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The current status of environmental requirements for deep seabed mining issued by the International Seabed Authority

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ABSTRACT

Up to September 2018, the International Seabed Authority has issued a total of 100 mandatory requirements (published between 2011 and 2015) as guidance for potential future miners when collecting data for their environmental baseline studies during the exploration phase. An in-depth analysis of all current requirements highlights twelve themes covered by multiple requirements: methodology for seabed sampling, methodology for water column sampling, statistical evidence, spatio-temporal considerations, toxicology, modelling needs, genetic studies, species-specificity, documentation and archival storage, impact-related studies, area-based management tools, and comparison and assessment. Within each theme, the relevant requirements are compared with each other to allow a comprehensive assessment of the research effort needed to satisfy all of the 100 requirements.

1. Introduction

There appears to be no example where a solid, statistically robust environmental baseline study has proven to be adequate to assess completely novel environmental impacts of anthropogenic activities on land. This reality becomes worse when dealing with aquatic environments such as lakes and coastal areas under national jurisdiction. The problem becomes critical, however, when dealing with the deep ocean beyond national jurisdiction. Currently, we are on the verge of carrying out a large-scale experiment of mining deep-sea minerals that constitute the common heritage of humankind located in areas beyond national jurisdiction, called simply "the Area". The main problem at the moment is the lack of enforcement of environmental regulations and the lack of data for a proper environmental impact assessment. In the Area, we are confronted with poorly understood ecosystems, pitifully sampled with at times only a single point-source sample for every 1000 km^2.

The International Seabed Authority (ISA) was created in 1996 based on Part XI of UNCLOS (1982, and its Implementation Agreement of 1994), with the dual purpose of organizing and controlling activities in the Area (Article 157), i.e. to regulate the extraction of mineral resources in areas beyond national jurisdiction as well as the protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment, especially from harmful effects of such activities as drilling, dredging, excavation, disposal of waste and other sources (Article 145). Protection and conservation are required as the Area and its resources are the Common Heritage of Mankind and thus belong to all humanity, including future generations. Therefore, the ISA has to function as the guardian of the Common Heritage of Mankind. To do so, the Authority has to take the necessary measures to ensure effective protection of the marine environment from harmful effects which may arise from anthropogenic activities by adopting appropriate rules, regulations and procedures (Article 145).

In practice, any member state or company interested in pursuing deep seabed mining (also known as a contractor seeking exploitation) has to commit to a lengthy period of exploration (usually for 15 years). During this period, "the Contractor shall, in accordance with the Regulations, gather environmental baseline data as exploration activities progress and develop and shall establish environmental baselines against which to assess the likely effects of the Contractor's activities on the marine environment." (as stated in the Standard Clauses for an Exploration Contract, Section 5.3). These environmental baseline data are intended to serve as the basis for the environmental impact assessment (EIA) that the contractor has to perform before applying for a mining permit, and thus constitutes one of the main tools to warrant the protection and conservation of natural resources. Equally important, the combined environmental baseline data of the contractors should also serve as the basis for region-wide Strategic Environmental

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Assessments (SEA; e.g., ISBA/17/LTC/7, para. 51, and ISBA/19/LTC/8, para. 16). Such assessments are needed to account for cumulative impacts not only of all mining activities in the region, but also of additional anthropogenic impacts such as from pollution or climate change [1–3].

In several documents, the Legal and Technical Commission (LTC) of the ISA has issued minimum requirements for the environmental baseline studies of contractors. These requirements are at times provided for each mineral separately but more frequently identical for all three minerals currently considered for exploitation (polymetallic nodules, polymetallic sulphides, and cobalt-rich ferromanganese crusts). According to Regulation 32 of the exploration regulations for nodules (ISBA/19/C/17) on 'environmental baselines and monitoring' (paragraph 1), "each contract shall require the contractor to gather environmental baseline data and to establish environmental baselines, taking into account any recommendations issued by the Legal and Technical Commission … against which to assess the likely effects of its programme of activities under the plan of work for exploration on the marine environment and a programme to monitor and report on such effects", thus making the environmental requirements of the LTC binding to contractors. Regulation 34 for sulphides and crusts (ISBA/16/A/12/Rev.1 and ISBA/18/A/11, respectively) provides the same binding text for the other two minerals.

In this article we describe and analyse the coverage of environmental regulations that are mandatory for all contractors to fulfill their obligations regarding environmental baseline studies. The aim of this exercise is twofold, a) to document the variables that are mandatory to study, and b) to provide a reference to the scientific community when evaluating environmental impact assessments that are likely to be submitted to the Authority in the near future. For these purposes, we compile all environmental baseline requirements in a single document, structure them according to minerals and habitats, and finally discuss the possible implications for contractors and humankind. In addition to making these requirements more accessible and drawing attention to ISA's past achievements, this paper aims at facilitating their observance in future EIAs as well as in any revision of relevant ISA documents.

2. Relevant documents

Between 2010 and 2013, the Assembly of the ISA adopted fundamental regulations on prospecting and exploration of three marine mineral resources, the Regulations on Prospecting and Exploration for Polymetallic Nodules [PMN] (ISBA/19/C/17 and ISBA/19/A/9), for Polymetallic Sulphides [PMS] (ISBA/16/A/12/Rev.1), and for Cobalt-rich Ferromanganese Crusts [CFC] (ISBA/18/A/11). The regulations contain underlying environmental requirements. As far as the environment is concerned, the requirements in these four documents are rather basic and will not be dealt with in the following. For non-environmental guidance (not dealt with here), the LTC has issued additional documents such as ISBA/19/LTC/14 for training programmes or ISBA/21/LTC/11 for reporting exploration expenditure.

Between 2011 and 2015, the LTC issued three documents that provide detailed guidance to the contractors for their collection of environmental baseline data:

1. *Environmental Management Plan for the Clarion-Clipperton Zone* (**ISBA/17/LTC/7**)
2. *Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area* (**ISBA/19/LTC/8**)
3. *Recommendations for the guidance of contractors on the content, format and structure of annual reports* (**ISBA/21/LTC/15**)

Combined, these three documents contain the requirements for contractors when collecting data for their environmental baselines. The first document is the only regional EMP adopted, so far, for the CCFZ in the Pacific Ocean between Hawai'i and Mexico. The second document (ISBA/19/LTC/8), however, contains the majority of these dispersed over 32 pages. Moreover, the document contains an 'Explanatory commentary' and a 'Glossary of technical terms' as two annexes that facilitate understanding the intention of the mandatory recommendations. All paragraphs in each of the ISBA documents are numbered consecutively, and these numbers will be used in the following to highlight environmental requirements.

The explanatory commentary in Annex I of ISBA/19/LTC/8 also provides a useful categorization (in para. 7): "Baseline data requirements include seven categories: physical oceanography, geology, chemistry/geochemistry, biological communities, sediment properties, bioturbation and sedimentation." In the following paragraphs, these categories are somewhat rearranged, but the breadth of environmental studies required is well explained, and readers are referred to Annex I for additional explanation.

Furthermore, the majority of environmental requirements is valid for the exploration of all three minerals. Due to the specificity of the deep-sea habitat involved (abyssal plains, hydrothermal vent systems, and seamounts), several requirements are only valid for one or two specific mineral ores.

3. Results

A careful analysis of the three documents mentioned above provided a list of 100 environmental requirements (listed in chronological order in Table 1; supplementary material online). Not all 100 environmental requirements are applicable to all three minerals, however, as indicated under applicability in Table 1. Eighty-two requirements apply to Polymetallic Nodule environments, 83 to Polymetallic Massive Sulphide environments, and 80 to Cobalt-rich Ferromanganese Crust environments. Furthermore, requirements can be characterized according to the environmental topic they relate to, either physical (20 requirements), chemical (21), sedimentological/geological (22), biological (55) or any combination of these four topics. The predominant focus on biological topics may reflect the LTC's concern about the living component of the Common Heritage of Mankind, of which the vast majority of species is still completely unknown to science [4,5].

Beyond the two categorizations mentioned above, it appears noteworthy to analyse how frequently certain areas of concern (here called 'Thematic Themes') are highlighted in the requirements. Not every requirement speaks to one of the themes identified here, but – on the other hand – several relate to more than one. In Table 1, we identified twelve themes that are described in detail below. The original wording of the requirements (as numbered in Table 1) was used, where possible, while emphasizing relevant parts.

3.1. Methodology for seabed sampling

In environmental studies, comparable results can only be achieved with the use of highly specialized methods and/or standardized instrumentation. Moreover, the quality of scientific data depends on the proper use of certain techniques. Therefore, it comes as no surprise that the LTC issues methodological requirements – 63 in total. A few of them are highlighted as examples in the following:

Standardization of methodology and reporting of the results is extremely important for all minerals (see Requirement no. 64 in Table 1). Contractors should follow the best available methodology and of an international quality system and certified operation and laboratories (Requirement no. 41). Collection and analytical techniques follow best practices (Requirement no. 87). PMN contractors in the CCFZ are required to apply the principles of ISO 14001-33 (Requirement no. 1). The ISO 14001 defines criteria for an environmental management system. For all minerals, contractors need to identify relevant species and assess temporal variability in sightings of marine mammals, near-surface turtles and fish schools as well as bird aggregations

(Requirement no. 20). Properly studied, this may require special surveys using line-transect sampling and passive acoustic monitoring – methods commonly used in other marine extractive industries –, particularly for intended mining of high acoustic intensity on biologically productive seamounts.

In PMS and CFC contract areas, fauna should be collected using precision sampling by either remotely operated vehicles or submersibles (Requirements no. 34, no. 40 and no. 67). Especially less abundant but potentially key megafauna, such as fish, should be analysed based on video and photographic transects – with species identification confirmed by collection (Requirements no. 37, no. 39 and no. 68). Identification and enumeration of biological samples from all mineral resource areas should be complemented not only by molecular but also by isotopic analyses in specialized laboratories (Requirement no. 62). Rates of bioturbation (i.e. the mixing of sediments by organisms) must be measured to analyse the importance of biological activity prior to a mining disturbance and can be evaluated from profiles of excess Pb-210 activity from cores (Requirement no. 79). For sulphide deposits, hydrothermal vent areas should be classified as either dormant vent sites or extinct sites (Requirement no. 83). Contractors are requested to provide information on bioturbation (PMN), food webs (PMS and CFC), stable isotopes, fatty acids (PMS and CFC) and sediment community oxygen consumption (PMN) (Requirements no. 90, no. 91 and no. 92).

3.2. Methodology for water column sampling

Although mining takes place at the seabed, the water column above is also likely to be impacted and thus has to be studied in detail. "The characterization of pelagic and benthic communities should be carried out within all subhabitats that may be impacted by mining operations" (Requirement no. 58). Therefore, "the environmental studies to be conducted during exploration will include the monitoring of environmental parameters so as to confirm the findings that there is no serious environmental harm from any activities being conducted on the seabed, in mid-water and in the upper water column" (Requirement no. 85). Out of the 100 requirements, 24 speak to studying the water column and pelagic biota – all relevant for all three mineral types.

Because oxygen-minimum zones vary in size regionally and to some extent seasonally, environmental studies should determine the depth range of the oxygen-minimum layer in each test-mining area (Requirement no. 26). Information on changes in the behaviour of the fauna at and below the discharge plume is to be provided (Requirement no. 28). At the proposed depth of the discharge plume, measurements of the currents and particulate matter are required to predict the behaviour of the discharge plume and to assess natural particle loads in the water (Requirement no. 46). Measurements of currents only at the sea surface and/or the seabed are unlikely to be sufficient. Measurements of water properties in the vertical plane should be no more than 100 m apart. The resolution should be greater in high-gradient regions (e.g. to locate and quantify the boundaries of oxygen-minimum zones) (Requirement no. 48).

The study of plankton communities, especially gelatinous plankton, over a wide depth range may be indispensable when a sediment plume is to be released into the water column (Requirement no. 74). Ultra-fine particles might adhere to gelatinous plankton and flocculate. Plankton collection with a net in the uppermost 300 m may not be sufficient. Measurements should be made of phytoplankton composition, biomass and production, zooplankton composition and biomass, and bacterial plankton biomass and productivity. Temporal variation of the plankton community in the upper surface waters on seasonal and inter-annual scales should be studied.

3.3. Statistical evidence

With the burden of proof resting on the contractor, each contractor is obliged to collect sufficient data to be able to quantify reliably the magnitude of any mining-related impact. To show the existence or non-existence of non-negligible changes will depend on comparisons (e.g., before vs. after or control site vs. impact site) that require sufficient statistical power to be able to provide statistically significant results. Sixteen requirements relate to the proper use of statistics.

The contractor is requested to provide: An assessment of statistical robustness/power, taking into account sample sizes, sample number and, for biological communities, the abundance of individual species (with evidence for statistical significance) (Requirement no. 93). Metadata that detail the analytical techniques, error analyses, descriptions of failures, techniques and technologies to avoid, comments on sufficiency of data and other relevant descriptors should be included with the actual data (Requirement no. 42). For parameters without significant horizontal gradients, the determination of baseline ranges (e.g. means and standard deviations) is adequate. For parameters with significant spatial structure (gradients, extremes), the sampling resolution must allow the physical oceanographic structure of the area to be characterized (Requirement no. 48). Geographic Information System mapping tools are recommended for planning stratified random sampling programmes (Requirement no. 59). Biological samples from PMN claim areas must be large enough to generate good sample sizes in terms of abundance and biomass for robust statistical analyses (Requirement no. 66).

3.4. Spatio-temporal considerations

The documentation of species distributions and their connectivity, as well as the achievement of statistically significant results requires a reasonable density of data in space and time. Thirty-five requirements impose lower limits in the spatial and temporal extent of investigations.

The contractor should establish at least one station within each habitat type or region, as appropriate, to evaluate temporal variations in water column and seabed communities (Requirement no. 21). The presence of key taxa should be mapped and their position relative to potential mining locations assessed to a radius of 10 km from the proposed PMS mine site (Requirement no. 32). Abundance and coverage of the dominant taxa in each PMS subhabitat should be determined (Requirement no. 35). Abundance, percentage cover and diversity of megafauna should be based initially on at least four transects in a CFC contract area. These transects should extend from the flat sea floor 100 m or more from the base of the seamount, along the slope of the seamount and across its summit (Requirement no. 37). The number and location of oceanographic moorings need to be appropriate for the size of the area to adequately characterize the current regime, with station spacing not exceeding 50 km. The suggested location of the lowest meter should be as close as possible to the sea floor, normally 1–3 m. The location of the upper current meter should exceed the highest element of the topography by a factor of 1.2–2. Along with this, the basic levels of the current meters should be 10 m, 20 m, 50 m, 100 m and 200 m above the seabed (Requirement no. 47). Vertical profiles and temporal variation also need to be addressed in the field measurement programme (Requirement no. 51). Dispersal potential must be assessed over timescales that range from the tidal frequencies to the largest of these environmental-impact timescales (Requirement no. 53). An assessment of the dispersal potential in the deep ocean generally requires long-term monitoring.

The baseline data of biological communities is targeted to collect data on natural communities, including natural spatial and temporal variability (Requirement no. 57). This variability depends on natural mortality, among other factors, especially in long-lived species such as some corals and sponges. The characterization of pelagic and benthic communities should be carried out within all subhabitats that may be impacted by mining operations (Requirement no. 58). Temporal variation must be evaluated for at least one test-mining site and the preservation reference site prior to the test-mining activity (ideally, with a minimum of annual sampling over at least three years) (Requirement no. 76). Data should include samples from the immediate test area before and after test mining, from selected distances away from the mined area to determine the effect of the benthic plume, and at repeated intervals after test mining (Requirement no. 78). It is recommended that deployment of moorings with sediment traps on a mooring line be undertaken, with one trap below 2000 m to characterize the particulate flux from the euphotic zone and one trap approximately 500 m above the sea floor to characterize the flux of materials reaching the sea floor. Sediment traps should be installed for a suitable period of time, with samples collected monthly to examine seasonal changes in flux and to evaluate inter-annual variability, in particular between climatic event years (e.g. El Niño, La Niña) (Requirement no. 80). The contractor is requested to provide an examination of ecosystem recovery from natural and anthropogenic disturbances (Requirements no. 95, no. 96, and no. 97). Such recovery may take decades to centuries.

3.5. Toxicology

Substances released either from the rocks/sediment during deep seabed mining or from anthropogenic sources into the water column may prove to be toxic under high pressure. Eleven requirements relate to the analysis of toxicity.

The contractor should collect information on heavy metals and trace elements that may be released during mining and their concentrations (Requirements no. 10, no. 11, no. 12, and no. 19). Furthermore, the contractor should determine what additional chemicals may be released in the discharge plume following processing of the resource (Requirement no. 13). Any chemicals added to separate the mineral phases from the waste material and water need to be assessed for potential harmful effects (Requirement no. 44). Levels of metals found in dominant benthic fauna subjected to resettled sediment from the operational and discharge plumes should be determined (Requirement no. 29). Trace metals and potential toxic elements should be assessed in muscle and target organs of dominant demersal fish and invertebrate species. This should be replicated over time before test-mining operations begin (to measure natural variability) and thereafter at least annually to monitor possible changes resulting from test-mining activity. A combination of monitoring and shipboard and laboratory experimentation may be necessary to resolve, prior to test mining, potential ecotoxicological impacts, including possible impacts on phytoplankton and zooplankton if the discharge plume occurs at the sea surface or in mid-water (Requirement no. 75).

3.6. Modelling needs

The spatial extent of most mining-related impacts will depend on the prevailing system of currents at any given depth. Detailed long-term measurements can be used to model the distribution, for example, of plumes of various particle size fractions and with different output concentrations. At the same time, these models may forecast the dispersion of accidental spills (six requirements in total).

At the proposed depth of the discharge plume, measurements of the currents and particulate matter are required to predict the behaviour of the discharge plume and to assess natural particle loads in the water (Requirement no. 46). To complete an assessment of the dispersal potential in a PMS habitat, a three-dimensional hydrodynamic numerical model that covers the temporal and spatial scales important for dispersal must be constructed (Requirement no. 54). After validation, the numerical model should be used to investigate potential scenarios, such as to estimate the potential impact of accidental spills or for certain extreme cases (Requirement no. 55). Knowledge of in situ settling velocities for test-mining discharge particles, both in mid-water and near the sea floor, will help to verify and improve the capacity of mathematical models for predicting the dispersion of the mid-water and benthic plumes (Requirement no. 80). High-resolution, high-quality bathymetric data should be collected for the area where the dispersal of test-mining by-products is expected to significantly affect the environment (i.e. over the entire region covered by the numerical circulation model) (Requirement no. 81).

3.7. Genetic studies

Some requirements with biological aspects – such as those relating to population connectivity – cannot be fulfilled easily without the use of molecular methods which is why six requirements relate to the collection and analysis of genetic data.

The contractor should assess regional distribution of species and genetic connectivity of key species (Requirement no. 22). Identification and enumeration of samples should be complemented by molecular analyses (Requirement no. 62). Because the populations of fauna of some deposits will be subsets of meta-populations that interact through dispersal and colonization, it is important to know the degree of isolation of populations occupying the mineral deposits that are to be removed and whether a given population serves as a critical brood stock for other populations (Requirement no. 65). Classical and molecular taxonomy must be supported, either directly by the contractor or as part of cooperative research programmes. Molecular sequences should be deposited in Genbank or equivalent internationally recognized sequence databases (Requirement no. 77).

3.8. Species-specificity

Any EIA will require knowledge of species-specific information such as densities and abundances or connectivity of species. Higher-level taxonomic data are unlikely to provide sufficient resolution, which is why 22 requirements request species-specific information.

The contractor is requested to provide the abundance of individual species (with evidence for statistical significance) (Requirement no. 93). It will be important for all taxonomic groups to be assessed at each site. Taxonomy by numbers (e.g. species 1, species 2), if consistent rules are used and vouchers maintained, is a good basis for baseline studies, but classical and molecular taxonomy must be supported (Requirement no. 77). Species-abundance and species-biomass matrices should be standard products wherever practical (Requirement no. 62). Specimens must be archived for comparison with taxonomic identifications from other sites and to understand the details of changes in the composition of species over time (Requirement no. 63).

3.9. Documentation and archival storage

The samples collected by contractors during exploration are essential evidence for the status of their contract area and for the quality of their baseline studies. Therefore, not only type specimens of newly described species have to be archived, but rather all animals collected as well as water samples and sediment cores amongst others. This theme also includes the documentation required in peer-reviewed scientific publications, for example. Seventeen requirements relate to this theme.

Collections should be photo-documented (and indexed to video imaging) in situ to provide an archive of context/setting information for each sample (Requirement no. 23). Specimens must be archived (Requirement no. 63). Data and information that are necessary for the formulation by the Authority of rules, regulations and procedures concerning protection and preservation of the marine environment and safety should be made freely available for scientific analysis no later than four years after the completion of a cruise (Requirement no. 42). An inventory of the data holdings from each contractor should be accessible on the World Wide Web (Requirements no. 42 and no. 87). To allow for later analysis of additional parameters, water samples suitable for analysis of dissolved and particulate matter should be collected and archived in a repository accessible for future study (Requirement no.

50). Representative pre-test-mining cores and sediment samples should be collected and archived (Requirements no. 56 and no. 82). Colour photographic documentation of organisms should be obtained whenever possible (organisms in situ and/or fresh material on deck to document natural colouration). The photographs should be archived (Requirement no. 60). The contractor is requested to provide a list of relevant publications in peer-reviewed journals published during the reporting year (Requirement no. 100).

3.10. Impact-related studies

Since the environmental baseline data are intended to serve as the basis for the contractor's EIA (as outlined in the Introduction), several requirements specifically target such potential impacts (18 in total).

PMN Contractors will include in their environmental management plans specific measures that will maximize the potential for the recovery of biota impacted by their activities in the Clarion-Clipperton Fracture Zone (Requirement no. 3). The contractor is to provide the following information after the performance of a specific activity: Abundance and diversity of benthic communities and changes in behaviour of key species subjected to smothering by sedimentation; changes in the distribution, abundance and diversity of benthic communities in the mining area, including rates of recolonization; possible changes in the benthic communities in adjacent areas not expected to be perturbed by the activity, including the operational and discharge plumes; changes in the characteristics of the water at the level of the discharge plume during the mining test, and changes in the behaviour of the fauna at and below the discharge plume (Requirement no. 28).

A plan of work for exploration should include activities that address the following environmental requirements: (a) Establish an environmental baseline study against which to compare both natural change and impacts caused by mining activities; (b) Provide methods to monitor and evaluate the impacts of deep seabed mining on the marine environment; (c) Provide data for an environmental impact assessment required for an exploitation contract for marine minerals in the Area; (d) Provide data for the regional management of resource exploration and exploitation, the conservation of biodiversity and the recolonization of areas affected by deep seabed mining; (e) Establish procedures to demonstrate no serious harm to the environment from exploration for marine minerals (Requirement no. 43). The contractor should set-up and validate a numerical circulation model that covers the temporal and spatial scales important for dispersal, and carry out experiments, e.g. to investigate the potential impact of accidental spills (Requirement no. 52). Spatial variation in the biological community must be evaluated prior to test mining by sampling at least three mineral deposits in the Area, each separated by a distance greater than the projected deposition of 90 per cent of the particles suspended by the mining operation (Requirement no. 65). Information on faunal succession following test mining is essential to determining recovery rates of benthic populations from the effects of mining (Requirement no. 78).

3.11. Area-based management tools

Seven requirements relate to the establishment of area-based management tools such as defining 'Impact Reference Zones' and 'Preservation (or Control) Reference Zones' that will allow a proper quantification of impacts while accounting for natural processes at the same time.

A plan of work for exploration should provide data for an environmental impact assessment required for an exploitation contract for marine minerals in the Area, including the designation of impact reference zones and preservation reference zones (Requirement no. 43). In the CCFZ, contractors will provide in their environmental management plans the designation of the required impact and preservation reference zones for the primary purposes of ensuring preservation and facilitating monitoring of biological communities impacted by mining activities. Impact reference zones should be designated to be within the seabed claim area actually mined. Preservation reference zones should be designated to include some occurrence of polymetallic nodules in order to be as ecologically similar as possible to the impact zone, and to be removed from potential mining impacts (Requirement no. 2). The impact reference area should be representative of the site to be mined in terms of environmental characteristics and the biota. The preservation reference area should be carefully located and large enough not to be affected by mining activities, including the effects from operational and discharge plumes. The reference site will be important in identifying natural variations in environmental conditions. Its species composition should be comparable to that of the mining area (Requirement no. 27).

During the mining tests, the notification of proposed impact reference zones and preservation reference zones is recommended. The impact reference zone should be selected based on the area being representative of the environmental characteristics, including the biota, of the site where test mining will take place. The preservation reference zone should be carefully located and be large enough so as not to be affected by the natural variations of local environmental conditions. The zone should have species composition comparable to that of the test area. The preservation reference zone should be outside the test area and areas influenced by the plume (Requirement no. 86). The characterization of pelagic and benthic communities should be carried out within all subhabitats that may be impacted by mining operations and to determine the regional distributions for the creation of preservation reference areas and for mitigation strategies to promote the natural recolonization of areas affected by mining activities (Requirement no. 58). Temporal variation must be evaluated for at least one test-mining site and the preservation reference site prior to the test-mining activity (ideally, with a minimum of annual sampling over at least three years) (Requirement no. 76).

3.12. Comparison and assessment

The environmental baselines by definition need to be assessed and compared. Thirteen requirements relate to such obligations.

The contractor is requested to provide an interpretation of the findings, including comparisons with published data from other studies (Requirement no. 89). Standardization should include instruments and equipment; quality assurance in general; sample collection; treatment and preservation techniques; determination methods and quality control on board vessels; analytical methods and quality control in laboratories; and data processing and reporting. Method standardization will allow for comparison of results across provinces and lead to selection of critical parameters for monitoring efforts (Requirement no. 64). With regard to activities that do require environmental impact assessment, a monitoring programme is needed before, during and after a specific activity to determine the effects of the activity on the biological activities, including the recolonization of the disturbed areas (Requirement no. 84). Overall conservation strategies need to take into account non-test-mining impacts on faunal communities (Requirement no. 88). The contractor is requested to provide a gap analysis and future strategy to achieve the goals of the five-year programme of activities and the requirements (Requirement no. 94). The contractor is requested to provide an evaluation of the advantages and disadvantages of different sampling and analysis methods, including quality control (Requirement no. 98). The contractor is requested to provide a comparison of environmental results in similar areas to understand species ranges and dispersal on the scale of ocean basins (Requirement no. 99).

4. Discussion

The Law of the Sea provides for the obligation to protect and preserve the marine environment as well as for the protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment (UNCLOS Art.

192 and 145, respectively). To administer deep seabed mining, the ISA has provided guidance to potential miners. The 100 requirements listed in Table 1 represent the guidance provided by the LTC, so far, to contractors on the cardinal elements of an environmental baseline study, the results of which form an integral part of any EIA. Guided by the ecosystem approach, the requirements cover not only the seabed to be mined and its benthic organisms, but also the entire water column above it and the organisms depending on these (e.g., bird aggregations). In light of the large proportion of undescribed deep-sea species as well as the novel character and magnitude of potential deep seabed mining impacts, this approach appears to be to some degree precautionary. We have chosen arbitrarily twelve themes to demonstrate the scope of these environmental requirements.

Any state or company with a contract to explore (or exploit) the mineral resources of the Area needs to follow best environmental practices and utilize the best available methodology, including advanced methods such as precision sampling by remotely operated vehicles or autonomous underwater vehicles, molecular and isotopic analysis, analysis of Pb-210 activity for bioturbation, laboratory experimentation to resolve potential eco-toxicological impacts, and specialized line-transect surveys and/or static acoustic monitoring for marine mammals [6] and other large vertebrates. The methods may be costly in ship-time and equipment, but without this knowledge, assessment of the potential environmental impact of deep seabed mining will not be adequate.

Depending on the parameter to be measured, the three-dimensional sampling scheme for the water column can be dense, requiring a multitude of physical, chemical and biological sampling before, during and after an impacting activity. The body of water that needs to be monitored may be extensive due to the volatile nature of any sediment plume. Plankton sampling, including sampling of extremely delicate gelatinous plankton, will be important especially at the proposed depth of the discharge plume and below covering all seasons as well as cyclical multi-year events such as ENSO. At this point, the sensitivity of benthopelagic and pelagic plankton species to sediment load and toxics may still need to be evaluated.

Any use of environmental baseline data will require robust statistical analysis, which will largely depend on sufficient sample sizes depending on the scale of natural variation. The application of statistical robustness also becomes evident in the requirements for reference zones (see below). Since the absence of evidence (i.e. statistical proof) is not the evidence of absence (e.g. of an impact), contractors will need to aim for high statistical power to prove the absence (or negligible magnitude) of an impact. Considering that abundances of some (pelagic) organisms may be cyclical whereas others (benthic) may be rare, the sampling scheme will also require a temporal extent over several years.

Spatio-temporal considerations require covering natural spatial and temporal variability, including all habitat types, in general, as well as all sub-habitats that may be impacted. Depending on the mineral resource in question, biological sampling may be required to assess key taxa to a radius of 10 km around the PMS mine site or along at least four detailed transects from the seafloor to the top of the seamount (for CFC). Moored current meters need to probe – ideally for a duration of three years – at least the 200 m above the seabed and may not be spaced more than 50 km apart. Sediment traps and other measurements of particle flux are needed at similar densities as well as higher up in the water column. The required studies of changes in behaviour of (potentially) impacted organisms also have an extensive temporal component. Last but not least, the contractor is required to examine ecosystem recovery from anthropogenic disturbances, which is likely to take decades (possibly even centuries) as far as studies of the man-made disturbances of the past forty years have shown [7–12].

The toxicity of heavy metals and trace elements may change significantly with ambient pressure, which necessitates the thorough study of naturally occurring chemicals (but normally fixed in the mineral or in the sediment) as well as introduced chemicals [13]. Such toxicological studies also require complex experimentation with living organisms under pressure. Furthermore, metal contents in organ tissues of dominant demersal fish and invertebrate species need to be quantified for several years before and after mining.

Three-dimensional hydrodynamic numerical models are indispensable to predict the dispersion of any plume through time and space. Such models, however, require large amounts of high-resolution data of current velocities, sediment characteristics (e.g., settling velocities) and the ambient bathymetry probably over an area of – at least – several hundred square kilometers.

The necessity for molecular studies goes hand in hand with the need for species-specificity, as only genetic tools may be able to identify in a timely manner the vast majority of deep-sea species that is still unknown to science. Furthermore, some of the key questions for ecosystem recovery relating to population connectivity can be studied practically only with molecular methods [14].

Species-abundance and species-biomass matrices for individual species are expected as a good basis for baseline studies. All taxonomic groups should be assessed at each site and specimens should be archived to make taxonomic identifications verifiable. This level of detail is needed to understand changes in species composition, e.g., due to a mining impact. To achieve this for a few characteristic species only will not be sufficient, however, as it is likely to be the rare species that will be most impacted, e.g., because they are ecologically more sensitive to environmental impacts or because they are K-selected and/or apex predators [15]. At this point, it is unclear, how any loss of species richness (i.e. biodiversity) could be monitored without all taxa being surveyed and quantified at species-level.

The provisions for archiving include water samples, sediment cores, and specimens as well as photographs and contextual information. These materials are expected to be stored in accessible repositories, inventoried online, and – if possible – results should be published in peer-reviewed scientific journals. This process will ensure verifiability of the findings and transparency in any EIA [16]. For that reason, the ISA Secretariat has been asked repeatedly by the Assembly and Council to publish the environmental data of contractors, and a databank is being developed for these purposes.

The only area-based management tools mentioned in the environmental requirements are the so-called Impact Reference Zones and Preservation Reference Zones, which every contractor has to designate within the contract area either during test-mining or before applying for an exploitation permit. The identification of suitable areas for reference zones will necessitate a detailed and long-term study of large parts of the contract area as well as a long-term plan for the location of future mine sites within the contract area so as not to interfere with reference zones from past or future activities. The function of Preservation Reference Zones may not be entirely clear yet, but by having to remain un-impacted by mining activities, it may well serve both as a control area for an EIA as well as a source area for natural recolonization of affected areas. The creation of an environmental baseline before the impact and regular monitoring of impact and control (aka. preservation) reference zones supports the intention of using a BACI (before-after-control-impact) design for the EIA [17–19].

The intended use of a BACI design also explains the amount of detail required by the LTC from contractors. The reference areas are supposed to be ecologically similar to the intended mining site, i.e., representative in terms of environmental characteristic and the biota. The Preservation Reference Zone is required to be large enough not to be affected by mining activities or by natural variations of local environmental conditions, and its species composition has to be comparable of the mining area (before it is affected). This arrangement will allow the monitoring of natural developments in the absence of mining impacts during the lifetime of the mine as long as the Preservation Reference Zone is large enough to accommodate sustainable populations over decades. These reference zones will also be ideal to study long-term recovery after closure of the mine.

4.1. Future discussions

The aim of this article is to describe and analyse the coverage of the current environmental regulations issued by the ISA to regulate deep-sea mineral exploration. The twelve themes were chosen to illustrate the complexity of the regulations and the amount of detail that is expected to be delivered by contractors during their environmental baseline studies. We are aware, however, that a multitude of questions might arise from this collation and welcome their public discussion.

We purposefully did not attempt to discuss the completeness and sufficiency of the requirements in context with either scientific advice on deep-sea sampling and standardization [20], or their comprehensiveness and usefulness for later EIAs, and whether or not procedural requirements are in place to provide for an assessment of the contractors' data.

Furthermore, what is the probability of the 100 requirements to provide for a holistic approach to a successful EIA and what are the practical implications? Could there be alternative environmental baselines that are meaningful for decades or centuries and on various spatial scales? And how can the sufficiency and adequacy of contractors' data be ensured to serve jointly for the regional SEA and cumulative studies required? How are the best available methodologies for standardization determined, and what are the practical implications (e.g., a standard monitoring programme)? Does the adaptive management of environmental requirements mean that improved requirements become binding to older contracts as well [21]? Does the extreme difficulty of studying the most sensitive deep-sea organisms in situ make a zero-emission target for toxics not more practical? What are "measures that will maximize the potential for the recovery of biota impacted" (Requirement no. 3) and "procedures to demonstrate no serious harm to the environment from exploration for marine minerals" (Requirement no. 43; also in combination with Requirements no. 78, 85, 95–97)? What kind of long-term temporal and spatial monitoring scheme would be required to determine the faunal succession following mining-related activities? What other area-based management tools may be needed to ensure effective protection of the common heritage of humankind, and how would they relate to existing schemes of other intergovernmental conventions? Should the ISA carry out a strategic assessment of contract areas regarding their conservation value and their economic value?

Considering that pilot mining activities (including equipment testing) are likely to start in the Area soon, assessment procedures with indicators and thresholds as well as associated procedural requirements for evaluation and updating also need to be established. However, these discussions – necessary as they may be – go beyond the scope of this article.

5. Conclusion

Careful interpretation of ISA's existing 100 environmental requirements leads to a general sampling design that differs depending on the target mineral ore. It will need to be augmented with the special tasks as outlined in the discussion above to satisfy all requirements listed in Table 1.

An entire PMN contract area (of approximately 75,000 km^2) should be sampled systematically and with sufficient density to allow for the proper positioning of IRZs and PRZs. Within such target areas, the entire water column as well as the sediment should be sampled over a minimum of three years. Beyond the BACI reference zones, all (potentially) impacted areas should be monitored consistently (with sufficiently high sampling station density) throughout the lifetime of the mine(s) or until the impact is no longer significant. At the same time all (sub)habitats need to be sampled, thus possibly requiring additional stations. Depending on natural variability, it may be necessary to sample more stations and/or to collect three or more parallel samples at each station to obtain sufficient statistical power.

For PMS and CFC contract areas, the distribution of sampling will differ, because samples will be collected by autonomous underwater vehicles/submersibles or remotely-operated vehicles most likely at a density of meters rather than kilometers. In any case, the final number of samples will be governed by the statistical power needed by the contractor when quantifying impact(s).

In the water column, for all three minerals a fine-scale sampling design will need to concentrate, in particular, on oxygen and toxics concentrations as well as particulate matter fluxes (including all particle size classes relevant to living organisms). Plankton abundances need to be studied at the species-level at the intended discharge depth of sediment-laden waters and below it. For all biological studies (pelagic and sedimentological), special emphasis should be put on rare species as they may be the first to be lost.

For all biological analyses, additional focus will have to be put on genetic studies to warrant the collation of complete species inventories as well as on experimental studies to assess toxicological impacts. Impact-related studies and fine-scale modelling will be needed to fulfill the requirements for implementing area-based management tools. The requirements for documentation and archival storage will guarantee the availability of data and evidence for the development of a transparent and objective EIA [22].

We conclude that these requirements provide an excellent basis for the environmental exploration studies by contractors for their EIAs as long as all 100 are adhered to. To the authors, none of these requirements appear to be redundant. In the future, the LTC will keep the available guidance under review and may wish to amend it periodically for aspects not well covered yet. Depending on humankind's decision on how much of its common heritage may be sacrificed in the process, it might be necessary to implement additional studies on population dynamics of rare and/or long-lived species.

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Declaration of Interest statement

All authors declare to have no competing interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2018.09.003.

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