law of the Sea (UNCLOS) and its 1994 Implementing Agreement[8] as well as the ISA's Mining Code, which is an umbrella term for the ISA's existing and future rules, regulations, procedures, and recommendations.

The ISA and its 167 member States have far-reaching environmental obligations, such as to 'ensure effective protection for the marine environment from harmful effects' of mining activities, including 'prevention of damage to flora and fauna of the marine environment'[9]. The ISA also needs to assess the predicted impacts of DSM,[10] protect vulnerable ecosystems,[11] and determine whether a proposed mining plan provides for environmental protection[12]. Achieving such a high bar requires environmental baselines, including a basic understanding of the environmental dynamics and its history so all data may be put into a context of periodic and episodic change to be able to apply robust and proactive environmental management. This involves at least ten tasks, the first six of which already apply during the exploration phase and are required under the ISA's Mining Code, as summarized in Table 1. Tasks seven to ten should be required for any future mineral exploitation, although some of those tasks will already be carried out during the exploration phase in order to be ready by the time a contractor applies for exploitation.

An environmental baseline should be established during the 15-year exploration stage, prior to any mining, to allow for an EIA. As the LTC notes, a baseline is designed '*to acquire the capability necessary to make accurate environmental impact predictions*'[13], and to demonstrate that the activities planned will not cause serious harm to the marine environment[14].

Current governance challenges

While the fundamental importance of baselines is clear, their use in decision-making processes is somewhat less understood. There are at least three governance questions.

First, how is the quality of environmental baselines assessed? There are currently no publicly available criteria for assessing the quality and completeness of baselines (Clark, 2019, p. 457; Ginzky et al., 2020, p. 6-7). Such criteria are important both for transparency of environmental decision-making and to ensure all contractors are held to the same standard and address comparable questions. The section on quality criteria for a robust baseline below offers criteria that could be used as a starting point to assess environmental baselines.

Second, who assesses the quality of baselines? Within the ISA, the LTC is the primary body that reviews environmental data, although constraints on the LTC's time and expertise in the fields of environmental management and marine biology are well known[15] (Jaeckel, 2017b, ch 8.3; Ginzky et al., 2020).

Third, when is the quality of baselines assessed? Ultimately, when a contractor submits an application for mineral exploitation, the LTC needs to assess a prior EIA which should be based on site-specific environmental baseline data collected during the exploration period. At that point, the LTC can assess the baseline information and approve or reject a plan of work for exploitation[16], as visualized in Figure 1.

Ideally, the LTC should assess baseline data well before the exploitation application stage, not least to assist the contractor in improving its baseline, where necessary. Contractors have to report on their baseline investigation program annually[17], during 5-yearly reviews of their plans of work for exploration[18], as well as at the end of an exploration contract[19]. Arguably, the 5-yearly reviews as well as the final review should be used to conduct a thorough assessment of baseline data and determine which gaps will need filling. This would support the contractor and improve the Council's ability to 'exercise control over activities in the Area'[20]. The review and baseline studies should re reported transparently (Ardron, 2018; Ardron, 2020; Haeckel et al., 2020; Komaki and Fluharty, 2020; Willaert, 2022), not least to address challenges around non-compliance with annual reporting requirements.[21]

7 UNCLOS, articles 1(1)(1), 136, 137, 157.

8 Agreement Relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea, 1994.

9 UNCLOS, article 145.

10 UNCLOS, article 165(2)(d).

11 ISA, Regulations on Prospecting and Exploration for Polymetallic Sulphides in the Area, ISBA/16/A/12/Rev.1, 7 May 2010, regulation 33(4); ISA, Regulations on Prospecting and Exploration for Cobalt-rich Ferromanganese Crusts in the Area, ISBA/18/A/11, 22 October 2012, regulation 33(4); see also ISA, Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area, ISBA/19/C/17, 22 July 2013, regulation 31(4).

12 UNCLOS, article 165(2)(b); ISA, Draft Regulations on Exploitation of Mineral Resources in the Area, ISBA/25/C/WP.1, 22 March 2019, draft regulation 13(4)(e).

13 ISBA/25/LTC/6/Rev.1, para. 13.

14 ISBA/25/LTC/6/Rev.1, annex I paras. 2, 65

15 ISA, Suggestions for facilitating the work of the International Seabed Authority – Submitted by the Delegation of Germany. ISBA/24/C/18, 27 June 2018.

16 ISBA/25/C/WP.1, draft regulation 13(4)(e).

17 ISBA/19/C/17, regulation 32, annex IV sections 5, 10.

18 ISBA/19/C/17, regulation 28.

TABLE 1 Selected environmental tasks and requirements involved in DSM and selected corresponding legal provisions.

	Environmental tasks for ISA contractors	Selected legal references
Exploration phase		
1	Create environmental baseline	ISBA/19/C/17, regulations 18, 31, annex IV sec. 5 ISBA/25/LTC/6/Rev.1, paras. 8, 11, annex I para 2 1994 Implementing Agreement, annex sec. 1(7)
2	Provide methods to monitor and evaluate environmental impacts	UNCLOS, articles 204, 206 ISBA/19/C/17, regulations 31(6), 32 ISBA/25/LTC/6/Rev.1, paras. 8, 11, annex I para 2
3	Conduct EIA for particular exploration work	UNCLOS, article 206 ISBA/19/C/17, regulation 18(b), 31(6) ISBA/25/LTC/6/Rev.1, para. 8, annex I para 2
4	Provide data for regional management	ISBA/25/LTC/6/Rev.1, paras. 15, 16, annex I para 2
5	Establish procedures to demonstrate no serious harm from exploration work	UNCLOS, article 145 ISBA/19/C/17, regulations 2(2), 31(4), 22, 34(4) ISBA/25/LTC/6/Rev.1, para. 11, annex I para 2
6	Establish preservation and impact reference zones	ISBA/19/C/17, regulation 31(6) ISBA/25/LTC/6/Rev.1, paras. 35, 38(o)
Exploitation phase		
7	Conduct EIA for exploitation work	UNCLOS, article 206 ISBA/25/C/WP.1, draft regulation 3(e), 7(3)(d), 47
8	Monitor impacts before, during, after exploitation	ISBA/27/C/6, para. 40
9	Compare monitoring data with baseline data	/
10	Create an Environmental Management and Monitoring Plan, incl mitigation measures	ISBA/25/C/WP.1, draft regulation 48

When a contractor conducts equipment testing during the exploration stage, or similar activities which require an EIA[22], the LTC has an additional opportunity to review the baseline and assess the quality of the monitoring programfor the testing. From a regulatory perspective, this is a key point at which the contractor must present baseline knowledge 'that would enable an assessment of the potential environmental impact, including, but not restricted to, the impact on biodiversity, of the proposed exploration activities […]'[23]. This presents an important opportunity for the LTC to indicate whether the contractor has conducted sufficient baseline studies and which gaps may need attention.

The EIA process during the exploration stage is problematic (Jaeckel, 2017b, p. 240). The ISA cannot formally accept or reject an EIA during the exploration stage, partly because the EIA occurs *after* the exploration contract has been concluded. Instead, the LTC merely reviews the resulting environmental impact statement (EIS) for 'completeness, accuracy and statistical reliability'[24]. The LTC can then recommend to the Secretary-General whether or not the EIS should be incorporated into the contractor's 5-year program of activities[25]. If the LTC makes a negative recommendation, the contractor needs to amend and resubmit its EIS. It remains unclear whether the LTC's Recommendations will be published in full and whether its recommendations are binding on the Secretary-General. A regulator should assess and approve or reject an EIS to avoid EIAs becoming box-ticking exercises (Jaeckel, 2017b, p. 238) rather than the important environmental management tool they can and should be.

To fully operationalize the EIA and monitoring program, the Mining Code should require contractors to submit to the LTC a comparison of the environmental effects of mining (tests) with the established environmental baseline. This would require full-scale mining tests of sufficient duration to enable a reliable evaluation of impacts to be expected from commercial mining (Singh and Christiansen, 2022, pp. 198, 200). Similarly, for the exploitation phase, it will be important to compare baseline data, pre-mining monitoring data, and monitoring data collected during and after mining to determine the actual impacts caused by mining. While the current draft exploitation regulations do not explicitly include such a requirement, the relevant *Draft guidelines for the preparation of environmental*

19 ISBA/19/C/17, annex IV, sec 11.2.

20 UNCLOS, article 162(2)(l).

21 ISA, Report of the Chair of the Legal and Technical Commission on the work of the Commission at its session in 2017, ISBA/23/C/13, 9 August 2017, para. 15(c).

22 ISBA/19/C/17, annex IV, section 5.2; ISBA/25/LTC/6/Rev.1, para. 33.

23 ISBA/19/C/17, regulation 18(b), see also regulation 32.

24 ISBA/25/LTC/6/Rev.1, para. 41(c).

25 ISBA/25/LTC/6/Rev.1, para. 41(h)-(i).

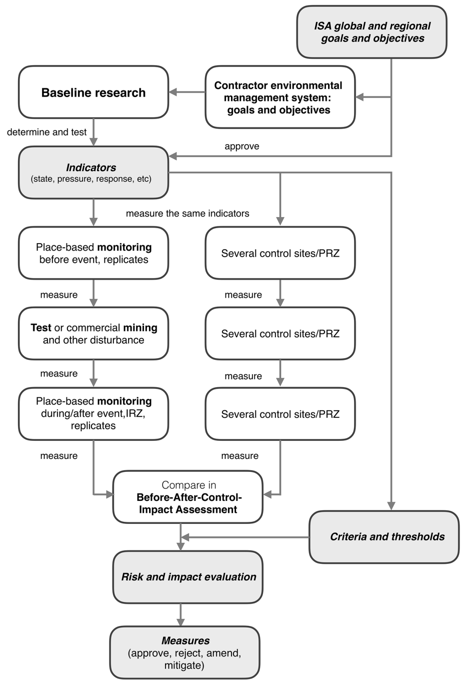

FIGURE 1
Timeline of key environmental management steps for seabed mining.

management and monitoring plans express an expectation that monitoring data will be compared against baseline data.

Legal consequences of inadequate baselines

Failure to establish an adequate environmental baseline can have a range of legal consequences. First, it can ultimately lead to a mining operator having their exploitation application rejected because without a compliant baseline, a plan of work should not meet the required standard of providing for 'effective protection of the Marine Environment'[26].

If little to no baseline data has been shared with the ISA, an application could also be rejected based on draft regulation 7(3)(a) of the draft Exploitation Regulations, which requires an applicant to have submitted baseline and other environmental data from the exploration stage to the ISA. Moreover, in assessing an exploitation application, the applicant's 'previous operating record of responsibility' will likely be taken into account[27]. Hence, any breach of the relevant Exploration Regulations could affect a contractor's chances of obtaining an exploitation contract.

During the exploration stage, there are few consequences for failing to establish adequate baselines. Indeed, the Exploration Regulations lack procedural safeguards to ensure baseline data is submitted (Jaeckel, 2017b, p. 246). While the regulations require contractors to collect baseline data, there are no direct consequences for failing to do so (Ginzky et al., 2020, pp. 6-7). Ultimately, failure to comply with the requirement to establish a baseline, may lead to the contractor losing their preferential or priority option to apply for an exploitation contract in respect of the area in question[28]. Additionally, a lacking baseline is unlikely, though not impossible, to lead to a termination of an exploration contract, which can only occur in rare circumstances[29].

In principle, inadequate baselines could also lead the LTC to voice concerns when reviewing an EIA for test mining or other exploration activities. Though, as noted above, the LTC has no formal power to reject an EIA during exploration phase.

The risk is that as long as there are no agreed quality criteria for an "adequate" or "sufficient" environmental baseline, an inadequate baseline may still satisfy the legal requirements. Thus, the key question is on the basis of what criteria can a baseline be regarded as adequate or robust? The Exploration

26 ISBA/25/C/WP.1, draft regulation 13(4)(e).

27 ISBA/25/C/WP.1, draft regulation 12(4)(c).

28 ISBA/19/C/17, regulation 24(2).

29 ISBA/19/C/17, annex IV sec 21.

Regulations require a baseline which takes into account the LTC's Recommendations for EIA[30]. These Recommendations specify the type of information baselines must include but do not set out criteria for assessing the adequacy of baselines. The section on quality criteria for a robust baseline below seeks to fill this void.

Technical baseline requirements

Existing technical requirements for baselines

The LTC has issued recommendations for building environmental baselines (LTC Recommendations)[31], which while non-binding, carry significant weight within the ISA regime[32]. These already require exploration contractors, inter alia, to characterize all environments likely to be affected by DSM during exploration, mining tests and exploitation[33]. The studies should cover not only all aspects of biodiversity, the physical, chemical, geological, biological and sedimentary properties of the seafloor and the water column[34], but also the background levels of contaminants[35], noise[36], and other anthropogenic pressures[37] prior to any testing or mining, as well as provide an integrated view on ecosystem functioning[38] and genetic connectivity[39]. Temporally, investigations must be continued long enough to describe the natural variability of parameters[40], including prevailing trends, e.g., due to climate change. With the deep-sea environment governed by periodic and episodic long-term cycles, however, the required duration of three years for long-term measurements is unlikely to be sufficient[41]. Spatially, baseline investigations should extend to all parts of the exploration contract area, with a higher intensity of sampling at potential mine or test sites as well as broader reference areas[42]. The latter is required for identifying representative impact reference zones and preservation reference zones, as well as for not impacting larval source areas and connectivity patterns of benthic species and communities in the wider region[43] (Baco et al., 2016). The LTC's Recommendations include over 100 requirements (Bräger et al., 2020) and incorporate sampling methodologies and broad impact indicators for benthic and pelagic habitats, as collated in Table 2[44].

Suggestions for additional technical baseline requirements

While the current LTC Recommendations are a good starting point for establishing environmental baselines, they are incomplete and at times relatively vague, prompting this section to suggests additional requirements for baseline studies in the Area.

Comparability

A baseline offers the comparator against which to assess the effects measured by the monitoring program for a scientific disturbance or testing exercise. Generally, only those parameters measured and recorded during the baseline studies can be compared later, and only when employing comparable methods. Therefore, a baseline investigation requires careful and systematic planning from the start of the exploration period to ensure all parameters that may have to be captured by the monitoring program are already included during baseline investigations. For example, the baseline studies need to identify those species and habitats which are presumed to be particularly vulnerable to mining and might serve as indicators for the environmental state and for the range of mining-related effects.

All contractors exploring the same resource should attain baselines of comparable quality, using the same or directly comparable methods to ensure a level playing field and similar costs (Glover et al., 2016). The LTC recognized such

30 ISBA/19/C/17, regulation 32; ISBA/25/LTC/6/Rev.1.

31 ISBA/25/LTC/6/Rev.1.

32 ISA Standard clauses for exploration contract, ISBA/19/C/17, annex IV section 13.2 (e).

33 ISBA/25/LTC/6/Rev.1, para. 13.

34 ISBA/25/LTC/6/Rev.1, para. 15.

35 ISBA/25/LTC/6/Rev.1, annex I para. 45.

36 ISBA/25/LTC/6/Rev.1, annex I para. 43.

37 ISBA/25/LTC/6/Rev.1, annex I para. 61.

38 ISBA/25/LTC/6/Rev.1, para. 40(b), annex I paras. 29, 41(e), 46, 60.

39 ISBA/25/LTC/6/Rev.1, para. 15(d)(vii), annex I paras. 30, 38.

40 ISBA/25/LTC/6/Rev.1, paras. 15(d)(vi), 15 (f), annex I paras. 21, 29, 46

41 'Temporal variation must be evaluated for at least one test-mining site and the preservation reference zone following the terminology agreed prior to the test-mining activity (ideally, with a minimum of annual sampling over at least three years).' (ISBA/25/LTC/6/Rev.1, annex I para. 46)

42 ISBA/25/LTC/6/Rev.1, para. 38(o), annex I para. 67.

43 ISBA/17/LTC/7, paras. 25, 51, 52.

44 With scientific methods rapidly developing, Table 2 is intended to only provide examples, concentrating on fundamental issues that are unlikely to change soon.

TABLE 2 Selected environmental exploration requirements from ISBA/25/LTC/6/Rev.1 sorted by impact, methodology and habitat. All references are to ISBA/25/LTC/6/Rev.1.

Impact	Benthic habitat	Pelagic habitat
Turbidity	annex I para. 53(b)	para. 15(a)(ii); annex I para. 53(b)
Heavy metals	para. 15(c)(ii); annex I para. 45	para. 15(c)(ii); annex I para. 45
Smothering	para. 40(b(-(d); annex I para. 38	
Interrupted connectivity	para. 15(d)(vii); annex I para. 38	
Discharge plume		annex I para. 42(c)
(Lack of) bioturbation	annex I para. 52	
Methodology	Benthic habitat	Pelagic habitat
Spatial sample distribution	annex I para. 10; annex I para. 38	para. 15(a)(ii); annex I para. 12; annex I para. 21; annex I para. 53(b)

Temporal sample distribution	para. 15(d)(vi);
	annex I para. 41(g);
	annex I para. 46
		annex I para. 21;
		annex I para. 42(c);
		annex I para. 53(b)

Species-specificity & ecology	para. 15(d)(vii);
	para. 38(o);
	para. 40(b)-(d);
	annex I para. 38;
	annex I para. 41(a);
	annex I para. 47
		para. 15(d)(iv);
		para. 15(d)(v);
		para. 15(d)(vii);
		annex I para. 42(c);
		annex I para. 47

Statistical robustness	annex I para. 39	annex I paras. 39, 44
Experimentation	annex I para. 14; annex I para. 45	

standardization of methods as 'extremely important'[45]. Comparable baselines in terms of quality and methodology will allow pooling of contractor data to create regional baselines. This also helps to determine whether faunal uniqueness so far observed at every geographic scale (e.g. Washburn et al., 2021) is real and requires precautionary protection. Regional baselines are required for assessing cumulative effects of multiple projects in regions, providing the basis for a regional management plan[46].

Indicators

Baselines need to identify suitable indicators to be monitored, which could be set at a regional level through regional environmental management plans (REMPs). Suitable indicators need to be informed by the knowledge about the respective environment and by environmental goals and objectives for a particular region. As the latter do not exist in sufficient regional detail for ISA contractors, it is currently not foreseeable that all contractors will work towards the same indicators and proceed with similar monitoring methods and strategies. Furthermore, the indicators identified from the baseline studies, as well as eventual thresholds for deviations from normal, can only be verified with information from small-to-medium-scale test mining yet to take place.

Monitoring of the selected indicators would have to start a long time before any (test-) mining to establish the indicators' representativity and sensitivity to the pressure from test mining. Ideally, the deep-sea ecosystem would need to be investigated and well understood before allowing impacts. Equally undefined is whether the impact monitoring should take place only inside (possibly numerous) Impact Reference Zones (IRZs) and Preservation Reference Zones (PRZs), or whether a wider area needs to be surveyed, e.g., radially and with distance from the mine site, to follow mining-related plumes throughout their impact area on the seafloor and the water column.

Duration

A baseline should study the environment for a defined period of time to facilitate understanding of the long-term effects of DSM. Current knowledge is rather limited, but indicates that processes take place over long to very long (if not geological) time-scales (Jones et al., 2017; McQuaid et al., 2020). Deep ocean ecosystems are subject to large-scale natural

45 ISBA/25/LTC/6/Rev.6, annex I para. 37.

46 ISBA/17/LTC/7, paras. 34, 37, 40, 51; ISBA/25/LTC/6/Rev.1, annex I para. 51

variability (e.g. El Niño Southern Oscillation, a global oceanic-atmospheric phenomenon)[47] and long-term trends (e.g., due to climate change). These need to be identified in the data, including from sediment cores, and incorporated in assumptions on the future development of the relevant aspects of oceanography and ecosystems including, for example, increased vulnerability to other stressors and impacts on ecosystem services (Levin et al., 2020). This requires the monitoring and assessment of time-series of sufficient duration[48] and spatial extent over all habitat types[49] to detect the long cycles and ephemeral events such as eddy formation (Aleynik et al., 2017).

Sample sizes

Baselines must include statistically meaningful sample sizes for biological community metrics such as biomass, abundance, community diversity, structure and composition, and a list of species present in the contract area (Glover et al., 2018). In particular, for benthos sampling, this requires multiple replications in impacted and control areas, covering all size classes of organisms (Glover et al., 2016; O´Hara et al., 2016; Schiaparelli et al., 2016; Jones et al., 2020). Samples taken in a particular environment cannot be used to extrapolate predictions for mining impacts in different environments. This is particularly important given the high percentage of species that are only found at a single site (Washburn et al., 2021, Fig. 13).

Detection of any environmental change with some confidence, e.g., in the abundance of some (or all) species, will depend on the statistical power which again depends on the number of (high-quality) samples collected under standardized conditions[50]. Where the contractor seeks to prove the absence of a significant difference, such as between species densities before and after mining, an even larger sample size may be required. The sample size required to attain sufficient statistical power can be assessed beforehand with a power analysis (Ardron et al., 2019). For benthic fauna at the sea floor, these requirements should be achievable, but in the highly dynamic water column their application for pelagic fauna may prove to be rather challenging though still necessary.

Quality criteria for a robust baseline

In this section, we offer criteria that are designed to help assess the quality of an environmental baseline for DSM. Environmental baseline investigations have to reflect the whole of the *in situ* environmental situation in a contract area. The baseline captures the environmental state at a certain time, taking into account natural variability and change, in order to determine additional change (impact), as a response to mining-related activities (pressure). The ecosystem approach to management best reflects this comprehensive interaction and provides for transparent and stakeholder-inclusive processes including an assessment of the cost of environmental degradation (Elliott et al., 2017; European Commission, 2020).

In the following, we build on the requirements currently included in the LTC Recommendations[51] under nine topic headings (same numbering as in Table 3) and reorganize them to match elements of good environmental management suggested in the scientific literature. Under each topic heading, we indicate the key question which an assessment of the quality of the baseline should address. Within each topic, we articulate criteria that could be used to assess the quality of environmental baseline programs and the data they produce. The criteria are examples only and are not exhaustive. In fact, Table 3 includes additional criteria, which we deem important but are not discussed here for lack of space. These are topics (8) best environmental practice and (9) collaboration and regional integration. The criteria are designed to offer a starting point for assessing the quality of baselines. Table 3 lists the proposed criteria and example actions and indicators and, where applicable, provides links to the literature that elaborates on the relevant criteria as well as to selected ISA documents or other international instruments that encapsulate the relevant criteria. The last column of the Table indicates whether the proposed criteria are sufficiently covered by existing requirements in the ISA's Mining Code, in a preliminary effort to indicate potential gaps in the current Mining Code.

Substantial LTC requirements

Does the baseline comply with existing LTC requirements and provide essential ecosystem information for evaluating change?

As discussed above, current LTC Recommendations provide an extensive list of elements of the ecosystem to be investigated. However, the Recommendations lack specificity with respect to the temporal and spatial scales to be covered for establishing the natural spatial heterogeneity and temporal variability at the seafloor and in the water column. These gaps are addressed in the additional technical considerations outlined above. A robust baseline should follow the current LTC requirements as well as the additional considerations outline above.

47 cf. ISBA/25/LTC/6/Rev.1, annex I para. 39.

48 ISBA/25/LTC/6/Rev.1, annex I paras. 21, 53(b).

49 ISBA/25/LTC/6/Rev.1, annex I paras. 10, 38.

50 cf. ISBA/25/LTC/6/Rev.1, annex I para. 39.

51 ISBA/25/LTC/6/Rev.1.

TABLE 3 Broad governance criteria and indicators for determining good baseline investigation programs and knowledge.

Topics	Criteria	Example actions and indicators	Example scientific references	ISA documents and other legal instruments	Current requirement for baseline
1. Baseline consistent with substantial LTC requirements	Basics to understand the composition, structure and functioning of ecosystems	Coarse scale topographic and resource multi-beam mapping of the whole contract area; Fine scale description (seafloor mapping) and investigations in all areas of interest; Time series measurements, including sediment cores, long enough to identify effect of large scale (e.g. El Nino/La Nina) and long-term trends (i.e. climate change) on ecosystems and predict future development (all aspects of oceanography and ecosystems, incl. ecosystem services); Statistically adequate sampling; Highest possible taxonomic resolution.	(Snelgrove et al., 2014; Swaddling et al., 2016; Volz et al., 2018; Haeckel et al., 2020; Levin et al., 2020)	ISBA/25/LTC/6/Rev.1, paras. 15(d)(i), (vi), annex I para. 25	Many individual requirements, but no comprehensive system
		Life history, feeding types, food web relations, reproduction, respiration, mobility, feed-back loops between biota; Hydrodynamics incl. natural sinking flux of materials and biogeochemistry; Bioturbation, stable isotopes and sediment community oxygen consumption for nodules communities, food webs, stable isotopes, fatty acids and methane and hydrogen sulphide metabolism in sulphides communities, and food webs, stable isotopes and fatty acids in ferromanganese crust communities.	(Snelgrove et al., 2014; Christiansen, 2016; Christiansen et al., 2020; Clark et al., 2020; Haeckel et al., 2020)	ISBA/25/LTC/6/Rev.1 paras. 15(f), (g), (h); ISBA/21/LTC/15, para. 9 (g) annex I, II	Major deficiencies, especially with respect to ecology and foodwebs
		Species, community, and population connectivity.	(Taboada et al., 2018; Dunn et al., 2019; Popova et al., 2019; Yearsley et al., 2020)	ISBA/25/LTC/6/Rev.1, paras. 14, 15(d)(vii), 38, annex I paras. 30, 47; ISBA/21/LTC/15, annex I-III para. 10(h)	Required but not linked to action
		Relate regional productivity, depth, current speed, topographic features, nodule abundance with benthic and benthopelagic community composition (and dynamics).	(Amon et al., 2016; Leitner et al., 2017; Simon-Lledó et al., 2019; Simon-Lledó et al., 2020; Leitner et al., 2021)	ISBA/25/LTC/6/Rev.1, annex I para. 38	No regional long-term synthesis required
		Relate oceanographic patterns and processes with pelagic community composition and development.	(Drazen et al., 2021; Perelman et al., 2021)	ISBA/25/LTC/6/Rev.1, paras. 15(a), 15(d)(iv), annex I paras. 8, 10, 12, 16, 42(c), 53(b).	No regional long-term synthesis required
	Statistically validated results	For biological communities: Benthos: predefined high accuracy sampling schemes (depends on heterogeneity of habitat and abundances of individuals) to provide statistically meaningful sample numbers, sample sizes, and multiple replications in impacted and control areas, covering multiple size classes of organisms; Benthopelagos and Pelagos: sampling grid to represent a) main biotic and abiotic features of the mine site, b) at least three locations representing maximum, medium and minimum particle concentrations from operational and discharge plumes, and c) one or more reference stations. Replications needed; Deepsea fish and scavengers; Megafauna; Birds.	(Christiansen, 2016; O´Hara et al., 2016; Schiaparelli et al., 2016; Ardron et al., 2019; Christiansen et al., 2020; Jones et al., 2020)	ISBA/25/LTC/6/Rev.1, annex I paras. 30-52 ISBA/25/LTC/6/Rev.1, paras. 13, 15 ISBA/25/LTC/6/Rev.1, paras. 15(a), 15(d)(iv), annex I paras. 8, 10, 12, 16, 42(c), 53(b)	Required (criterium for EIS review)

(Continued)

TABLE 3 Continued

Topics	Criteria	Example actions and indicators	Example scientific references	ISA documents and other legal instruments	Current requirement for baseline
	Provides baseline knowledge of biological community metrics	Biomass, abundance, species richness, diversity, water column and seafloor topography, structure and composition; Species, community, and population connectivity; Species and habitats to be protected.	(Swaddling et al., 2016; Ardron et al., 2019; Ardron, 2020)	ISBA/21/LTC/15, annex I- III para. 9(g); ISBA/25/LTC/6/Rev.1, paras. 14, 15(d)(vii), annex I paras. 30, 47; ISBA/21/LTC/15, annex I-III, para. 10(h)	No standard metrics required
	Characterizes the environments likely to be impacted by exploration, or testing	Baseline assesses the dispersal potential for particles and dissolved substances; Full impact areas defined, including buffer zones; Suitable indicator organisms or processes identified for monitoring mining effects	(Aleynik et al., 2017; Gillard et al., 2019; Baeye et al., 2021; Muñoz-Royo et al., 2021)	ISBA/25/LTC/6/Rev.1, paras. 14, 15(a)(ii), (iv), (v), annex paras. 20-21 (ISA, 2017, p. 20)	No definition of impact and impacted area
		Establishes background levels of heavy metals in sediments, water column and interface.	(Mestre et al., 2017)	ISBA/25/LTC/6/Rev.1, paras. 15(b), 15(c)(ii), 40(f), annex I paras. 14, 28, 45	Required
		Establishes background levels of ambient noise, light (here bioluminescence), litter, and other pressures.		ISBA/25/LTC/6/Rev.1, paras. 13, 14, annex para. 51 (only noise)	Only noise
	Documents the avoidance of serious harm	Demonstrate that there is no serious environmental harm from any activities being conducted on the seabed, in mid-water, and in the upper water column.	(Levin et al., 2016)	ISBA/25/LTC/6/Rev.1, annex I, paras. 2, 65	Required but no criteria for checking
2. Baseline established with highest standards	Baseline programme makes a clear statement of objectives	Project-specific objectives, including environmental objectives, identified and embedded into goals and objectives of respective region and globally; Objectives, incl. for PRZ and IRZ, inform sampling design; High level of precaution to account for deficiencies in knowledge.	(Sullivan et al., 2006; Clark et al., 2016b; O´Hara et al., 2016; Swaddling et al., 2016; Van Dover et al., 2016; Jones et al., 2020)	ISBA/21/LTC/15 para. 6 (plan of work, PoW), annex I-III para 9(a) (monitoring); ISBA/17/LTC/7, para. 41(a) as part of ISO 14001	Only general objectives in PoW
	Baseline programme operates with a conceptual model	Model provides e.g. for a framework for characterizing environment, making predictions, and testing hypotheses.	(Clark et al., 2016b; O´Hara et al., 2016)	ISBA/25/LTC/6/Rev.1/, annex I para. 65 speaks of a plan of the contractor reviewed by LTC	Not required
	Desktop review of scientific literature provides basis for field studies	Characterizes all environments likely to be impacted by mining-related activities; Includes all topics named in LTC Recommendations (physical oceanography, geology, chemistry/geochemistry, sediment properties, bioturbation and sedimentation, and biological communities); For biological communities: reports on the likely vulnerability, temporal and spatial scale of certain species, communities, ecosystem processes to mining-related impacts.	(Durden et al., 2017; Clark, 2019)	ISBA/25/LTC/6/Rev.1, paras. 13-18	Desktop study not required as a starting point
	Systematic design of field surveys	Systematic investigation and monitoring concept from the start, including: Specification of aims, design and plan for spatial and temporal execution of multidisciplinary research; All ecosystem elements possibly affected by mining are covered; Data collection to cover the entire water column and the seafloor in appropriate spread and repetition over sufficient periods to measure natural variability; Use of high-resolution seafloor maps to plan biological sampling,	(Glover et al., 2016; O´Hara et al., 2016; Schiaparelli et al., 2016; Swaddling et al., 2016; Durden et al., 2017; Glover et al., 2018; Jones et al., 2019)	ISBA/25/LTC/6/Rev.1, paras. 13, 14, 15(d)(vi), 15(f), annex I paras. 8, 10, 12, 18, 21, 29-32, 37, 38, 46, 53(b)	Many individual requirements, but no comprehensive systematic design

(Continued)

TABLE 3 Continued

Topics	Criteria	Example actions and indicators	Example scientific references	ISA documents and other legal instruments	Current requirement for baseline
		Standardised sample processing and analysis.			
	Best scientific methods	Independent and replicate samples for any combination of space, time, habitat, and gradient to estimate variability between samples/groups of samples. Higher variability requires more replicates; Gear-type and deployment standardized between surveys, and documented in detailed protocol; The sampling methods are suitable for measuring the reported parameter, including sufficient sample size, and as specified in LTC Recommendations.	(Underwood, 1994; Underwood and Chapman, 2003; Underwood and Chapman, 2005; Clark et al., 2016b; Stocks et al., 2016)	ISBA/25/LTC/6/Rev.1, para. 15(d), annex I paras. 8 (speaks of a 'stratified random sampling programme'), 30, 37, 45. ISBA/25/LTC/6/Rev.1, annex I paras. 39-41	Required but no criteria for checking
	Data presented are complete, and representative	Complete means no sampling data are excluded from analysis, plausibility check, and no null data. Metadata are provided with the data; Representative means that the variability of environment and biota is captured and higher heterogeneity is sampled with an increased spatial resolution.	(Stocks et al., 2016, p. 370)	ISBA/25/LTC/6/Rev.1, paras. 15(d)(ii), 20-21	Required but no criteria for checking
	Conclusions are supported by statistical rigour and sound logic for analysis and interpretation	Variability and confidence limits are essential information to validate all analyses; Power and effect size of statistical analysis should be disclosed; Adequacy and uncertainties of interpretation described.	(Underwood and Chapman, 2003; Underwood and Chapman, 2005; Jones et al., 2020)	ISBA/25/LTC/6/Rev.1, paras. 14, 15(d)(ii), annex I paras. 39-40; ISBA/21/LTC/15, annex I-III para. 10(d)	Required but no criteria for checking
	Reporting delivers documentation of methods, results, and conclusions;	Uncertainties and knowledge gaps in baseline specified; Where relevant, differences in scientific understanding acknowledged; Research plan identifies how to address gaps.	(Gerber and Grogan, 2020)	ISBA/21/LTC/15, Annex I-III para. 10(e) (gaps with regard to plan of work)	Required but only formal gap analysis
	Results published and peer reviewed	Mandatory publication of results as reports or peer-reviewed literature.		ISBA/21/LTC/15, Annex I-III, para. 17(a) (list of publications), environmental data included in ISA database	Not required
3.Baseline informs Reference Zones	Baseline provides data for the identification of one or more PRZ and IRZ (in the likely path of mining effects in the test or mine site)	Baseline enables spatial planning of contract area, incl. PRZ and IRZ location; All reference zones are within the contract area; Baseline documents that PRZ are truly representative of the mined area (IRZ) and justifies that it will not be affected by mining over the progressing mining period; Baseline determines and justifies the size, number and locations(s) of PRZ and size of buffer zones; Baseline determines necessary number and size of IRZ along the gradient of environmental effects of each contractor's activities, such as from testing or mining, on the seafloor and the water column.	(Underwood, 1994; Underwood and Chapman, 2003; Underwood and Chapman, 2005; Billett et al., 2019; Haeckel et al., 2020; Jones et al., 2020) (Underwood, 1994; Underwood and Chapman, 2003; Underwood and Chapman, 2005; Billett et al., 2019; Haeckel et al., 2020; Jones et al., 2020)	ISBA/25/LTC/6/Rev.1, para. 38(o); ISBA/17/LTC/7, para. 41 (c-e) (ISA, 2017; ISA, 2018)	No contractor guidance as to positioning, number, size, permanence etc.
4. Baseline informs a comprehensive monitoring programme	State-of-the-art monitoring methodology developed based on baseline results	Monitoring programme is in line with ISA LTC Regulations, Recommendations and standards and guidelines; Methods and parameters are verified, standardised and regularly updated; Sampling strategies are adequate:	(Zampoukas et al., 2013; Haeckel et al., 2020; Jones et al., 2020)	ISBA/19/C/17, reg. 32; ISBA/25/LTC/6/Rev.1, paras. 2, 8, 11, 35-37, annex I paras. 65, 65; ISBA/21/LTC/15, annex I-III paras. 9(d), 10(e), 10(g), 10(h) (ISA, 2017, p. 35)	No clear criteria for monitoring programme, no link to indicator development

(Continued)

TABLE 3 Continued

Topics	Criteria	Example actions and indicators	Example scientific references	ISA documents and other legal instruments	Current requirement for baseline
		To measure a comprehensive set of parameters which reliably detect effects from activities; In fit-for-purpose locations, periodicity, intensity and methods; To link with project-scale and regional assessments; To detect impacts in time and space and provide statistically defensible data; To establish the whole impact area from a test or mining event, including beyond the contract area; To apply the precautionary principle; Contractors must consider variance and statistical power in IRZ and PRZ monitoring.			
	Baseline provides the basis for identifying and justifying indicators	The chosen environmental indicators are based on longer term measurements and are: Anticipatory to provide an early warning of deterioration; Biologically important, applicable and indicative over space and time; Scientifically sound and measurable and quantifiable over space and time; Sensitive to different levels of harm, including serious harm from pressures and responsive to management; Socially relevant and interpretable by stakeholders. Reference points are determined for the chosen indicators from which to measure: Pressure, environmental state and change; Progress towards environmental targets; The effectiveness of measures.	(Rice and Rochet, 2005; Elliott, 2011; Zampoukas et al., 2013)	ISBA/25/LTC/6/Rev.1, annex I para. 41(e) speaks of the integration of metabolites information into the analysis of taxonomic and function gene diversity provides additional quantitative indicators of ecosystem functions (and services)'.	No requirement to determine and justify indicators
	Baseline indicates preliminary precautionary thresholds to avoid harm;	Baseline research justifies appropriateness of indicators and preliminary thresholds (desktop review or experimental); Baseline shows iterative improvement of appropriate threshold type (ecological tipping points, management) and level (normal/ precautionary/limit).	(Groffman et al., 2006; Levin et al., 2016; Tunnicliffe et al., 2020)	Not required during exploration, but should have been developed until prior exploitation EIA[52]	Not required
5. Baseline Informs environmental impact assessment[54]	Baseline includes results of mining tests	Test design adequate for conclusions on type, scale, duration of impacts; Full impact area known and sampled along environmental gradient; Cumulative impacts, e.g. from additive or synergistic sources considered.	(Clark, 2019; Jones et al., 2019)	ISBA/25/LTC/6/Rev.1, para. 13	Tests not required
	Data enable environmental risk assessment	Sensitivities of biota and communities identified; Vulnerability to mining-related hazards identified.	(O et al., 2015; Hauton et al., 2017; Mestre et al., 2017; Kaikkonen et al., 2018; Cormier and Londsdale, 2020)		Not required

(Continued)

TABLE 3 Continued

Topics	Criteria	Example actions and indicators	Example scientific references	ISA documents and other legal instruments	Current requirement for baseline
	Data enable reliable environmental impact predictions	Environmental and technical information and data Enable a reliable prediction of changes and harm to be expected under commercial mining conditions; Estimate recovery times; Ascertain that the plan of work does not induce serious harm.	(Durden et al., 2018; Jones et al., 2020)	ISBA/25/LTC/6/Rev.1, para. 13, annex I, paras 2, 29, 30, 64; ISBA/21/LTC/15, annex I-III para. 10(f)	No comprehensive requirements
	Numerical models	Models are validated by field studies; Models to support prediction of environmental impact, e.g. predictive habitat mapping, plume modelling, toxic effects; Models to assess extinction risks under various management strategies, including various options for the design of protected areas; Modelling undertaken, collaboratively where possible, and linked closely to field studies.	(O´Hara et al., 2016, p. 389; Jones et al., 2020)	ISBA/25/LTC/6/Rev.1, annex I paras. 21, 56, 61	Required
6. Baseline demonstrates good governance	Baseline reflects a precautionary approach	Sources of uncertainty are identified, reduced, acknowledged, quantified, managed, and communicated; Where there are uncertainties, precautionary buffers are to be applied; Conservative estimates to err on the side of caution.	(Underwood and Chapman, 2003; Van Dover et al., 2016, p. 423; Durden et al., 2018; Clark, 2019; Clark et al., 2020; Hyman et al., 2022, p. 607)	Seabed Disputes Chamber, 2011, paras. 125-135; ISBA/25/LTC/6/Rev.1, only annex III (EIS template); ISBA/21/LTC/15, annex I-III, para. 10(e) (only formally with respect to PoW goals); ISBA/17/LTC/7, para. 13 (b)	Not mentioned
	Baseline results are communicated transparently	Results published and/or reviewed by experts in a transparent process: External experts consulted; Effective stakeholder interface is operational; Adjacent coastal States and contractors have been informed of the ongoing activities.	(Van Dover et al., 2016, p. 423; Jones et al., 2020)		Not required for exploration
	Respects measures of other bodies	Identifies and maps existing and planned spatial measures such as marine protected areas, EBSAs and closures for vulnerable marine ecosystems.	(Van Dover et al., 2018; Johnson, 2019; Jones et al., 2020)	ISBA/17/LTC/7, paras. 12, 36(b) (only tasks ISA as a whole in Clarion Clipperton Zone)	Not required from contractors
7. Contractor Environmental management system (EMS)	EMS is established and operational	Each contractor should have an environmental managem ent unit, responsible for the tasks below; Each organization to establish its environmental objectives and targets in line with e.g. ISO14001.	(Swaddling et al., 2016; Durden et al., 2017; Komaki and Fluharty, 2020)	ISBA/27/C/7, para. 14; ISBA/21/LTC/15 para. 6; ISBA/17/LTC/7, para. 41(a) creation of site-specific EMP; ISO 14001:2015 on environmental management[55]; the European Union Eco-Management and Audit Scheme[56]	Only project management required during exploration
	EMS provides for advanced data and information management	Data archival and retrieval system to enable exchange with researchers, regulator, other contractors and reporting.	(Stocks et al., 2016)	ISBA/25/LTC/6/Rev.1, paras. 15(d) (viii), 19-24, annex I paras. 26, 32 (a), (e) 33, 34, 36, 41(a), 54, 55	Required, but no standard procedures
	EMS provides for quality control procedures	Follow best available methodology and the use of an international quality system and certified operations and laboratories; Standard procedures, chain of custody for site identification and sample tracking, taxonomic standardization, sample preservation and archival, and suitable analytical detection limits; Types of data to be collected, the frequency of collection and the analytical techniques should follow the use of an international quality system and certified operation and laboratories.	(Stocks et al., 2016, p. 375)	ISBA/25/LTC/6/Rev.1, para. 19, annex I paras. 31, 32, 47, 54, 55-56.	Required, but no standard procedures determined

(Continued)

TABLE 3 Continued

Topics	Criteria	Example actions and indicators	Example scientific references	ISA documents and other legal instruments	Current requirement for baseline
	EMS ensures best environmental and research practices and techniques are employed	Apply state-of-the-art research standards, Best Environmental Practice, Good Industry Practice, and Best Available Techniques; Avoid research practices which disturb or compromise sites, populations, or processes and aim to collaborate; Provide for independent auditing.	(Devey et al., 2007; OSPAR Commission, 2008; Clark et al., 2016a; Clark et al., 2016b; Swaddling et al., 2016; Gerber and Grogan, 2020)	ISBA/25/LTC/6/Rev.1, annex I para. 54; ISBA/17/LTC/7, para. 38(a); (see also general obligation in ISBA/25/C/WP.1, draft reg 46(2)(b))	Framework or reference for application needed
	EMS provides for transparent public reporting	Assessed and interpreted results are reported; Environmental management activities are made public, e.g. on website; Contractor publishes the environmental sections of its annual and periodic review reports to the ISA.	(Komaki and Fluharty, 2020)	ISBA/25/LTC/6/Rev.1, paras. 24-27, annex I para. 54; ISBA/21/LTC/15, annex I-III paras. 17(a), (b); ISBA/17/LTC/7, paras. 13(f), 41(b)	Transparent reporting required, but not enforced
	EMS provides for adaptive management cycle	Mechanisms available for e.g. designating and relocating preservation/no mining areas and developing Best Environmental Practice	(Durden et al., 2017; Craik, 2020; Gerber and Grogan, 2020; Jones et al., 2020)		Not required
8. Baseline informs Best Environmental Practice	Data suitable to ensure that mine plan and mining practices protect the environment	Baseline provides for spatial planning of the contract area; Baseline establishes relevant data for the selection and design of test and mine sites; Baseline informs Best Environmental Practice.	(Gerber and Grogan, 2020; Haeckel et al., 2020)	ISBA/25/LTC/6/Rev.1, para. 38(l) (no requirement to take account of biotic environment when locating test/mine site)	Not required
	Mine sites do not comprise habitats or species in need of protection	Identifies vulnerable species and habitats in potential mining areas, including in impact areas due to plume dispersal; Identifies whether potential mine sites include unique, rare or threatened habitat or species.	(Ardron et al., 2014; Watling and Auster, 2017; Wagner et al., 2020; Watling and Auster, 2021; Gollner et al., 2021)	(CBD, 2009; FAO, 2009; CBD, 2012)	Not required
9. Baseline collaboration and regional integration	Collaboration with independent research or other contractors	Partnership with scientific community or relevant scientific body; Partnership with other contractors; Respect the PRZ of other contractors; Cooperate to ensure permanent protection of PRZs from mining impacts.	(Van Dover et al., 2016, p. 412; Haeckel et al., 2020)	ISBA/25/LTC/6/Rev.1/, annex I paras. 54, 57-63; ISBA/21/LTC/15, para. 14; ISBA/17/LTC/7, paras. 40, 41(e).	Encouraged
	Data integration	Methodologies are standardised to enable regional assessments, incl. inter-contractor comparisons and compilation of experiences, i.e. a greater database to predict the effects of large-scale disturbance such as from commercial mining of minerals; cumulative impact assessment in related REMP; development of best practices through ISA.	(Jones et al., 2017; Billett et al., 2019; Haeckel et al., 2020)	ISBA/25/LTC/6/Rev.1, para. 15(d); annex I paras. 55-56; ISBA/17/LTC/7, paras. 49-52 (ISA tasks)	Well covered but optional

The Table collates suggestions from the literature as well as existing ISA requirements and recommendations.

Highest standards

Do the reported baseline investigations demonstrate best available scientific information and process?

Applying 'Best Available Techniques'[57] and 'Best Environmental Practices'[58] in protecting the marine environment are general obligations of the ISA, sponsoring States and contractors[59] and Best Environmental Practices are also considered part of the sponsoring state's due diligence[60]. The draft exploitation regulations also introduce a different terminology, requiring environmental decision-making to integrate 'Best Available

57 Defined in ISBA/25/C/WP.1, schedule 1 as: 'the latest stage of development, and state-of- the-art processes, of facilities or of methods of operation that indicate the practical suitability of a particular measure for the prevention, reduction and control of pollution and the protection of the Marine Environment from the harmful effects of Exploitation activities, taking into account the guidance set out in the applicable Guidelines'.

Scientific Evidence'[61], 'including all risk assessments and management undertaken in connection with environmental assessments, and the management and response measures taken under or in accordance with Best Environmental Practices'[62].

As the combination of these terms suggests, it is important for baselines to focus not only on the outcome (the baseline data), but also on the scientific processes to achieve the outcome, including clearly stated research objectives, good experimental design, robust methods, and peer review of results. The limits of the conclusions, uncertainties and knowledge as well as underlying values should be disclosed and discussed, and ideally confirmed or dismissed by independent review to allow for transparent environmental decision-making (Sullivan et al., 2006). Unless such limitations are clearly stated, the predictive value of ecological modelling may be much overstated and provide a false basis for assessing the environmental impacts of mining (Bowden et al., 2021). Therefore, independent expert review and the standardization of procedures and criteria for decision-making on environmental matters are important (Sullivan et al., 2006; Lallier and Maes, 2016). At present, environmental baseline data are not subject to a mandatory review by experts or the public. The LTC may consult external experts when reviewing an EIA, which should include baseline data, and may 'encourage' the sponsoring state to seek views from stakeholders on the EIA[63]. Stakeholder review and independent scientific review should become mandatory under the future exploitation regulations[64], although it is too early to say.

Best practice for deep-sea biological study methods, including cruise and sampling design as well as data management, are compiled by Clark et al. (2016a); Swaddling et al. (2016), and Glover et al. (2016). All research programs should focus on producing best scientific knowledge, and to proceed from a desktop review of the state of research to formulating hypotheses and operational objectives for the research program. This requires defining the survey design, extent of the survey area, ecosystems to be investigated, necessary sampling gear, and of course the required time and human effort (Swaddling et al., 2016).

Reference zones

Do the baseline studies appropriately inform and justify the selection of impact and preservation reference zones?

Baseline investigations have to inform the selection of impact and preservation reference zones in terms of their location, size, number and representativeness. These PRZ and IRZ form part of the before-after-control-impact (BACI) design (Green, 1979; Underwood, 1994; Stewart-Oaten & Bence, 2001; Urban et al., 2021, and articles therein), which, if applied correctly, enables an assessment of environmental impacts in defined places. As Figure 2 illustrates, baselines are the basis for the BACI design as they determine the natural situation prior to the start of activities. Representative impact and control/reference sites are used for long-term monitoring of the impacts. The ISA's Mining Code already implies a BACI design by requiring (1) baselines, (2) Preservation Reference Zones, (PRZ), (3) Impact Reference Zones (IRZ), and (4) monitoring. In order to operationalize these requirements and fulfill the BACI design, robust baselines are thus essential.

Similarly, in order for BACI to be successful and function as a comparison with impacted sites, the PRZs have to be comparable to the IRZ in all respects except for the impact of the activities. This comparability requires them to be located at similar depth and within the same biogeographic zone, include an equivalent size and density distribution of nodules featuring the same habitat composition and housing self-sustaining populations of the entire species assemblage (McQuaid et al., 2020; Stratmann et al., 2021; Washburn et al., 2021). In other words, the baseline investigations have to demonstrate that the PRZs are truly representative of the IRZ. The IRZ should be located along the gradient of environmental disturbance expected to occur from testing or mining (Billett et al., 2019; Jones et al., 2020) to determine the footprint of biologically relevant mining effects beyond the immediate mine site, i.e. the sediment load, concentration and toxicity of the plumes near the seabed and in the water column, but also vibrations, noise, light and other artificial disturbances. Based on dispersal studies, the baseline data will also have to justify that the PRZ will not be affected by mining and indicate the buffer zones required.

59 See e.g. ISBA/25/C/WP.1, draft regulation 44; see also ISBA/25/LTC/6/Rev.1, annex I para. 54.

60 *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*, Seabed Disputes Chamber of the International Tribunal for the Law of the Sea (case No 17), 17 February 2011, para. 136.

61 Defined in ISBA/25/C/WP.1, schedule 1 as: 'the best scientific information and data accessible and attainable that, in the particular circumstances, is of good quality and is objective, within reasonable technical and economic constraints, and is based on internationally recognized scientific practices, standards, technologies and methodologies'.

62 ISBA/25/C/WP.1, draft regulation 44.

63 ISBA/25/LTC/6/Rev.1, para. 41(c), (d).

64 ISA, Facilitator draft - Draft regulations on exploitation of mineral resources in the Area: Parts IV and VI and related Annexes, ISBA/27/C/IWG/ENV/CRP.1, 8 February 2022, draft regulation 46bis(4).

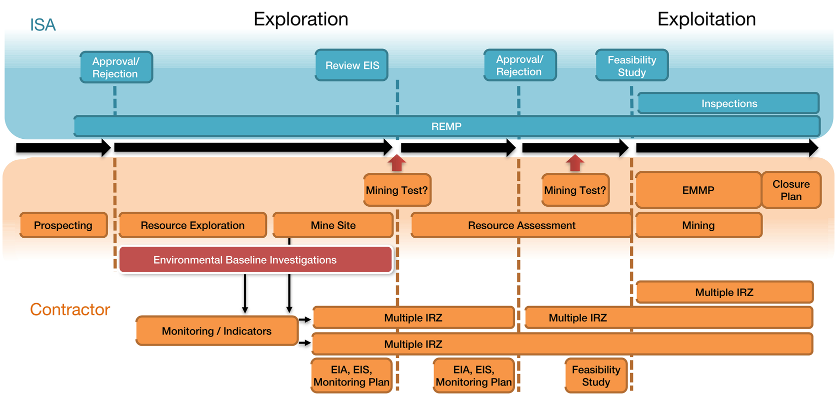

FIGURE 2
The key role of baseline research for environmental management by the ISA.

Monitoring program

Do the baseline studies deliver the necessary knowledge to inform a comprehensive monitoring scheme, including the determination and testing of indicators, their metrics and also thresholds?

Contractors have to monitor the environmental effects of their exploration activities[65]. The monitoring program will have to measure a selected set of most significant indicators[66] as derived from the baseline investigation to allow for temporal and spatial comparisons and help to communicate the results (Elliott, 2011). Figure 2 highlights that baseline investigations during the exploration phase are (1) the crucial first step to determine monitoring sites and suitable indicators, (2) start an iterative process to develop measurable thresholds for harm and serious harm, and (3) inform impact assessment.

An effective monitoring and management strategy will to a large extent also depend on the understanding of the environmental drivers of the variability and patterns in ecosystem processes and functions, biota diversity, dominance and relative abundance of certain taxa as well as community patterns across the microscale to regional gradients in topography, bathymetric and oceanographic variables (Snelgrove et al., 2014). On the seafloor, topographic features, from shallow depressions and slight depth gradients to abyssal hills and seamounts, have a strong influence on the type of substrate, its organic content and hence also community composition. The density of nodule cover of the sedimentary plains is an important habitat factor for the benthic fauna (Amon et al., 2016; Simon-Lledó et al., 2019) as well as for the abundance and community composition of top-level benthopelagic predators and scavengers (Leitner et al., 2017; Simon-Lledó et al., 2020). At regional scale, in the Clarion-Clipperton Zone a decreasing north-south and east-west pelagic productivity in conjunction with increasing water depth results in changed community compositions and lower abundances (Simon-Lledó et al., 2020). Other variables include bottom current speed and direction. When planning a monitoring program, care has to be taken to consider multiple factors for ensuring that the locations of impact and control sites are comparable.

To assist the development of a monitoring program, a qualitative, so-called Level 1 risk assessment could be carried out at the beginning of the exploration phase to identify the most critical issues to be investigated (Clark, 2019, p. 461 and literature cited). To enable quantitative risk and impact assessments and the development of measures, the formulation of indicators and other monitoring parameters has to be SMART[67], and they should be (Elliott, 2011):

a. anticipatory to provide an early warning of deterioration;
b. biologically important, applicable and indicative over space and time;
c. scientifically sound and measurable and quantifiable over space and time;
d. sensitive to pressures and responsive to management; and
e. socially relevant and interpretable by stakeholders.

65 ISBA/19/C/17, regulation 32; ISBA/25/LTC/6/Rev.1.

66 An indicator is a parameter, or a combination of parameters, chosen to represent (indicate) a certain situation or aspect and to simplify a complex reality, see (Zampoukas et al., 2013).

67 SMART stands for specific, measurable, achievable, realistic, and time-bound; see e.g. (Rice et al., 2005).

However, some elements that are important for the monitoring program have yet to be decided, such as the definition of 'serious harm' (Levin et al., 2016). It is agreed that seabed mining must provide for effective environmental protection and not cause serious harm[68] but it remains unclear how the ISA will determine whether this threshold is reached or crossed. For example, it has to be considered how rare species could be represented, and what the role of rare species is when determining the level of harm (Chapman et al., 2018). Comparable to fishing (Jennings and Dulvy, 2005), for each indicator an unexploited reference point as well as a precautionary limit (harm) and a limit (risk of serious harm beyond which operations are to be stopped) will have to be determined. In other words, the baseline investigations have to determine which indicators should be sampled for the monitoring program (Rice and Rochet, 2005) to be able to compare them later on.

EIA

Are the baseline studies suitable to inform a prior EIA of commercial mining with a degree confidence?

Any mining-related changes in the environment, as monitored in the area impacted by mining during and after the operations take place, will have to be assessed against what would be the "normal" environmental state. This is the major task of environmental baseline investigations, which have to provide reliable information on the natural spatial and temporal patterns of ecological community development and interaction. Due to the long-term patterns of climate oscillations and trends, these baseline parameters may have to be investigated over a long time period, i.e. throughout the exploration period. In addition, the baseline studies must provide the contractor and the regulator with a first set of possible indicators and thresholds which will enable the measurement and monitoring of the effects of mining. Most importantly, together with well-designed testing, monitoring and impact assessment of the tests, the baseline should enable the contractor to make accurate predictions on the degree of environmental harm to be expected.

Based on real data, modelling can further extend the temporal and spatial understanding of environmental interaction. For example, McQuaid et al. (2020) used data on topography, particle flux to the seafloor and nodule abundance as a proxy to classify and predict the regional distribution of habitats and associated biological communities across the Clarion-Clipperton Zone. For the same region, Wedding et al. (2013) offered modelling to support the establishment of APEIs. Similarly, Uhlenkott et al. (2020) modelled the predictive distribution of meiofauna communities on the scale of a contract area. The classification, if ground-truthed and refined for each contract area, will help to establish representative preservation reference zones as control sites when monitoring the effects of mining activities. However, Bowden et al. (2021) caution that the predictive value of habitat models is usually more limited than extrapolation from photographic seabed identification, because uncertainties of modeled variables cannot be quantified. This includes, for example, the certainty of taxonomic identification, the lack of some ecologically important variables that influence distributions, the lack of confirmed absence data for most taxa, and modeling at a rather coarse taxonomic resolution. For this reason, the LTC also requires contractors to confirm photographic species identification by collection and permanent storage of specimens[69]. Overconfidence in modelling, and underestimation of uncertainties is likely to result in poor decision-making (Regan et al., 2005; Bowden et al., 2021).

Environmental baseline studies, where possible undertaken collaboratively with researchers and other contractors, will feed conceptual and numerical models which can assist in the prediction of at least some aspects of environmental harm from commercial mining operations, although upscaling (i.e., extrapolation beyond the period or area measured) is a contentious issue and needs detailed verification. Overall, the environmental baseline studies should provide as much certainty (sensu Clark, 2019, p. 460) as possible about the environmental effects of permitting a mining operation to take place, so that decision-making can be best informed.

Good governance

Do the baseline studies reflect good governance principles, such as transparency and participation?

As the international seabed is the common heritage of humankind, contractors should be required to implement good governance in their baseline investigations. This is somewhat separate from the call on the ISA as a whole to follow good governance practices, an ambition for which the ISA has been found lacking (Ardron, 2018; Ardron, 2020; Woody and Halper, 2022). Good governance is generally understood to include at a minimum transparency, open communication, and stakeholder involvement in decision-making processes (Ardron, 2020). In the context of DSM, precautionary management of the seabed may be added to the list, as a direct obligation of contractors (and the ISA and states)[70]. Implementing the precautionary principle includes acknowledging uncertainties, risks, and knowledge gaps and seeking to close them (Jaeckel, 2017a). In fact, baseline investigations offer a

68 UNCLOS, article 145; ISBA/19/C/17, regulation 33.

69 ISBA/25/LTC/6/Rev.1, annex I para. 41(a).

prime opportunity to address and reduce uncertainties in line with the precautionary principle.

As outline above, baseline data should be subject to expert review. To that end, contractors' annual reviews should be published on the ISA website, which will also support transparent reporting and compliance. Similarly, EIAs by contractors should provide for early and meaningful stakeholder participation, including an opportunity to review the baseline data that informs the EIA. Lastly, an open and transparent dialogue between contractors and the LTC will help guide contractors during their baseline studies and have positive side effects on the governance structure of the ISA as a whole.

Contractor environmental management system

Does the contractor manage its baseline investigations, analysis and reporting in a dedicated environmental management unit or system?

An environmental management system (EMS) as a company-internal quality control system has been recommended by the International Marine Minerals Society and supported by the World Bank (Durden et al., 2017). The value of EMS is explicitly recognized in the environmental management plan for the Clarion-Clipperton Zone, though only as a non-binding management objective[71]. That plan requires contractors to follow Standard ISO 14001,[72] which includes establishing a process for public consultation and making all efforts to limit and control the environmental effects of the contractor's DSM activities, as well as seeking continuous performance improvements.

Essential elements of a contractor-led EMS include the establishment of environmental objectives and targets in line with ISA and states' global and regional goals and strategies (Tunnicliffe et al., 2020), an effective data and information management system (Stocks et al., 2016), including quality control (Stocks et al., 2016), development and implementation of best environmental practice and best available techniques (Clark et al., 2016b; Swaddling et al., 2016; Gerber and Grogan, 2020), as well as ensuring fit-for-purpose reporting and adaptive management of activities (Durden et al., 2017; Komaki and Fluharty, 2020). Moreover, baseline data should be published in (open access) peer-reviewed literature to ensure its quality has been independently verified, and the data is stored in an open, accessible, and safe manner, can contribute to capacity building, and is accessible for scientists and contractors conducting regional or connectivity studies.

70 ISBA/19/C/17, regulation 31(2); *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*, Seabed Disputes Chamber of the International Tribunal for the Law of the Sea (case No 17), 17 February 2011.

71 ISBA/17/LTC/7, paras. 40-41.

72 ISO 14001 is the international standard for environmental management systems (EMS), accompanied by ISO 14004 Environmental Management Systems – General Guidelines on principles, systems and support techniques. Available from the website of the International Organization for Standardization at: http://www.iso14000-iso14001-environmental-management.com/.

Conclusion

While improvements have been made, there continues to be a lack of environmental baselines for deep ocean sites that are being eyed for mineral mining (Amon et al., 2022). In fact, the LTC has repeatedly called on contractors 'to include in the annual reports a review of how the baseline data are building up to a level sufficient to support a robust environmental impact assessment'[73]. This paper is designed to help with such a review by demonstrating the key role of baselines as the foundation for assessing and managing the environmental impacts of DSM. We set out criteria for evaluating the quality of a baseline in Table 3 and the corresponding text, which could be further refined by the LTC. These criteria are compiled from peer-reviewed literature and build upon existing ISA requirements. The criteria are designed to ensure contractors, sponsoring States, the ISA, and the public can evaluate the quality of baselines ahead of any formal environmental impact assessments, which will increase confidence in the decision-making process for both current and future generations. This is arguably especially important in light of the minerals on the international seabed being the common heritage of humankind[74].

At present, there are no publicly available criteria for the ISA's Legal and Technical Commission to evaluate the quality of a contractor's environmental baseline. The criteria set out in this paper seek to address that gap and could inform the ISA's future exploitation regulations:

1. Specifically, the future exploitation regulations should require the BACI approach and the ISA should specify in detail the data and information required from baseline studies and the procedures to be complied with, including those for a reliable and replicable application the BACI approach for assessing mining impacts.

73 ISA, Report of the Chair of the Legal and Technical Commission on the work of the Commission at the second part of its twenty-sixth session, ISBA/26/C/12/Add.1, 25 September 2020, para. 14; See also ISA, Report of the Chair of the Legal and Technical Commission on the work of the Commission at the second part of its twenty-fifth session ISBA/25/C/19/Add.1, 11 July 2019.

2. Moreover, a compulsory test mining stage would greatly increase the information available to contractors, the ISA, states, and the public in order to assess and discuss the impacts of DSM.
3. Lastly, a standardized methodology, statistical robustness and (public) transparency should be critical parameters to help characterize a high-quality baseline.

The criteria set out in this paper will support precautionary management of DSM by contributing to a meaningful assessment of the risks and impacts of DSM. The criteria will also help to achieve the aim articulated by the Seabed Disputes Chamber, namely the 'uniform application of the highest standards of protection of the marine environment'[75].

75 *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*, Seabed Disputes Chamber of the International Tribunal for the Law of the Sea (case No 17), 17 February 2011, para. 159.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

All authors conceived the manuscript and all authors provided input on all sections and participated in the editing and final preparation of the manuscript. SC conceived and created the list of criteria for evaluating baselines (see Table 3).

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Conflict of interest

For information, SB was employed at the ISA Secretariat as Scientific Affairs Officer from 2013 to 2018, which we do not consider posing a 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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