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Review of the recommendations for the guidance of contractors for the assessment of possible environmental impacts arising from the exploration for marine minerals in the Area

Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area

Issued by the Legal and Technical Commission*

I. Introduction

1. During exploration for marine minerals, the International Seabed Authority is required to, among other things, establish and keep under periodic review environmental rules, regulations and procedures to ensure effective protection for the marine environment from harmful effects which may arise from activities in the Area and, together with sponsoring States, apply a precautionary approach to such activities on the basis of recommendations by the Legal and Technical Commission. In addition, contracts for mineral exploration in the Area require the contractor to gather oceanographic and environmental baseline data and to establish baselines 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. The contractor shall cooperate with the Authority and the sponsoring State or States in the establishment and implementation of such monitoring programmes. The contractor shall report annually on the results of its environmental monitoring programmes. Furthermore, when applying for approval of a plan of work for exploration, each applicant is required to provide, inter alia, a description of a programme for oceanographic and environmental baseline studies in accordance with the relevant regulations and any environmental rules, regulations and procedures established by the Authority that would enable an assessment of the potential environmental impact of the proposed exploration activities, taking into account any recommendations issued by the Legal and Technical Commission, as well as a preliminary assessment of the possible impact of the proposed exploration activities on the marine environment.

* The present document replaces ISBA/25/LTC/6/Rev.1, ISBA/25/LTC/6/Rev.1/Corr.1 and ISBA/25/LTC/6/Rev.2.

2. The Legal and Technical Commission may from time to time issue recommendations of a technical or administrative nature for the guidance of contractors to assist them in the implementation of the rules, regulations and procedures of the Authority. Under article 165, paragraph 2 (e), of the 1982 United Nations Convention on the Law of the Sea, the Commission shall also make recommendations to the Council on the protection of the marine environment, taking into account the views of recognized experts in that field.

3. It is recalled that in June 1998 the Authority convened a workshop on the development of environmental guidelines for exploration for polymetallic nodule deposits. The outcome of the workshop was a set of draft guidelines for the assessment of possible environmental impacts from exploration for polymetallic nodule deposits in the Area. The workshop participants noted the need for clear and common methods of environmental characterization based on established scientific principles and taking into account oceanographic constraints. One year after the approval of the regulations on prospecting and exploration for polymetallic nodules in the Area (ISBA/6/A/18), the Legal and Technical Commission issued guidelines in 2001 as document ISBA/7/LTC/1/Rev.1 and later revised them in 2010 in the light of increased understanding (see ISBA/16/LTC/7). In the light of the approval of the regulations on prospecting and exploration for polymetallic sulphides in the Area (ISBA/16/A/12/Rev.1) in 2010 and of the regulations on prospecting and exploration for cobalt-rich ferromanganese crusts in the Area (ISBA/18/A/11) in 2012, it was decided that there was a need to create a combined set of environmental guidelines that included guidance with regard to exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts.

4. A workshop entitled "Polymetallic sulphides and cobalt crusts: their environment and considerations for the establishment of environmental baselines and an associated monitoring programme for exploration" was held in Kingston from 6 to 10 September 2004 in response to the need for environmental guidance during exploration for those two resources. The recommendations of the workshop were based on the current scientific knowledge of the marine environment and the technology to be used at the time at which they were prepared. Subsequent to these workshops, several national and regional deep-sea mining research programmes have been conducted, most notably by countries in Europe (the Managing Impacts of Deep-sea Resource Exploitation (MIDAS) project (2013–2016) and the JPI Oceans MiningImpact project (2015–2017)), the south-west Pacific (the joint Pacific Community-European Union Deep Sea Mineral project (2011–2016)), New Zealand (the Enabling Management of Offshore Mining project at the National Institute of Water and Atmospheric Research (2012–2016)) and Japan and France (a joint project entitled "EcoDeep"), that have evaluated scientific requirements for baseline and monitoring surveys. In addition, a series of taxonomic standardization workshops were organized by the Authority (on megafauna in Wilhelmshaven, Germany, in 2013; on macrofauna in Uljin-gun, Republic of Korea, in 2014; and on meiofauna in Ghent, Belgium, in 2015). A workshop entitled "The design of 'impact reference zones' and 'preservation reference zones' in deep-sea mining contract areas" was held in Berlin from 27 to 29 September 2017. Outputs from those workshops and programmes are now available to update the previous recommendations to contractors contained in ISBA/19/LTC/8.

5. Unless otherwise noted, the recommendations herein relating to exploration apply to all types of deposits. At some sites, it may not be feasible to implement some of the specific recommendations. In that situation, it is recommended that the contractor provide arguments to that effect to the Authority, which can then exempt the contractor from the specific requirement.

6. The Commission is of the opinion that, given the technical nature of the recommendations, it is vital to provide, as annex I to the recommendations, an explanatory commentary. The explanatory commentary is supplemented by a glossary of technical terms.

7. The nature of the environmental considerations associated with test-mining and testing of mining components depends on the type of mining technology used to extract the minerals and on the scale of the operation. Mechanical removal without initial processing at the seabed was deemed the most likely technology to be used and is the method of mineral extraction assumed herein. It is likely that future mining operations will employ techniques not considered here. Given that the recommendations contained herein are based on the current scientific knowledge of the marine environment and the technology to be used at the time at which they were prepared, they may require revision at a later date, taking into account the progress of science and technology. In accordance with each set of regulations, the Commission may from time to time review the present recommendations, taking into account the current state of scientific knowledge and information. It is recommended that such a review be carried out periodically and at intervals of no more than five years. To facilitate the review, it is recommended that the Authority convene workshops, at appropriate intervals, in which the members of the Commission, contractors and recognized experts from the scientific community, international and governmental organizations and non-governmental organizations are invited to participate.

8. After approval of the plan of work for exploration in the form of a contract and prior to the commencement of exploration activities, the contractor is required to submit to the Authority:

(a) An impact assessment of the potential effects on the marine environment of all proposed activities, excluding those activities considered by the Legal and Technical Commission to have no potential for causing harmful effects on the marine environment;

(b) A proposal for a monitoring programme to determine the potential effect on the marine environment of proposed activities; and to verify that there is no serious harm to the marine environment arising from the prospecting and exploration for minerals;

(c) Data that could be used to establish an environmental baseline against which to assess the effect of future activities.

II. Scope

A. Purpose

9. The present recommendations describe the procedures to be followed in the acquisition of baseline data, and the monitoring to be performed during and after any activities in the exploration area with potential to cause serious harm to the environment. Their specific purposes are:

(a) To define the oceanographic, chemical, geological, biological and sedimentary properties to be measured and the procedures to be followed by contractors to ensure effective protection for the marine environment from harmful effects that may arise from the contractors' activities in the Area;

(b) To facilitate reporting by contractors;

(c) To provide guidance to potential contractors in preparing a plan of work for exploration for marine minerals in conformity with the provisions of the Convention, the 1994 Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea and the relevant regulations of the Authority.

B. Definitions

10. Except as otherwise specified in this document, terms and phrases defined in each set of the regulations shall have the same meaning in the present recommendations. A glossary of technical terms is contained in annex II to the present document.

C. Environmental studies

11. Every plan of work for exploration for marine minerals shall take into consideration the following phases of environmental studies:

(a) Environmental baseline studies;

(b) Monitoring to ensure that no serious harm is caused to the marine environment from activities during prospecting and exploration;

(c) Monitoring during and after testing of mining components.

12. Contractors shall permit the Authority to send its inspectors on board vessels and installations used by the contractor to carry out exploration activities in the Area to, among other things, monitor the effects of such activities on the marine environment.

III. Environmental baseline studies

A. Information needed for baseline studies

13. It is important to obtain sufficient information from the exploration area to document the natural conditions that exist prior to test-mining or testing of mining components to gain insight into natural processes such as dispersion and settling of particles and benthic faunal succession, and to gather other data that should make it possible to acquire the capability necessary to make accurate environmental impact predictions, for example the assumed impact and its process, including the seabed-disturbance plume, discharge plume, potential toxicity, noise and intensity of light. The impact of naturally occurring periodic processes on the marine environment may be significant but is not well quantified. It is therefore important to acquire as long a history as possible of the natural responses of sea-surface, mid-water, near-bottom and seabed communities to natural environmental variability before the mining-related activities. The best available technology and methodology for sampling should be used in establishing baseline data for environmental impact assessments.

B. Baseline data requirements

14. To set up the environmental baseline in the exploration area as required under the relevant regulations, the contractor, utilizing the best available technology, including the Geographical Information System, and using robust statistical design in preparing the sampling strategy, shall collect data for the purpose of establishing

baseline conditions of physical oceanography, chemical oceanography and geological, biological and other parameters that characterize the environments likely to be impacted by exploration and possible test-mining or testing of mining components activities. 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.

15. Data to be addressed should include:

(a) Physical oceanography:

(i) The measurement programme should be adapted to the geomorphology of the seabed and the regional hydrodynamic processes at the sea surface, in the water column and at the sea floor;

(ii) Collect information on the oceanographic conditions, including pressure, current direction and velocity, temperature, salinity and turbidity regimes, at intervals down the entire water column and, in particular, near the sea floor;

(iii) Measure the physical oceanographic parameters at the depths likely to be impacted by plumes caused by the processing discharge and seabed-disturbance plumes;

(iv) Physical parameters need to be measured with sufficient temporal and spatial resolution to adequately characterize the oceanographic environment;

(v) Measure natural particle concentrations and composition to record distribution throughout the water column;

(b) Chemical oceanography:

(i) Collect information on water column chemistry, including water overlying the resource, in particular on metals and other elements that may be released during the mining process, including interactions that may occur through crushing processes, leaks in the riser pipe, dewatering on the surface vessel and the consequent discharge plume;

(ii) Provide information on potential additional chemicals that may be released, if any, in the discharge plume following dewatering and/or processing of the ore, if it is to occur offshore;

(iii) Measure oxygen concentration, generating profiles in the water column, as far as possible near and across the sediment-water interface into the sediment column;

(iv) Measure pH and other components of the carbonate system where appropriate (e.g. carbon dioxide, alkalinity);

(c) Geological properties:

(i) Produce Geographic Information System regional maps with high-resolution bathymetry and sea floor bottom type showing major geological and geomorphological features to reflect the heterogeneity of the environment. These maps should be produced at a scale appropriate to the resource and habitat variability;

(ii) Record baseline levels of heavy metal and trace element content of the resource that may be released during the activity of test-mining or testing of mining components;

(iii) Determine the basic properties of the substrata to characterize the surficial deposits which are the potential source of seabed-disturbance plumes;

(iv) Sample the substratum taking into account the variability of the seabed and the nature of each resource category;

(d) Biological communities:

(i) Use high-resolution bathymetric maps to plan the biological sampling strategy, taking into account variability in the environment:

(ii) Gather data on biological communities, taking samples of fauna representative of variability of habitats, bottom topography, depth, seabed and sediment characteristics, the water column and mineral resource being targeted;

(iii) Collect data on the near-bottom and seafloor protozoan and metazoan communities specifically relating to megafauna, macrofauna, meiofauna, microbial communities, demersal fishes and scavengers and biota associated directly with the resource, both in the exploration area and in areas that may be impacted by operations (e.g. the areas affected by discharge and seabed-disturbance plumes);

(iv) Assess pelagic communities in the water column and near-bottom (in the benthic boundary layer) that may be impacted by operations (e.g. noise and discharge plumes);

(v) Record sightings of marine mammals, other near-surface large animals (such as turtles and fish schools) and bird aggregations, identifying the relevant species where possible. Details should be recorded in transit to and from areas of exploration and on passage between stations;

(vi) Establish time series stations to evaluate temporal variations in water column and seabed communities;

(vii) Assess regional distribution of species and communities/assemblages as well as genetic connectivity of key and representative species;

(viii) Where possible, collections should be photo-documented (and indexed to video imaging) in situ to provide an archive of context/setting information for each sample;

(e) Record and describe bioturbation activity and mixing of sediments;

(f) Evaluate linkages between pelagic and benthic habitats, including fluxes to the sediment: gather time series data on the sinking flux and composition of materials (including particulate organic matter) from the upper water column to the seabed;

(g) Measure sediment community oxygen consumption as a metric of whole community (largely microbial) function;

(h) Evaluate the food web structure of the pelagic and benthic habitats.

16. In addition to analyses of the data, raw data should be provided in electronic format with annual reports as agreed with the secretariat. These data will be used for regional environmental management and assessment of cumulative impacts.

17. In addition to the information provided above, the following information is specific to polymetallic sulphides:

(a) Any modification of fluid discharge in hydrothermal settings and associated fauna (using photo documentation, temperature measurements and other metrics, as appropriate) should be recorded;

(b) For active sulphide deposits, temperature-fauna relationships should be analysed (e.g. 5 to 10 discrete, video-documented temperature measures within each subhabitat);

(c) The distribution, abundance, species structure and diversity of the dominant taxa in each subhabitat (active, inactive vent areas, non-vent habitats) should be determined. This includes the assessment of specialist localized chemosynthetic communities relative to potential mining locations;

(d) Meiofaunal and microbial community structure and biomass associated with the polymetallic sulphide deposits should be obtained from remotely operated vehicle/submersible sampling, where possible, or be examined from rock dredge and rock drill samples. A statistically defensible number of samples should be taken from polymetallic sulphides, where possible. Species that live on the rock or in crevices and pits in the deposit should be identified, where possible;

(e) Biological samples from active hydrothermal vent systems should only be collected using precision sampling by remotely operated vehicle/submersible technology according to subhabitat and placed into discrete sample boxes.

18. In addition to the information provided above, the following information is specific to cobalt-rich ferromanganese crusts:

(a) Biological communities associated with cobalt-rich ferromanganese crusts may have a highly localized distribution. Biological sampling within the contractor's area must therefore be stratified by habitat type, which will be defined by topography (e.g. summit, slope and base for seamounts), hydrography, currents regime, predominant megafauna (e.g. coral mounds, sponge and octocoral fields), oxygen content of the water (if the oxygen minimum layer intersects the feature) and, potentially, depth. Both spatial and temporal replicate biological samples should be obtained using appropriate sampling tools in each subhabitat. A statistically defensible number of replicate samples per stratum is recommended for collection of specimens and to assess species richness;

(b) Photographic or video transects should be undertaken to determine habitat type, community structure and associations of megafauna with specific types of substrata. Abundance, percentage cover and diversity of megafauna should be based initially on at least four transects. These transects should include flat sea floor at the base of the seamount, the slope of the seamount and its summit. Further transects should be carried out in crust areas of potential test-mining interest;

(c) Demersal fishes and other nekton living over the sea floor should be assessed using towed photographic/video transects, benthic landers and/or submersible/remotely operated vehicle observations and photographs. Seamounts can be important ecosystems with a variety of habitats for a number of fish species that form aggregations there for spawning or feeding.

IV. Data collection, reporting and archival protocol

A. Data collection and analysis

19. The types of data to be collected, the frequency of collection and the analytical techniques in accordance with the present recommendations should follow the best available methodology and the use of an international quality system and certified operations and laboratories.

B. Data archival and retrieval scheme

20. A cruise report with station list, list of activities and other relevant metadata should be submitted to the secretariat of the Authority within one year of the completion of the cruise.

21. The contractor should provide the Authority with all relevant data, data standards and inventories, including raw environmental data in the format agreed with the Authority, as outlined in paragraph 23. 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, other than proprietary equipment design data (including hydrographical, chemical and biological data), should be made freely available for scientific analysis no later than four years after the completion of a cruise. An inventory of the data holdings from each contractor should be accessible on the World Wide Web. 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.

22. The contractor should take all reasonable efforts to ensure that representative examples of any remaining good-quality biological, mineral and molecular samples are archived in the appropriate long-term storage facility when studies are completed, for example, natural history museums, core depositories, geological institutes and international labelled collections (microbiology).

23. All data relating to the protection and preservation of the marine environment, other than equipment design data, collected pursuant to the recommendations contained in paragraphs 24 and 38, should be transmitted to the Secretary-General to be freely available, subject to confidentiality requirements as contained in the relevant regulations.

24. The contractor should transmit to the Secretary-General any other non-confidential data in its possession which could be relevant for the purpose of the protection and preservation of the marine environment.

C. Reporting

25. Assessed and interpreted results of the monitoring shall be periodically reported to the Authority together with the raw data in accordance with the recommendations for the guidance of contractors on the content, format and structure of annual reports (ISBA/21/LTC/15) using the appropriate contractor's reporting template, to be found on the website of the International Seabed Authority.

D. Transmission of data

26. All data relating to the protection and preservation of the marine environment, other than equipment design data, collected pursuant to the recommendations contained in paragraphs 24 and 38, should be transmitted to the Secretary-General to be freely available for scientific analysis and research within four years of the completion of a cruise, subject to confidentiality requirements as contained in the relevant regulations. This procedure does not preclude the obligation to report and transmit the data to the Authority in accordance with section 10 of annex IV to the regulations on prospecting and exploration for polymetallic nodules in the Area, entitled "Standard clauses for exploration contract".

27. The contractor should transmit to the Secretary-General any other non-confidential data in its possession which could be relevant for the purpose of the protection and preservation of the marine environment.

V. Cooperative research and recommendations to close gaps in knowledge

28. Cooperative research may provide additional data for the protection of the marine environment and may be cost-effective for contractors.

29. Interaction between multiple oceanographic disciplines and multiple institutions can be useful in closing the gaps in knowledge (especially regional-scale environmental patterns) that result from contractors working individually. The Authority can support the coordination and dissemination of the results of such research, in accordance with the Convention. The Authority should serve in an advisory capacity to exploration contractors in terms of identifying cooperative research opportunities, but contractors should seek their own links to academic and other professional expertise.

30. Cooperative research programmes may prove especially synergistic, bringing together the expertise, research facilities, logistic capabilities and common interests of mining companies and cooperative institutions and agencies. In this way, contractors may make best use of large-scale research facilities such as vessels, autonomous underwater vehicles and remotely operated vehicles and expertise in geology, ecology, chemistry and physical oceanography of academic institutions.

31. To answer certain questions on the environmental impacts of future mining, specific experiments, observations and measurements must be conducted. All contractors need not execute the same studies. Repeating certain experiments or impact studies would not necessarily add to scientific knowledge or to impact assessments, and would needlessly consume financial, human and technological resources. Contractors are encouraged to explore opportunities to unite their efforts in international cooperative oceanographic studies and to build on each other's findings to achieve needed (expanded) understanding of the target ecosystems.

VI. Environmental impact assessment during exploration

A. Activities not requiring environmental impact assessment during exploration

32. On the basis of available information, a variety of technologies currently used in exploration are considered to have no potential for causing serious harm to the marine environment and thus do not require environmental impact assessment. These include:

(a) Gravity and magnetometric observations and measurements;

(b) Bottom and sub-bottom acoustic or electromagnetic profiling of resistivity, self-potential or induced polarization, or imaging without the use of explosives or frequencies known to significantly affect marine life;

(c) Water, biotic, sediment and rock sampling for environmental baseline study, including:

(i) Sampling of small quantities of water, sediment and biota (e.g. from remotely operated vehicles);

(ii) Mineral and rock sampling of a limited nature, such as that using small grab or bucket samplers;

(iii) Sediment sampling by box corers and other corers;

(d) Meteorological observations and measurements, including the setting of instruments (e.g. limited number of moorings);

(e) Oceanographic, including hydrographic, observations and measurements, including the setting of instruments (e.g. moorings, benthic landers);

(f) Video/film and still photographic observations and measurements from non-bottom contact gear (e.g. towed camera platforms, remotely operated vehicles and autonomous underwater vehicles);

(g) Shipboard mineral assaying and analysis;

(h) Positioning systems, including bottom transponders and surface and subsurface buoys filed in notices to mariners;

(i) Towed plume-sensor measurements (chemical analysis, nephelometers, fluorometers, etc.);

(j) In situ faunal metabolic measurements (e.g. sediment community oxygen consumption);

(k) DNA screening of biological samples;

(l) Dye release or tracer studies, unless an environmental impact assessment is required under national or international laws for certain potentially harmful dyes/tracers.

B. Activities requiring environmental impact assessment during exploration

33. The following activities require prior environmental impact assessment, as well as an environmental monitoring programme to be carried out during and after the specific activity, in accordance with the recommendations contained in paragraphs 33 and 38. It is important to note that these baseline, monitoring and impact assessment studies are likely to be the primary inputs to the environmental impact assessment for commercial mining. The activities include:

(a) Use of sediment disturbance systems that create artificial disturbances and plumes on the sea floor;

(b) Testing of mining components;

(c) Test-mining;

(d) Testing of discharge systems and equipment;

(e) Drilling activities using on-board drilling rigs;

(f) Sampling with epibenthic sled, dredge or trawl, or similar technique, in nodule fields, that exceeds 10,000 m^2;

(g) Taking of large samples to test land base processes.

34. The environmental impact statement and the information set out in the recommendation contained in paragraph 38 are to be submitted by the contractor to the Secretary-General no later than one year in advance of the activity taking place, bearing in mind the importance of having sufficient time to allow the submission to

be assessed following the process outlined in section E below, and taking into account the annual meetings of the Commission.

35. Environmental monitoring data are required prior to, during and following activities listed in paragraph 33, including testing of mining components at the impacted site and control sites (to be selected according to their environmental characteristics and biotic composition). Impact assessment must be based on a properly designed monitoring programme that should be able to detect impacts in time and space and to provide statistically defensible data. When test-mining is being carried out, in addition to the recommendations above, an impact reference zone and preservation reference zone should be established to monitor impacts (see paragraph 38 (o)).

36. Environmental impacts are expected to be at the sea floor and also may occur at any discharge depth (if applicable) in the water column. The impact assessment should address impacts on benthic, benthic boundary layer and pelagic environments. The impact assessment should address not only areas directly affected by the activity but also the wider region impacted by seabed-disturbance plumes, the discharge plume and any materials that may be released by transporting the minerals to the ocean surface, which will depend on the technology used. An environmental impact assessment is required to assess whether there would be environmental changes from the discharge plume resulting in the alteration of food chains with the potential to disturb vertical and other migrations and lead to changes in the geochemistry of an oxygen-minimum zone, if present or applicable.

37. Testing of mining components or test-mining may be conducted by contractors individually or collaboratively. For environmental assessments, this test phase should be monitored intensively to allow the prediction of changes to be expected from the development and use of larger-scale commercial systems. When test-mining has already been carried out, even if by another contractor, the knowledge gained through those tests should be made available and applied, where appropriate, to ensure that unanswered questions are resolved by new investigations.

C. Information and measurements to be provided by a contractor performing an activity requiring an environmental impact assessment during exploration

38. The contractor is to provide the Secretary-General with some or all of the following information, depending on the specific activity to be carried out, following the template in annex III:

(a) Mineral collection technique (passive or active mechanical dredge, hydraulic suction, water jets, etc.);

(b) Depth of penetration in the sediment or rock and the lateral disturbance caused by the collector;

(c) Running gear (skis, wheels, caterpillars, Archimedes screws, bearing plates, water cushion, etc.) which contacts the seabed, and the width, length and pattern of the collector tracks on the sea floor;

(d) Ratio of sediment separated from the mineral source by the collector, volume and size spectra of material rejected by the collector, size and geometry of seabed-disturbance plumes and the trajectory and spatial extent of the plumes relative to the particle sizes within;

(e) Methods for separation on the sea floor of the mineral resource and the sediment, including washing of the minerals, concentration and composition of sediment mixed with water in the seabed-disturbance plume, height above the sea floor of discharge plumes, modelling of particle size dispersion and settlement, estimates of depth of sediment smothering with distance from the mining activity, and estimates (based on plume models) of the spread of the plumes in the water column horizontally and vertically, including particle concentrations as a function of distance from, and duration of, the proposed mining activity;

(f) Processing methods at the seabed, if any;

(g) Mineral crushing methods;

(h) Methods for transporting the material to the surface;

(i) Separation of the mineral resource from the fines and the sediment on the surface vessel;

(j) Methods for dealing with the abraded fines and sediment;

(k) Volume and depth of discharge plume, concentration and composition of particles in the discharged water, chemical and physical characteristics of the discharge and behaviour of the discharged plume at the surface, in mid-water or at the seabed, as appropriate;

(l) Location of the mining test and boundaries of the test area;

(m) Probable duration of the test;

(n) Test plans (collecting pattern, area to be perturbed, monitoring, etc.);

(o) Delineation of the impact reference zone and the preservation reference zone for the impact assessment of test-mining. The impact reference zone should be the site where the test-mining and related direct impacts are to occur. The preservation reference zone should be carefully located and far enough away not to be affected by testing activities, including effects from seabed-disturbance and discharge plumes. The implementation of a good monitoring programme to detect any disturbance that may occur beyond the impact reference zone as a result of testing is crucial to rank the preservation reference zone location. Detection of physico-chemical and biological disturbances in the far field from the test-mining site (>10 km) shall be conducted. Preservation reference zones will be important in identifying natural variations in environmental conditions against which impacts of the mining tests will be assessed. Their species composition should be comparable to that of the impacted areas. Preservation reference zones established during an exploration test-mining should be within the contractor's area if possible;

(p) Baseline maps (e.g. side-scan sonar, high-resolution bathymetry, sea floor bottom type) of the deposits to be removed;

(q) Status of regional and local environmental baseline data.

39. Each contractor should include, in its programme for a specific activity as listed above, a specification of the events that could cause suspension or modification of the activities owing to serious environmental harm, if the effects of the events cannot be adequately mitigated.

D. Observations and measurements to be made after undertaking an activity that requires an environmental impact assessment during exploration

40. The contractor is to provide the Secretary-General with some or all of the following information, depending on the specific activity to be carried out:

(a) Thickness of redeposited sediment and rock rubble over the area affected by the operational plume caused by the mining activity and by the discharge plume and changes in substrate heterogeneity;

(b) Changes in species composition, diversity and abundance of pelagic (where applicable) and benthic communities, including microbes and protozoa, including recolonization, changes in foundation species, three-dimensional-habitat-forming species, ecosystem engineers, bioturbation rates, chemical effects and changes in behaviour of key species (subjected to impacts such as smothering by sedimentation);

(c) Possible changes in communities, including microbes and protozoa, in adjacent areas not expected to be perturbed by the activity, including discharge and seabed-disturbance plumes and food web structure;

(d) 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 biota at and below the discharge plume (see also annex I, para. 13);

(e) For mineral deposits, post-test-mining maps of the mined area, highlighting changes in geomorphology;

(f) Levels of metals found in key and representative benthic biota subjected to sediment from the operational and discharge plumes;

(g) Resampling of local environmental baseline data and evaluation of environmental impacts;

(h) Changes in fluid flux and response of organisms to changes in hydrothermal settings, if relevant;

(i) Changes in water currents and the response of organisms to changes in circulation.

E. Process for reviewing the environmental impact statement in relation to the testing of mining components or other activities requiring an environmental impact assessment during exploration

41. The process is to be guided by the following steps:

(a) The contractor is to submit the complete environmental impact statement following the template in annex III and in accordance with the timeline specified in paragraph 34 of the present recommendations. In its submission, the contractor is to include information on the stakeholder consultation conducted, as reflected in annex I to the present recommendations;

(b) The Secretary-General will acknowledge the receipt of the environmental impact statement within 30 days and check it for completeness against the template contained in annex III to the present recommendations. If the submission is incomplete, the Secretary-General will contact the contractor to seek additional information. The contractor is to respond within 30 days. A contractor unable to respond in that time frame can request a reasonable extension of this period;

(c) At its next meeting, the Legal and Technical Commission will initiate the review of the environmental impact statement for completeness, accuracy and statistical reliability in conformity with annex I, paragraph 69, to the present recommendations, without prejudice to the possibility of requesting the views of recognized external experts;

(d) The Commission may request the contractor, through the Secretary-General, to provide additional information on the statement, including on the conduct of the stakeholder consultation. The contractor has up to 30 days to provide such additional information;

(e) The Commission will continue and finalize its review on the basis of annex I, paragraph 69 to the present recommendations and will provide recommendations to the Secretary-General as to whether the environmental impact statement should be incorporated into the programme of activities under the contract. The Secretary-General will inform the contractor accordingly. Such a recommendation, including its underlying rationale, will be sent by the Secretary-General to the Council for informational purposes and will be published on the website of the Authority, along with the final environmental impact statement;

(f) If the Commission does not recommend the incorporation of the environmental impact statement into the programme of activities under the contract, the contractor may opt to resubmit the statement. If the contractor opts to resubmit the statement, the statement is to be resubmitted and reviewed in accordance with the process outlined herein, including, if required, the revised stakeholder consultation referred to in paragraph (a) above;

(g) The Chair of the Commission will report to the Council at its next session on the work under this matter.

Annex I

Explanatory commentary

1. In the light of paragraph 6 of the present recommendations and paragraphs 2 to 6 of this explanatory commentary, the aim of this commentary is to provide guidance to contractors on the current best available technologies and methodologies to support contractors in implementing the present recommendations for exploration and achieving the effective protection of the marine environment from harmful effects which may arise from activities in the Area. It should be understood that the following guidance represents currently relevant methodologies and technologies that are likely to change based on future research. It is also understood that this guidance will be specifically applied to each proposed operation and focused on the environments where impacts are likely to occur.

2. 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 background variability, climate 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 all activities listed in section VI of the present recommendations and for an application for an exploitation contract;

(d) Provide data for the regional management of resource exploration and exploitation, the conservation of biodiversity and the recolonization/monitoring of areas affected by deep seabed mining;

(e) Establish procedures to demonstrate no serious harm to the environment from exploration for marine minerals.

3. On the basis of current proposed methodologies, the main impacts are expected to occur at the sea floor. Additional impacts may be caused by processing on board the mining vessel and from the discharge plume or as a result of different technologies being used.

4. At the seabed, the mining equipment will disturb and remove the sea floor (rock, nodules and sediment), and in addition create a seabed-disturbance plume of particulate material, in some cases containing potentially toxic contaminants, including metals, that may impact marine life.

5. Processing of mineral slurry at the sea surface on board the mining vessel will bring large quantities of cold, nutrient-rich, carbon-dioxide-replete and particle-laden water to the sea surface, which must be carefully controlled so as not to alter sea surface ecosystems and allow the degassing of climate-active gases and the release of toxic contaminants, including metals from the mining process, in particular in relation to reduced mineral phases, such as sulphides. Any chemicals added to separate the mineral phases from the waste material and water need to be assessed for potential harmful effects.

6. Any discharges to the marine environment need to be carefully controlled and their impact assessed, including their potential ecotoxicity effects.

7. Baseline data requirements include six categories: physical oceanography, chemical oceanography, geological properties, biological communities, bioturbation and fluxes to the sediment. [Recommendation III.B.15]

8. Appropriate mapping tools such as the Geographic Information System are recommended for habitat mapping, recording sampling locations and planning stratified random sampling programmes. [Recommendations III.B.14; III.B.15.(c).(i)]

Physical oceanography

9. Physical oceanographic data are required to assess natural background conditions and estimate the potential influence of the operational and discharge plumes and, together with information on the geomorphology of the sea floor, to predict the potential distribution of species. Information is required on water characteristics, including pressure, currents, temperature, salinity, turbidity, oxygen, optical properties (e.g. light intensity, backscatter, attenuation, etc.) and particulate matter. [Recommendations III.B.14; III.B.15.(a); III.B.17–18 (as appropriate for the habitat)]

10. With regard to the collection of data:

(a) The oceanographic structure (both spatial and temporal) of the water column needs to be characterized, with profiles and sections performed that provide the stratification of the entire water column. The methodology used must provide sufficient resolution to properly characterize the spatial and temporal variability in the contract area. Such studies can be undertaken using a range of equipment; for example, conductivity-temperature-depth probes with additional sensors, expendable bathythermographs and expendable conductivity-temperature-depth probes, mooring and buoy systems, floats and drifters, autonomous underwater vehicles and gliders with appropriate sensors. To measure (intra- and inter-annual) temporal variation, moorings/buoys and/or floats/drifters with appropriate sensors are necessary. Spatial variability also needs to be determined, and can be achieved, for example, using a network of conductivity-temperature-depth stations or a range of autonomous underwater vehicles, gliders or floats and drifters. Satellite data can also be used for sea surface measurements;

(b) Measurements of currents can be undertaken using acoustic Doppler current profilers (including vessel-mounted acoustic Doppler current profilers and lowered acoustic Doppler current profilers), other current meters or floats/drifters. Moorings and buoys (with acoustic Doppler current profilers or with other current meters) and/or floats/drifters are used to measure temporal variation;

(c) The number and location of the moorings need to be appropriate for the size of the area to adequately characterize the current regime, in particular in areas of complex geomorphology. The recommended sampling resolution should follow World Ocean Circulation Experiment and Climate Variability and Predictability Research standards, with station spacing not exceeding 50 km. In regions of large lateral gradients (e.g. in boundary currents and near major geomorphologic structures), the horizontal sampling spacing should be decreased in order to allow resolution of the gradients. The number of current meters on a mooring is dependent upon the characteristic scales of topography of the area studied (difference in heights from the bottom). Current measurements are required from the bottom boundary layer up to 200 m above the sea floor. The location of the upper current meter should be higher than the surrounding topography. Analyses of currents and temperature, salinity and density field structures on the basis of obtained data need to be done;

(d) Data on turbulence intensity should be collected during baseline studies. Turbulence intensity measurements allow the rate of vertical eddy diffusion to be determined, which is a key parameter influencing the dispersion of particulate plumes, and is therefore used for plume modelling. Ideally, turbulence intensity data should be collected by repeated profiling over several tidal cycles during a representative range of conditions (e.g. spring and neap tides). Turbulence intensity can be measured using a turbulence profiler, or inferred from vertical profiles of conductivity, temperature and depth, if these profiles are of an appropriate quality (e.g. by analysis of the Thorpe scale of overturns in a density profile). [Recommendations III.B.14; III.B.15.(a)]

11. A satellite-data analysis of sea surface temperature and productivity (ocean colour) over multiple years is recommended for understanding synoptic-scale surface activity in the area and for larger-scale events. [Recommendations III.B.14; III.B.15.(a)]

12. The water column structure should be defined either by continuous profiling or by water column samples. The resolution should be greater in high-gradient regions (e.g. to locate and quantify the boundaries of oxygen-minimum zones). 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. Because of the strong influence of topography on the spatial scales of oceanic features, it is expected that this will require a survey plan with station spacing depending on local geomorphological scales (e.g. finer resolution is required in areas with steep slopes). [Recommendations III.B.14; III.B.15.(a); III.B.17–18 (as appropriate for the habitat); VI.C.38.(k); VI.D.40.(d) and (i)]

13. It is important to understand the temporal and spatial fluctuations of current velocity and direction. Therefore, measurement of the physical oceanographic parameters before the testing of collecting systems and equipment are required to establish the amplitude of tidal to seasonal variability, and their variations within a relevant radius from the operations, which will be region-specific. [Recommendations III.B.15.(a).(iii); VI.D.40.(i)]

14. In order to predict sediment and plume dispersal, a numerical circulation model coupled with an adequate sediment transport model that integrates the effects of particle aggregation and disaggregation should be developed and validated. This should cover the temporal and spatial scales important for plume and toxicant dispersal. The carrying out of experiments may also need to be considered in order to address potentially important impacts (e.g. to investigate the potential impact of accidental spills). The contractor should use a model that is accepted by the ocean modelling community as suitable for dispersal studies near the seabed but which can also be more broadly applied throughout the water column, especially in relation to plume dynamics/dispersal. Simple box models or z-coordinate models with coarse vertical resolution at depth are not expected to be adequate. The details of this model will depend on the topographic and oceanographic settings of the target site. Resolution should be in accordance with the scales described above (i.e. gradients should be resolved by several points). The model needs to be validated by comparison with the observational data. [Recommendations III.B.14; III.B.15.(a).(i)–(ii)]

15. The vertical distribution of light directly affects primary productivity in the euphotic zone. If there is surface discharge, transparency will show the effect of discharged particles on light attenuation and spectral bands over time, depth and distance from the mining ship. Those values can be used to detect any accumulation of the suspended particles at the pycnocline. In addition, any discharge plume may result in the release of large amounts of nutrients, temperature changes, the release of carbon dioxide and (at sulphide sites) potential changes in pH and ocean acidification. [Recommendations III.B.15.(a).(i)–(ii); III.B.15.(d).(iv)].

Chemical oceanography

16. Chemical oceanography data are required prior to any discharge in the water column or at the seabed. The data gathered are important for assessing the possible influence of mining, including test-mining or component testing, on the composition of the water (e.g. concentrations of metals) and on ecosystem processes (biological activity). Samples should be collected at the same locations as the physical oceanography measurements. The water overlying the mineral deposits and the pore water in the sediments should be characterized chemically, where possible, to evaluate processes of chemical exchange between the sediment and the water column. The chemical parameters to be measured include phosphate, nitrate, nitrite, silicate, carbonate alkalinity, oxygen, zinc, cadmium, lead, copper, mercury and total organic carbon. Once details of the proposed test-mining techniques are known, the parameter lists should be extended to include any potentially hazardous substances that may be released into the water column during test-mining. All measurements must be accurate in conformance with accepted scientific standards (e.g. GEOTRACES protocols). Oxygen impacts on fauna can occur depending on the ocean basin and type of respondent and need not involve oxygen minimum zones. Oxygen levels may be very sensitive to introduction of plume sediments, nutrients and microbes from the seabed. 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 by determining oxygen profiles (and their temporal variability) in each contract area at intervals throughout the water column. [Recommendations III.B.14; III.B.15.(b).(i) and (iv)]

17. Organic matter (e.g. particulate organic matter and dissolved organic matter) should be measured to assess the horizontal and vertical advective and eddy-diffusive dispersal potential of dissolved and particulate matter on environmentally relevant time and space scales. [Recommendations III.B.15.(b); III.B.15.(g); IV.B.22]

18. Vertical profiles and temporal variation (tidal, seasonal and inter-annual) also need to be addressed in the field measurement programme. [Recommendation III.B.14]

19. Regardless of the mining techniques to be employed, it is expected that some particulate and/or dissolved mining by-products will be released into the water column in the vicinity of the mined deposits, from transport conduits and from processing at the sea surface. With the currently proposed exploration and test-mining or testing of mining components techniques, the primary anticipated test-mining or testing of mining components by-products are particles created by the mechanical break-up of the mined minerals. While it is expected that mining operators will minimize the loss of economically valuable minerals, it does not seem realistic to assume zero loss. Since the particle size range is not known, it is assumed that the by-products of test-mining or testing of mining components will include very small particles or possibly colloidal-sized particles, which can remain in suspension for months. The possibility of the introduction of toxic substances cannot be excluded. While particle-bound metals may not be biologically available, release of metals due to particle dissolution and consequent metal toxicity may take place under particular environmental conditions (e.g. low pH, including within the guts of marine fauna, oxygen-minimum zones in the water column). Other possible examples include accidental or intended release of chemicals used during exploration and test-mining or testing of mining components. [Recommendations III.B.14; III.B.15.(b); III.B.15.(c).(i)–(ii)]

20. A primary goal of the physical baseline data collection consists of assessing the dispersal potential both for particles and for dissolved substances. Knowledge of the dispersal potential is also required for monitoring and mitigating the effects of

accidental spills relating to the test-mining or testing of mining components operations. To allow the prediction of the effects of accidental releases, the dispersal potential near possible mining sites should be assessed even if the design target of the mining technology includes avoidance of the release of any test-mining by-products into the environment. [Recommendations III.B.14; III.B.15.(a).(iii); III.B.15.(b); III.B.15.(c).(ii)]

21. For each test-mining by-product, the timescale over which it causes significant environmental impact must be modelled. If these timescales depend on dilution, determination of vertical and horizontal mixing rates near the target site must be included in the dispersal assessment. Dispersal potential must be assessed over timescales that range from the tidal frequencies to the largest of these environmental-impact timescales. An assessment of the dispersal potential in the deep ocean generally requires long-term monitoring. Even the determination of mean-flow directions and speeds at depth can require several years of current-meter data. Assessing eddy-diffusive dispersal is difficult and generally requires the application of Lagrangian techniques, such as neutrally buoyant floats or tracer experiments. For these reasons, it is recommended that an assessment of the regional dispersal potential at several levels in the water column begin early during exploration. It may be possible to assess dispersal near the surface and near 1,000 m from available data – surface drifters and Array for Real-time Geostrophic Oceanography floats, respectively. Before test-mining is to begin, the dispersal potential must be assessed at all levels where harmful by-products may be released into the water column by test-mining and where accidental spills may occur. The required vertical resolution will depend on the regional dynamical regime (vertical shear of the horizontal currents), but it is anticipated that at least three levels will need to be sampled (near-surface, mid-depth and near-bottom). The flow near the seabed in particular must be temporally and spatially resolved (e.g. using bottom-mounted acoustic Doppler current profiler measurements with sufficient sampling to resolve the dominant tidal flows). In regions of geomorphological relief near the test-mining site, horizontal and vertical resolutions should be increased to allow dynamical structures associated with deep-sea geomorphology (e.g. boundary currents, trapped eddies, overflows) to be resolved. [Recommendations III.B.15.(a).(i)–(iv); III.B.15.(b).(i)]

22. Near active hydrothermal vent fields, it is often possible to gain useful first-order dispersal information at the level of neutrally buoyant plumes from hydrophysical, chemical and optical observations. Interpreting plume-dispersal observations in terms of dispersal potential for mining by-products is complicated by a variety of factors, including poor knowledge of the temporal and spatial characteristics of hydrothermal sources; that hydrothermal plumes disperse at their equilibrium level, which depends both on the source and environmental background characteristics; and that the particle composition (and thus the settling velocity) of hydrothermal plumes cannot be controlled. Nevertheless, when such plumes occur in the vicinity of a mineral resource, it is expected that hydrothermal-plume dispersal observations will be useful, in particular for designing controlled follow-up dispersal studies. To complete an assessment of the dispersal potential, a three-dimensional hydrodynamic numerical model that covers the temporal and spatial scales important for dispersal must be constructed. [Recommendations III.B.14; III.B.15.(a).(i)–(iii); III.B.15.(c).(i)]

23. Modelling will be important in extrapolating from test-mining to commercial-scale mining. [Recommendations III.B.15.(a).(i) and (iv)]

Geological properties

24. Geological properties are targeted to determine the heterogeneity of the environment and assist in the placement of suitable sampling locations to characterize

the distribution and composition of faunal communities. [Recommendations III.B.14; III.B.15.(c).(i)]

25. High-resolution, multibeam bathymetric data (including backscatter) should be collected over the entire exploration area. In areas selected for test-mining operations and/or future exploitation activities, a representative coverage from multibeam sensors mounted in autonomous underwater vehicles, remotely operated vehicles or other systems that could provide centimetre to metre scale resolution should be obtained. A representative coverage from multibeam sensors should also be applied to the areas impacted by the sediment plume created by collector systems. Backscatter measurement (or sea floor acoustic reflectivity) may provide information on the sea floor roughness produced by features such as ripples, benthic reworking, etc., as well as rock outcrops, crusts, nodules and sediments occurrence. [Recommendations III.B.14; III.B.15.(c)]

26. As part of the high-resolution baseline survey, a suite of representative pre-mining cores of the sea floor sediment, where appropriate, should be collected and stored in a suitable repository. Sampling devices that collect undisturbed samples of the top few centimetres (e.g. a multiple corer or a push corer on a remotely operated vehicle) should be used. [Recommendations III.A.13; III.B.14]

27. For sulphide deposits, hydrothermal vent areas should be classified as either active vent sites or inactive/extinct sites. What is important biologically is whether the proposed mining site has active hydrothermal vents (case 1), inactive vents that may restart owing to mining activity (case 2) or extinct vents that will remain hydrothermally inactive even when disturbed by test-mining (case 3). It is important that the baseline assessment determine which of those cases apply. [Recommendation III.B.14]

28. Sediment properties, including pore water chemistry (see also the section on chemical oceanography), are targeted to predict the behaviour of the discharge plume and the effect of test-mining activity on sediment composition. This should include the properties of settled plume particles. In this context, the following parameters should be measured: specific gravity, bulk density, grain size, composition (carbonate percentage, total organic matter) as well as the sediment depth of change from oxic to suboxic (absence of oxygen and hydrogen sulphide), or suboxic to oxic conditions. Measurements should include dissolved and particulate organic and inorganic carbon in the sediment, metals and other chemicals that may be harmful in some forms, nutrients (phosphate, nitrate, nitrite and silicate), carbonate (alkalinity) and the redox system (Eh and pH) in pore waters. The geochemistry of the pore water and sediments should be determined as far down as 20 cm, or to the depth of sea floor removal by mining, whichever is deeper. With sea floor massive sulphides, other (eventually toxic) components (e.g. hydrogen sulphide, methane, arsenic, cadmium) may be enriched, and so further analyses at a particular site might be required. Following a test-mining or testing of mining components the properties of settled plume particles should be measured, as this is what becomes available for recolonization. [Recommendations III.A.13; III.B.15.(b).(ii); III.B.15.(d).(iv)]

Biological communities

29. This data group – biological communities – is targeted to determine communities and their ecosystem functions, including their natural spatial and temporal variability, so as to evaluate the potential effects of the activities on the benthic, demersal and pelagic fauna. [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(iii)]

30. 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 and patterns of connectivity for the creation of preservation

reference zones and for mitigation strategies to promote the natural recolonization of areas affected by mining activities. A well-thought-out and robust design for sampling is critical for the assessment of faunal assemblages and to take into account the ecological conditions in the site under investigation. If variation of ecological conditions or habitats is expected, stratified random sampling approaches should be considered. Careful planning is extremely important, as improper sampling can render a data set useless for determining baselines and impacts. For example, analysis of the macro- and meiofauna in the sediment samples should establish a species accumulation curve. From this it is possible to estimate the number of samples required to provide an adequate assessment of the number of species. [Recommendation III.B.15.(d).(i)]

31. Standard practices for the fixation and preservation of organisms should be followed, while noting that formaldehyde/formalin fixation is not appropriate for all taxa. Discrete sampling using appropriate equipment should ensure adequate collection from different habitats. With a remotely operated vehicle, this involves separate sample containers (preferably insulated) with closed lids to prevent washing on recovery. Recovery of samples to the surface should be made ideally within three hours for microbial samples and up to six hours for other faunal samples, or as soon as practicable. Quantitative core samples from sediment habitats should be assessed to ensure that they are of sufficient quality (e.g. the sample is not slumped or “washed” on retrieval). Only good-quality samples should be processed. Once on board, samples should be processed as soon as possible, and undergo immediate processing and preservation or be maintained in cold rooms for the shortest amount of time possible (i.e. no more than six hours before processing and preservation (especially where molecular assays are planned)). [Recommendations III.B.15.(e); III.B.17.(e)]

32. Multiple preservation methods should be used depending on taxon and study objectives, including freezing or preservation in molecular grade ethanol for molecular studies; preservation in ethanol or formaldehyde for morphological taxonomic studies; or the immediate freezing of whole animals and/or selected tissues for stable isotope, trace metal and biochemical analyses. With regard to the processing and preservation of samples:

(a) **Megafauna and macrofauna**. It is important that molecular studies be undertaken in conjunction with morphological taxonomic analyses. Samples destined for molecular studies should ideally be sorted live and photographed before further processing. If possible, only a tissue sample should be taken in order to preserve a voucher specimen for later morphological comparison. Specimens should then be preserved in molecular grade ethanol. It is important that a “cold chain” approach be adopted so that specimens are kept cold at all stages of the processing. DNA extractions can be carried out on board the exploration vessel or at the home institute, but polymerase chain reaction analysis should not be done on board owing to unavoidable contamination, which would compromise rare species analysis and material collected on subsequent cruises. Preferably, samples should be stored at -80°C for longer term storage and archived. Voucher specimens for molecular genetic studies should be stored in a long-term storage facility when studies are completed (e.g. natural history museums, core depositories, geological institutes);

(b) **Meiofauna**. Sieved meiofaunal samples can be preserved with a solution containing dimethyl sulphoxide, disodium ethylenediamine tetra-acetic acid and saturated salt (DESS), and samples can be held in solution for further processing, including for the preparation of temporary slides, video capture for morphological taxonomic study and DNA sequencing (following the protocols described in ISA Technical Study: No 7);

(c) **Microeukaryotes**. Foraminifera should be dried (hard-shelled) for morphological analysis or preserved in an appropriate stabilizer of nucleic acids such as RNA later for molecular analysis;

(d) **Microbiology**. Samples dedicated to microbiology (including microorganisms, bacteria, archaea, fungi, viruses, microeukaryotes) must be collected using sterile devices. Best sampling is done using a remotely operated vehicle/submersible. Samples must be brought back to the surface as rapidly as possible and within three hours, kept under cold conditions and processed immediately after recovery under sterile conditions. Diversity assessment should be undertaken through cloning/ sequencing approaches. Microbial diversity should also be, as much as possible, taken up through cultivation procedures to describe new species. Microbial activity measurements should be conducted to identify a possible mining impact;

(e) **Environmental DNA (eDNA) samples**. eDNA is one recognized tool for biodiversity monitoring through use of metagenomic or amplicon sequencing approaches (e.g. of bacteria, archaea, viruses, fungi, protists, meiofauna). Samples for eDNA are collected from water and sediment. The DNA must be extracted and purified from preserved samples in land-based laboratories to prevent cross-contamination. The size and quantity of preserved samples must be adjusted by habitat condition because DNA amounts vary depending on biomass. In the case of water samples, filtration must be carried out on board in the shipboard laboratory, and filter-captured particles are then archived. Pore size of filtration depends on the cell size of target organisms. The sediment and filter specimens for eDNA should be preserved at -80°C. [Recommendations III.B.14; III.B.15.(d).(ii)]

33. Colour photographic documentation of organisms, together with clear labels, should be obtained whenever possible (organisms in situ and/or live, fresh material), because features such as the presence of eyes and colour patterns may disappear when the specimen is fixed. The photographs should be archived digitally. [Recommendations III.B.15.(d).(i)–(iii); IV.A.19; IV.B.21]

34. All samples and sample derivatives (e.g. photographs, preserved material, gene sequences) should be linked to relevant collection information (the minimum requirement is date, time, method of sampling, latitude, longitude, depth and cruise identifier). [Recommendations III.B.15.(d).(i)–(iii); IV.A.19]

35. Identification and enumeration of samples at sea and in the laboratory should be complemented by molecular and isotopic analyses to determine food-web linkages. For biomarker food-web studies it is also important to obtain frozen samples of sediments (surface centimetre and deeper), water column detritus (sediment traps and water column filtration) and/or microbial mats (e.g. in vent regions). Species-abundance and species-biomass matrices should be standard products wherever practical. [Recommendations III.B.15.(d).(i)–(iii); IV.A.19]

36. 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. If species composition does change, it might be subtle, and reference back to the original animals (where there might only have been a putative identification) is essential. It is recommended that samples be archived as part of national or international collections and that appropriate funding be identified to facilitate this. [Recommendations IV.A.19; IV.B.22]

37. Standardization of methodology and reporting of the results is extremely important. Standardization should include instruments and equipment; quality assurance in general; sample collection protocols; 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 spatial scales and lead to selection of critical parameters for monitoring efforts. [Recommendation IV.A.19]

38. Spatial variation in the composition of the biological community and levels of connectivity must be evaluated prior to test-mining or testing of mining components. 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. Sampling should occur at three mineral deposit sites, if present, as well as at background communities in the contract area. Each site should be separated by a distance greater than the projected deposition by the mining operation; for example, deposition of sediment from the plume should not exceed 10 times the background sedimentation rates (e.g. in the Clarion-Clipperton Fracture Zone, >0.1 mm/year) or in the case of the water column to a distance where sediment concentration will not exceed 10 times the background levels. [Recommendations III.A.13; III.B.15.(d).(i)–(iii) and (viii)]

39. Different kinds of sampling equipment can be used depending upon the water column and seabed characteristics and the size of the biota to be collected. Methods for collecting baseline biological data must therefore be adapted to each specific set of conditions. The use of multiple corers in soft sediments provides the least disturbed surface and allows the distribution of different sampling tubes from the same station among the specialists that use different techniques for fauna identification and counting. Biological samples must be large enough to generate good sample sizes in terms of abundance and biomass for robust statistical analyses. However, in areas characterized by low faunal densities, such as the abyssal Clarion-Clipperton Fracture Zone, it may be necessary to use a box corer (0.25 m^2) to obtain statistically adequate samples of macrofauna. [Recommendations III.B.14; IV.A.19]

40. Hard substrata (such as polymetallic sulphides, cobalt crusts, basalt), especially where the organisms are small, are challenging environments to sample quantitatively. Multiple collection techniques may be required, including slurp sampling and grab samples of larger organisms and small rocks. It is possible to obtain the surface area of rocks (by weighing foil) to provide quantitative analysis of small attached fauna. Video documentation and photographic transects may be the only means suitable for developing a species-abundance matrix in some cases. Precision sampling using remotely operated vehicles is recommended for all habitats. Exposed rock surfaces may be irregular and, potentially, have steep slopes, which make them difficult to image quantitatively without the use of a remotely operated vehicle. [Recommendations III.B.15.(d); III.B.17; III.B.18]

41. The data to be collected and the corresponding methodology for the various classes/sizes of seabed biota should be as follows, with temporal variation on at least inter-annual scales studied:

(a) **Megafauna**. Data on the abundance, biomass, species structure and diversity of megafauna, including protists (xenophyophores), should be from video and photographic transects with a scale visible (e.g. lasers a set distance apart). Photographs need to have sufficient resolution to identify organisms greater than 2 cm in their smallest dimension. The width covered by the photographs should be at least 2 m. The pattern of the photographic transects should be defined taking into account the different features of the bottom, such as topography, variability of the sediment characteristics and abundance and type of deposit. A time-lapse camera should be installed at the study area for at least one year to examine the physical dynamics of surface sediment and document the activity level of surface megafauna and the frequency of resuspension events. Species identification has to be confirmed by collection of specimens at the site. In some cases this may be achieved by direct sampling, targeting areas where remotely operated vehicles collections along transects or short tows of small sleds/dredges/trawls can be carried out. Dredges and trawls are not effective and potentially destructive in active sulphide areas with localized chemosynthetic fauna, so their use in those areas should be avoided. Care is also needed in certain crust environments where there may be dense habitat-forming communities (e.g. corals). Sampling efforts, including with baited traps and baited cameras, should be used to characterize the less abundant but potentially important megafauna in the system (including fish, crabs and other motile organisms). Representative samples of organisms should be preserved for taxonomic, molecular and isotopic analyses; [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(ii); IV.B.22]

(b) **Macrofauna**. Data on macrofauna (300 µm sieve mesh size[1]) abundance, species structure, biomass and diversity should be obtained through a quantitative analysis of samples. In soft sediments, vertical profiles with a suitable depth distribution (suggested depths: 0–1, 1–5, 5–10 cm) should be obtained from box cores (0.25 m^2). Box corers will be most effective in abyssal polymetallic environments where faunal densities can be low. The box core samples may be applied as representative only if the sediments inside the core are not likely to be mixed by the presence of nodules. Even if there are nodules in the surface layer of sediment in a box core, the core may be sliced into layers. However, if there is any possibility of the sediments inside the core being mixed by nodules that are buried during sampling, only the upper layer should be sliced into a sample 0–1 cm thick and this sample should not be treated as representative. Whole box core samples should be used and not be significantly subcored or divided. The fauna on the surface and crevices of manganese nodules should be retained and appropriately preserved. In bathyal sediment environments a megacorer can be used. The protocols for sample treatment are similar to those for the box corer. Macrofauna can also be collected from soft sediments using a modified epibenthic sled. Such samples can provide useful material for biodiversity studies, in particularly those with a molecular focus; [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(ii); IV.B.22]

(c) **Metazoan meiofauna**. Data on metazoan meiofaunal (32 µm sieve mesh size) abundance, biomass and species structure should be obtained through a quantitative analysis of samples. Where possible a multiple corer with 10-cm tubes should be deployed to sample meiofauna in sediment systems. A minimum of three multiple corer deployments per station is suggested. At least one (complete) core from each deployment should be dedicated to metazoan meiofauna and at least one core allocated for molecular meiofauna. Analysis of the top 0–5 cm of each core should be processed (owing to potential problems associated with buried nodules) or, if eDNA analyses are being undertaken, then the top 0–2 cm should be processed. When nodules are present, they should be removed, noted and the sediments sectioned beneath them; [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(ii); IV.B.22]

(d) **Foraminiferal meiofauna**. Data on foraminiferal meiofauna abundance, biomass and species structure should be obtained through a quantitative analysis of samples from corers. A sieve mesh size of 125 µm is recommended. A foraminiferal community can be analysed either through specimen sorting and microscopic identification or through eDNA analysis of sediments. Cores for specimens should be sliced into 1-cm thick layers down to a depth of 5 cm unless the core has buried nodules, in which case only the top 0–1 cm should be sliced; for eDNA there is no

[1] Contractors can continue to use the sieve size they previously used to ensure that the data are compatible. A 300 µm sieve is preferred because data are then comparable with historic data. If contractors decide to continue to use a 250 µm sieve, then interpretation of the results will require some intercalibration between the two sieve sizes.

need to slice sediment and examine each layer separately; [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(ii); IV.B.22]

(e) **Microbiota**. The microbial community is important in biogeochemical cycles and ecosystem function (e.g. organic matter remineralization and nutrient cycling and benthic community food webs). Microbial biodiversity can be assessed using molecular methodologies based on environmental DNA sequencing. Samples from sediment habitats can be obtained using standard sampling equipment (e.g. a multiple corer or a push corer on a remotely operated vehicle). Samples should then be sliced on board and frozen at -20°C (or -80°C) or preserved in an adequate DNA preservation buffer, with extraction of gene material being carried out in the home laboratory. High throughput methods (e.g. Illumina sequencing) should be used for sequencing of the molecular material. The description is primarily relevant for soft sediment ecosystems but can also address hard bottom communities as well as the water column. Targeted metagenomics (or metabarcoding) focusing on taxonomic markers such as the ribosomal RNA gene should be based on RNA in conjunction with DNA material in order to distinguish the signal of living species from that of ancient, dead material and to account for different species' activity levels. Metabolomic analyses are becoming increasingly faster and routine, and cost is declining. The integration of metabolites information into the analysis of taxonomic and function gene diversity provides additional quantitative indicators of ecosystem functions (and services). Microbial metabolic activity should be determined using in situ sediment community respirometry or another standard assay appropriate to the metabolisms present. In soft sediment, vertical profiles should be obtained with suggested intervals for sampling of 0–1, 1–2, 2–3, 3–4 and 4–5 cm. One multiple corer tube per station could be devoted to this purpose; [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(ii); IV.B.22]

(f) **Nodule biota**. The biota living on and within the nodules should also be sampled and characterized from selected nodules taken from the tops of box corers or sampled by remotely operated vehicle. Large nodules with complex morphologies should be broken up and any biota living within the structures sorted, extracted and analysed; [Recommendations III.A.13; III.B.14; III.B.15.(d).(i)–(ii); IV.B.22]

(g) **Demersal fishes and scavengers**. Sampling demersal fishes requires the use of multiple sampling techniques to provide information on the composition and relative abundance of fish species. Photographic surveys in combination with baited lander deployments or remotely operated vehicle transects are recommended. Where applicable, direct capture by small trawl or sled may be possible for slow-moving species, but see paragraph 42 (d). [Recommendation III.B.15.(d).(iii)] Benthic landers are typically used for short-term deployments of both cameras and baited traps to characterize the community species composition. Baited cameras and traps should be deployed at a range of depths (for polymetallic sulphides and cobalt-rich crusts) and spread geographically (for polymetallic nodules) to measure depth and spatial variability. Short-term (24–48 hours) baited traps aimed at surveying amphipod and other crustacean necrophage communities can also be deployed. [Recommendations III.A.13; III.B.14; III.B.15.(d)]

42. Where there is high probability of discharge into the water column either through accident or normal operations, the pelagic community should be characterized. The pelagic community structure (including fishes) around the depth of the discharge plume, and at depths below, needs to be assessed prior to test-mining. In addition, the pelagic community in the benthic boundary layer should be characterized using near-bottom opening/closing mid-water nets, moored plankton pumps, sediment traps, and/or remotely operated vehicle sampling or remotely operated vehicle techniques. If enclosed riser pipes/buckets and discharge pipes minimize any material loss through the water column, then pelagic sampling should

focus primarily upon the depths that would be affected by a sediment plume from the sea floor, the depth of waste material discharge and the depths over which noise pollution (e.g. from the grinding up of mineral deposits at the sea floor) substantially exceed background noise levels: [Recommendations III.A.13; III.B.14; III.B.15.(d).(iii)]

(a) **Phytoplankton and primary production**. Measurements should be made of phytoplankton composition, biomass and production, and bacterial plankton biomass and productivity. Temporal variation on seasonal and inter-annual scales should be studied. This might be impractical to monitor over several years, but remotely sensed data (chlorophyll a and ocean colour) can provide information on levels of surface productivity and such analyses can substitute for specific phytoplankton sampling or be used to augment field programmes. Calibration and validation of remote-sensing data are essential; [Recommendations III.A.13; III.B.15.(d).(iii); IV.B.22]

(b) **Zooplankton (both holo- and meroplankton)**. Sampling is usually carried out with nets or, in deeper waters, with plankton pumps. Surface to a depth of 200 m can be sampled using a “Bongo net”, which is standard equipment (although this integrates the catch between depths). One net with a 350 µ mesh size cod end and one net with a 200 µ mesh size cod end are recommended. A flow meter should be attached to the frame, so that the amount of water filtered can be determined. Bongo nets do not sample mesopelagic fishes well, as they can avoid the nets. Sampling deeper than 200 m is best done with samplers that will enable a depth-stratified set of data for assessing likely impacts from mining operations and sediment plumes. As the density of zooplankton is low at greater depths, the sample volume often needs to be large to collect sufficient plankton to describe their composition and abundance. Multiple opening/closing net systems are required (with mesh sizes from 64 µm to 3 mm depending on the aim of the study and the target organisms). These consist of a series of single nets that can be opened and closed sequentially at a range of depths (either using acoustic control or preprogrammed), for example the MOCNESS and the MultiNet. It is very important that tows are depth-discrete and quantitative. Both vertical and horizontal/oblique tows can be used in quantitative sampling to determine the composition and abundance of zooplankton, and their variability with depth or site. Horizontal tows and gear should be used if narrow depth layers and large volumes need to be sampled (e.g. close to the sea floor or targeting specific sound-scattering layers). Other techniques are available that do not physically capture zooplankton. These include an underwater video profiler, which is an optical recorder useful in quantifying fragile gelatinous and filter-feeding plankton that are poorly sampled in nets. Acoustical sampling is a further technique to consider. It is recommended that zooplankton be sampled at discrete depth intervals. This may vary with site and resource type, but include: surface to 50 m; 50–100 m; 100–200 m; 200–500 m; 500–1,000 m; 1,000-plus (if appropriate, and can be flexible depending on the environmental setting); and sea floor to 10 m above the sea floor (epibenthic layer). The near-bottom layer can be sampled by plankton nets, but the nets require accurate pinger systems, depth meters or altimeters mounted on the gear to reduce the risk of damage from contact with the sea floor. This layer can also be sampled using plankton nets mounted on sleds that are towed across the sea floor (e.g. the “Brenke sled”). Plankton pumps moored near the sea floor can also provide quantitative zooplankton samples at very precise heights above the sea floor; moored sediment traps may provide qualitative samples of zooplankton; [Recommendations III.B.15.(d).(iii); IV.B.22]

(c) **Gelatinous zooplankton**. Gelatinous zooplankton constitute a high proportion of the plankton biomass, abundance and diversity from the epipelagic to the abyssopelagic, including the benthic boundary layer. They are often suspension feeders (and therefore may be sensitive to sediment plumes) and important particle processors that create/remove sinking particles in the water column. Optical tools (e.g. underwater video profilers) or autonomous underwater vehicle/remotely operated vehicle transects are the best way to survey for gelatinous zooplankton. These should be placed at depth intervals down the water column similar to the towed nets; [Recommendations III.B.15.(d).(iii); IV.B.22]

(d) **Nekton**. There are several “types” of nekton that can be associated with mineral resource areas, and may need to be considered depending on the depths of discharges or operational sediment plumes: epipelagic fishes, typically found in the upper 300 m of the water column, often large-bodied and fast swimming (e.g. tunas); deep-diving surface fishes, such as devil rays and some shark species; mesopelagic fishes, shrimps and squids that are small to medium sized (i.e. micronekton) and perform synchronous or asynchronous (i.e. not total population) vertical migrations; non-migrating nekton that stay at mesopelagic or bathypelagic depths day and night; and benthopelagic fishes that can live and migrate several to tens of metres above the sea floor. These types require different approaches and some are very difficult to survey even with sophisticated fisheries acoustics or trawl sampling equipment. However, direct survey work may not be necessary on all types depending on the characteristics of the licence area; [Recommendations III.B.15.(d).(iii); IV.B.22]

(e) **Mesopelagic micronekton**. Mesopelagic micronekton (e.g. lantern fishes, hatchet fishes, sergestid shrimps, cranchid squids) are usually small bodied (2−20 cm). They can be detected and their relative biomass estimated using relatively high-frequency acoustic transducers over ranges of several hundred meters. They may be collected in larger zooplankton sampling gear (e.g. a 10 m MOCNESS). Their catches in vertical nets will be limited, but if larger opening/closing nets are used then smaller species will be retained. Depth distribution can be determined from deployment of nets at different heights through the water column. These should match the ranges given in paragraph 42 (b) above; [Recommendations III.B.15.(d).(iii); IV.B.22]

(f) **Larger mesopelagic taxa**. These need to be sampled with towed mid-water trawls, which is a challenging task for non-fisheries-specific vessels. Acoustical sampling is a technique that can be applied to the larger-bodied mesopelagic nekton. Hull-mounted mid-frequency transducers (38 kHz is common) can effectively measure the sound-scattering density of mid-water animals (the micronekton, which include larger zooplankton, mesopelagic fishes, squids, etc.) to depths of 100–1,500 m, depending on water column structure and how “acoustically quiet” the vessel is. These data can give a measure of total acoustic backscatter, which can be used to estimate biomass but still requires direct observation or sampling to determine species/taxa composition. Sampling nets are usually twin-wire nets that are towed at 3–6 knots; [Recommendations III.B.15.(d).(iii); IV.B.22]

(g) **Fishes**. Larger-bodied fishes that live in close proximity to the sea floor will probably be seen in at least some photographic surveys. Many (but not all) fish tend to dive towards the sea floor when disturbed in mid-water depths, and an oncoming remotely operated vehicle or towed camera frame may herd them down to within sight. This will give information on species composition, but such data are not quantitative. [Recommendation III.B.15.(d).(iii)]

43. **Noise**. Baseline surveys will be needed to determine background noise levels in vertical profiles through the water column from the sea surface to the seabed. This can be accomplished with a number of instruments attached to conductivity-temperature-depth systems. Included in this analysis should be an estimation of the depths of the sound fixing and ranging (SOFAR) channel, which efficiently conducts noise (and would be a depth range specifically targeted for noise minimization). To characterize temporal variability in ambient noise levels, autonomous recorders,

several of which are commercially available (e.g. EARS, HARP), should be deployed on moorings, which could be used in tandem with other mooring equipment and left for a year. [Recommendations III.A.13; III.B.14]

44. **Vertical migration**. The vertical migration dynamics of mesopelagic zooplankton and nekton mean that sampling should be carried out both during the daytime and at night to determine the variation in vertical distribution. Tows should be carried out at depths above the likely plume height, as well as at several depths within it, and repeated temporally to account for vertical migrators. This will be site-specific, but the general depth bins defined in paragraph 42 (b) above should be a good starting point. At least three tows should be done at each level to give information on faunal variability at depth over the area of interest. [Recommendation III.B.15.(d).(iii)]

45. **Trace metals and potential toxic elements** should be assessed in muscle and target organs of dominant demersal fishes and invertebrate species. This should be replicated over time before test-mining operations begin (to measure natural variability) and at least annually thereafter 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 or the nekton that consume them, if the discharge plume occurs at the sea surface or in mid-water. On board bioassay for seawater quality monitoring using a delayed fluorescence of microalga is a potential approach. A range of common trace metals (e.g. arsenic, chromium, copper, cadmium, lead, mercury, nickel and zinc) are generally used to provide a baseline suite of potential contaminants of concern. An extended suite of trace elements may be required for mining-related studies in areas targeting rare earth elements. However, an assessment of the bulk toxicity of a resource (or discharge) may be more practical. The measurement of whole organism concentrations of bioaccumulated contaminants from a species sampled along a gradient from impacted sites to distant reference sites will provide a robust initial assessment approach. [Recommendation VI.D.40.(f)]

46. The temporal duration of environmental studies should also be relative to the setting. They should be long enough, with regular sampling, to understand seasonal and inter-annual variation and other relevant, potentially episodic and extreme, events. For example, tidal movements will affect sediment plume settling patterns. 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). The temporal study should be reviewed by the Authority prior to the start of test-mining. Studies of temporal variation at the seabed should be based on video and/or photographic surveys as well as current-meter studies. For sulphide deposits, associated temperatures and sampling of subhabitats are required. Simple time-lapse photography seabed observatory systems recording the seabed and effluent temperatures four to five times per day over a period of a year would provide high-resolution temporal data. Where possible, to provide information on ecosystem function, trophic structure and assemblage resilience to disturbance, ecosystem studies, such as growth rates, recruitment rates and the trophic status of dominant taxa, should be carried out. Where multiple test-mining sites are identified, the contractor must assess the degree to which temporal studies at one site are applicable to another; this assessment should also be reviewed by the Authority. [Recommendations III.B.15; VI.B.33–35]

47. Taxonomic standardization should be addressed. To facilitate identification, there should be an exchange of identification codes, keys, drawings and sequences at major laboratories and collections that carry out taxonomic studies of marine

organisms. Ideally, there will be consistency in this regard among contractors in a region. Taxonomic expertise is extremely limited, even for major faunal groups (e.g. fish, molluscs, crustaceans, corals, sponges, annelids and echinoderms). It will be important for all taxonomic groups to be assessed at each site. This can be accomplished most efficiently through the development of cooperative taxonomic centres or groups of experts. Taxonomy by numbers (e.g. species 1, species 2), if consistent rules are used and voucher specimens maintained, is a good basis for baseline studies, but classical and molecular taxonomy must be supported, either directly by the contractor or as part of cooperative research programmes. Modern taxonomy requires the application of molecular methods. Barcodes, or DNA sequences suitable for species identification, together with the morphological information, provide a more accurate and consistent identification. To maintain the link between morphology-based identifications and molecular-based identifications, the process of reverse taxonomy is advocated. This is a process in which a gene sequence (or sequences) is used as a barcode and the specimen from which the molecular material was obtained is imaged and its morphology described. The two sets of information are then published together in a scientific journal as well as added to international databanks (e.g. GenBank). These descriptions can help identify material collected by past sampling programmes. Molecular methods continue to advance rapidly, making biotic surveys at all levels, especially the level of microorganisms, much more rapid and economically feasible. Molecular sequences should be deposited in GenBank or equivalent internationally recognized sequence databases. Voucher specimens and molecular samples, including DNA extracts, should be deposited in a recognized curated collection facility such as a natural history museum and therefore be made available for wider study. [Recommendations III.B.14; III.B.15.(d).(i)–(iii) and (vii); IV.A.22]

48. For very small organisms (bacteria, archaea, micro- and meiofaunal protozoa and metazoa) metagenomic analyses using high throughput sequencing (next generation sequencing) is rapidly becoming a standard tool. Archiving frozen sediment samples (-80ºC) for future analysis is simple and relatively inexpensive and could be done regardless of the current ability to fund analyses or available bioinformatics skills. A clear and robust data management plan for molecular data annotation, storage and sharing needs to be developed for projects involving next generation sequencing protocols. This is especially relevant to diversity-cataloguing efforts and for collecting metadata associated with frozen sediment samples for the automation and efficiency of future workflows for both wet lab processing and bioinformatic/ statistical analyses. [Recommendations III.B.15.(d).(ii)–(iii); III.B.17.(c); VI.D.40.(b)]

49. Information on faunal succession following test-mining or testing of mining components is essential to determining recovery rates of benthic populations from the effects of mining. 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. Such impact experiments may be conducted collaboratively. [Recommendation VI.D.40.(b)–(d)]

50. Additional information on the effects of the discharge plume on pelagic fauna should be gathered by temporal studies similar in design to sea floor successional studies (see above) as well as recording of unusual natural events, such as fish kills and unusually large concentrations of fish, marine mammals, turtles and birds. [Recommendation VI.D.40.(d)]

51. **Marine mammals, birds, turtles and sharks**. It is important to know if such sensitive and/or protected species occur in the general region of potential mining. If observations recorded in transit to and from areas of exploration and on passage between stations are to be useful, they should be carried out in a systematic way by a single person or by a team of two. For example, the widely used marine mammal

observer protocols developed by the Joint Nature Conservation Committee of the United Kingdom of Great Britain and Northern Ireland or the protocols developed for the Edokko Mark 1 (SIP protocol series No. 4), might be considered. Wherever possible, records of mammals, sharks, turtles and seabirds should be backed up by photographs. Direct observations will give an idea of the extent to which marine mammals occur in the contract area, but they need to be combined with other information on the likely behaviour of the animals in the general region. Seasonal migration patterns are known for many species, while tracking data are available in some areas. Other information especially relevant to marine-mammal impacts includes studies of the ambient noise throughout the water column and the levels of noise generation expected to result from mining activities. [Recommendation III.B.15.(d).(vi)]

Bioturbation

52. The collection of data on bioturbation is targeted at collecting the background "natural" rates of sedimentary processes, including "natural spatial and temporal variability", in order to model and evaluate the effects of mining activities on such processes. Rates and depths 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, taking into account the variability in the sediment. Excess Pb-210 activity should be evaluated on at least six levels per core (suggested depths are 0–0.5 and 0.5–1.0 cm; 1–2 and 2–3 cm; and 3–5, 5–7 and 7–9 cm), and for at least four replicate cores (e.g., tubes from separate multiple corer drops) per site. Rates (Db) and depths of bioturbation (mixed layer) are to be evaluated by standard advection or direct diffusion-reaction models but may need to include non-local exchange terms. Additional methodologies include analysis of excess Th-234 and sediment profiling imagery. [Recommendation III.B.15.(e)]

Fluxes to the sediment

53. With regard to fluxes to the sediment:

(a) Baseline data on this group is collected to model and evaluate the effects of the discharge plume. Given that the flux of materials from the upper water column into the deep sea is ecologically significant in the food cycle of bottom-dwelling organisms, an adequate characterization of the material flux in mid-water and flux to the sea floor is necessary for a comparison with the effect of the tailings discharge plumes. Knowledge of in situ settling velocities for test-mining or testing of mining components discharge particles, both in mid-water and near seabed-disturbance and discharge plumes, will help to verify the predictions of mathematical models regarding the dispersion of mid-water and benthic plumes and improve those predictions in the future. This information is relevant to the concerns expressed regarding the discharge plume and from the operation plume on the benthic biota and benthic boundary layer pelagic organisms;

(b) It is recommended that moorings with sediment traps be deployed, with one trap below 2,000 m to characterize the particulate flux from the euphotic zone, one trap approximately 500 m above the sea floor and one trap at 10 m above the sea floor within the benthic boundary layer to characterize the baseline fluxes of materials in the water column and 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). The trap installation may share the same mooring as the current meters described above if practicable (and avoiding mooring "sag"). The temporal resolution of the particle-flux measurements must be one month or better and nephelometry time series should be recorded on the sediment traps. [Recommendations III.A.13; III.B.15.(f)]

Data management

54. Part IV of the recommendations deals with data collection and reporting. It is recommended that collection and analytical techniques follow best practices such as those developed by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization and available at world data centres, national oceanographic data centres or those recommended by the Authority. An inventory of the data holdings from each contractor should be accessible on the World Wide Web via the Authority. [Recommendation IV]

55. The environmental baseline studies and the monitoring programmes represent a significant source of data and knowledge. A data archival and retrieval scheme could assist all contractors in the search for environmentally significant indicator elements. Syntheses of data and experience can work to the advantage of all contractors. Increased data accessibility increases the likely accuracy of models and will assist in:

(a) Identification of best practices;

(b) Development of a common approach to data management;

(c) Multilateral exchange of views and data leading to international cooperation;

(d) Savings of time, effort and costs in alerting the community to failures;

(e) Savings through reduction of measurement of some parameters. [Recommendations IV; V]

56. Models can be validated and fine-tuned by such ground-truthing of data and can then partially supplement costly data-collection exercises. Some claim areas may lie adjacent to or in the vicinity of other claims, providing further justification for data accessibility and joint efforts in modelling, so that the impact of activities in neighbouring areas do not interact, and so that impacts might be evaluated without repeating all aspects of environmental assessment. [Recommendations V; VI.C.38.(e)]

Cooperative research

57. Part V of the recommendations deals with cooperative research and recommendations to close gaps in knowledge. Recent years have witnessed a revolution in the development of knowledge and technology in deep-sea science. A number of research institutes around the world are carrying out extensive research programmes. Those institutions have considerable biological and scientific expertise and could be willing to join with mining contractors in conducting some of the required environmental research. They could provide sampling equipment and expertise and assist in sampling remote areas. [Recommendation V]

58. Cooperative research can facilitate the establishment of baselines of natural variability on the basis of geological, biological and other environmental records acquired in selected areas at a range of scales from sites within a licence area to broad regional areas. [Recommendation V]

59. A partnership between the scientific community and contractors may result in improved voucher collection repositories, gene sequence database repositories, stable isotope analysis and interpretation and photographic libraries of species/specimens. The basic scientific information acquired in partnership should result in the cost-effective acquisition of information that will assist in development planning and decision-making and the timely recognition of any significant environmental effects

or issues prior to and during test-mining. This information can be used to find solutions with a minimum-conflict approach. [Recommendation V.30]

60. The effects of mining on biodiversity will depend largely on how localized or widespread the species are distributed, the connectivity among their populations and the distribution of biological communities controlling ecosystem functions. Assessment will require syntheses of the biogeography and community structures of the biota. This assessment should be facilitated by collaboration among contractors and with the scientific community. It would also support the development of appropriate regional environmental management plans. [Recommendations V.29–31]

61. Modelling studies should be undertaken collaboratively and linked closely to the field studies so as to assess extinction risks under various management strategies, including various options for the design of protected areas. Overall conservation strategies need to take into account other natural and anthropogenic impacts on faunal communities. [Recommendation V.30]

62. Contractors should work with each other, with the Authority and with national and international scientific research agencies on cooperative research programmes to maximize the assessment of environmental impact and minimize the cost of these assessments. [Recommendation V.30]

63. The Convention states that the Authority shall promote and encourage the conduct of marine scientific research in the Area and shall coordinate and disseminate the results of such research and analysis when available.

Environmental impact assessment

64. Part VI of the recommendations deals with environmental impact assessment. Certain activities have no potential for causing serious harm to the marine environment and therefore do not require environmental impact assessment. Such activities are listed. 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. [Recommendation VI]

65. The environmental impact statement should describe stakeholder engagement activities that took place during the process, including the consultation timelines, consultation methods and publication milestones.

66. The environmental impact statement should list any stakeholders that were consulted and describe the process by which they were identified. “Stakeholder” means a natural or juristic person or an association of persons with an interest of any kind or with relevant information or expertise.

67. The environmental impact statement should include:

(a) A description of the nature and extent of any consultations conducted for the purposes of the statement;

(b) A description of the protocol used for collecting, logging and responding to stakeholder comments and concerns. The environmental impact statement should include an evaluation of how the consultations aligned with relevant consultation obligations, if any;

(c) A description of the comments and concerns of the stakeholder and how they have been addressed by the contractor in the environmental impact statement.

68. The environmental impact statement, together with the information concerning the stakeholder consultation carried out by the contractor, will be made available on

the website of the contractor and through the website of the International Seabed Authority.

69. The environmental studies during exploration will be based on a plan proposed by the contractor and reviewed by the Legal and Technical Commission for completeness, accuracy and statistical reliability. The plan would then be incorporated into the programme of activities under the contract. The environmental studies to be conducted during exploration will include the monitoring of environmental parameters to provide an environmental baseline. This baseline should enable results from monitoring to establish that there is no serious harm from any activities being conducted on the seabed, in mid-water and in the upper water column. [Recommendations II.C.11–12; III.A.13; III.B.14–16]

70. Tests of mining components or test-mining are an opportunity to determine the environmental implications of mining. The contractor will submit to the Authority a plan for such testing, including the details for monitoring the environment, at least one year before testing begins. A plan for testing of mining components or test-mining shall include provision for monitoring of those areas impacted by the contractor's activities which have the potential to cause serious environmental harm, even if such areas fall outside the proposed test site. The programme will include, to the maximum extent practicable, specification of those activities or events that could cause suspension or modification of the tests owing to serious harm, including if the specified activities or events cannot be adequately mitigated. The programme will also authorize refinement of the test plan prior to testing and at other appropriate times, if refinement is necessary. The plan will include strategies to ensure that sampling is based on sound statistical methods, that equipment and methods are scientifically acceptable, that the personnel who are planning, collecting and analysing data are well qualified and that the resultant data are submitted to the Authority in accordance with specified formats. The procedure for submission and assessment of an environmental impact statement submitted for the testing of mining components and test-mining is given in section E and annex III to the present recommendations. [Recommendation IV]

71. During exploration test-mining, the notification of a proposed impact reference zone and a preservation reference zone is recommended. The impact reference zone should be selected as the site where test-mining will take place. The preservation reference zone should be carefully located and be (a) large enough to be representative of local environmental conditions, and (b) be beyond the range of environmental impacts from the test-mining. The preservation reference zone should have species composition comparable to that of the test area. The preservation reference zone should be within the contractor's area but be outside the test area and areas influenced by seabed-disturbance and discharge plumes. [Recommendation VI.C.38.(o)]

72. The monitoring programme proposed by the contractor must provide details of how the impacts of the testing of mining components and test-mining activities will be assessed. [Recommendation VI.D.40]

Annex II

Glossary of technical terms

Active sulphides	Polymetallic sulphides through which warm or hot water is flowing. Active sulphides (also called hydrothermal vents) deliver reduced compounds (e.g. sulphide) to the sea floor-seawater interface where they can be oxidized or otherwise autotrophically metabolized by free-living or symbiotic microorganisms.
Archaea	Microorganisms thought to be an ancient group, intermediate between bacteria and eukaryotes. Archaea are similar to bacteria in size but different in molecular organization.
ATP	Adenosine triphosphate, a complex organic compound that serves for short-term energy storage and conversion in all organisms. The amount of ATP present can be used as a measure of total microbial biomass in the sediment, as it corresponds to the number of active cells, most of which are bacteria.
Bathypelagic	Pertaining to open-ocean environments at depths greater than 1,000 m to approximately 3,000 m, deeper than the mesopelagic zone, which is 200–1,000 m.
Benthic boundary layer	Pertaining to the layer of water immediately above the ocean bottom water layer/sediment interface that is influenced by the bottom.
Benthos	The forms of marine life that live on, or in, the ocean bottom.
Chemosynthesis	Process by which microorganisms metabolically transform inorganic carbon to organic carbon (cells), using energy derived from oxidation of reduced compounds. Chemosynthesis is the basis for the food web associated with deep-sea hydrothermal vents. “Chemoautotrophy” is a more descriptive and precise term for the general phenomenon of chemosynthesis; the two words are often used interchangeably.
Cobalt-rich ferromanganese crusts	Ferromanganese crusts with enriched cobalt content typically formed by precipitation and found on hard substrata in the deep sea on features with significant topographic relief, such as seamounts and ridges.
CTD	Pertaining to a system for measuring conductivity (indicator of salinity), temperature and depth (defined from pressure measurements). The first two parameters are essential in oceanographic observations and the depth profile is required to delineate the vertical structure of the ocean. Additional parameters, such as pH and dissolved oxygen concentration, can be measured if optional sensors are installed.
Cumulative impacts	Impacts resulting from incremental changes caused by other past, present or foreseeable actions.
Demersal	Organisms living near the sea floor.

Ecosystem	A community of living organisms in conjunction with the non-living components of their environment interacting as a system.
Epipelagic	Referring to the upper region of the ocean depths, above the mesopelagic.
eDNA (environmental DNA)	Genetic material obtained directly from environmental samples (sediment, water, etc.) without any obvious signs of biological source material.
Euphotic zone	The upper section of the ocean which receives sufficient light for photosynthesis. In clear oceanic waters, the euphotic zone can extend to a maximum water depth of 150 m.
Foraminifera	The main protistan component of abyssal benthic communities across the meiofaunal, macrofaunal and megafaunal size categories.
Halocline	A layer of water in which there is a steep gradient in salinity.
Hard substrata	Outcrops in the form of carbonate concretions, solid material, crustal rocks or deposits of precipitated materials, metals and minerals discharged from the subsurface by hydrothermal systems.
High-throughput sequencing	Also “next generation sequencing”. A method for sequencing DNA.
Hydrodynamic	Referring to any event relevant to the movement of sea water.
Impact reference zones	Areas used to assess the effect of test-mining in the Area on the marine environment. The impact reference zone must be in the contractor’s area.
Inactive (or dormant) sulphides	Polymetallic sulphides through which warm water is no longer flowing into the overlying seawater (i.e. they are “cold”). Disturbance of these sulphides may result in renewal of hydrothermal fluxes into the water column, turning inactive sulphides into active sulphides (hence the concept of “dormant” sulphides).
Macrofauna	Animals retained on a 250- or 300-µm mesh, typically sorted and identified with a microscope, that include taxa such as polychaetes, bivalves, isopods and tanaids.
Megafauna	Animals large enough (larger than 2 cm) to be determined in photographs, proposed as key taxon (see taxonomy) for environmental impact assessment in deep-sea mining.
Mesopelagic	Referring to the portion of the oceanic province that is below the epipelagic and above the bathypelagic, usually corresponding to the dimly lit ocean or “twilight zone”.

Metabarcoding	A rapid method of biodiversity assessment that uses universal polymerase chain reaction primers to mass-amplify DNA barcodes from collections of organisms or from eDNA. The polymerase chain reaction product is analysed by a next generation sequencer and results in a wealth of DNA sequences.
Metabolomics	A high-throughput mass spectrometry approach used to analyse the composition and structure of diverse molecules produced in the environment by living organisms in order to screen metabolic exchanges and reconstruct biological interactions, based on the quantification of metabolites and other biomolecules involved in processes ranging from specific ecological signalling to large-scale ecosystem functioning.
Metagenomics	The application of modern genomics techniques without the need for isolation and lab cultivation of individual species. Used particularly in microbial studies.
Metozoan meiofauna	Animals of the benthic community that include taxa such as nematodes, harpacticoid copepods, ostracods and kinorhynchs. Operationally defined as >32 µm.
Microbiota	Organisms invisible to the naked eye, smaller than meiofauna. Operationally defined as <32 µm.
Microorganisms	Includes bacteria, Archaea and microscopic Eukarya.
Near-bottom layer	The region just above the sea floor associated with the benthic boundary layer. It generally relates to a distance of up to 50 m above the sea floor.
Nekton	Fish, squids, crustaceans and marine mammals that are active swimmers in the open ocean environment.
Next generation sequencing	High-throughput sequencing: a DNA sequencing method that produces large volumes of data.
Oxygen minimum	A water layer present in all oceans at depths between 100–1,000 m, caused by the sinking and degradation by bacteria of organic matter produced in the surface ocean. The oxygen scarcity can cause particulate metals to dissolve. An oxygen minimum is distinct from an oxygen minimum zone, which is defined as having very low oxygen content (<0.5 ml/L O_2), and is found in distinct geographic regions of the ocean (e.g. overlying the Clarion-Clipperton Fracture Zone).
PCR	Polymerase chain reaction: a method of DNA enrichment that allows for the copying of sufficient amounts of molecules that are specific to a gene marker region for the completion of sequencing approaches referred to as targeted metagenomics (or metabarcoding).
Pelagic	Pertaining to the open ocean environment.
pH	A measure of acidity based on the concentration of hydrogen ions.

Photosynthesis	The biological synthesis of organic material using light as an energy source. Plants convert carbon dioxide and water, in the presence of chlorophyll and light energy, into carbohydrate food and oxygen.
Phytoplankton	Microscopic plants that are primary producers in the oceans.
Plankton	Passively drifting or weakly swimming organisms. This includes larval stages of benthic and pelagic organisms, phytoplankton (in surface waters), zooplankton, jellies, larvae of benthic invertebrates and other drifting or weakly swimming organisms.
Plume	A dispersion of seawater that contains dense sediment particles. Seabed-disturbance plume is a stream of water containing suspended particles of seafloor sediment, abraded minerals and macerated benthic biota that emanates from the mining collector as a result of collector disturbance of the sea floor and spreads in a zone close to the sea floor. The far-field component of the seabed-disturbance plume is termed the “rain of fines”. Discharge plume is a stream of water containing suspended particles of sea floor sediment, abraded minerals and macerated benthic biota resulting from the separation, on board the mining ship, of the nodules from the water carrier, and spreads in a zone closer than seabed-disturbance plume to the ocean surface.
Polymetallic sulphides	Hydrothermally formed deposits of sulphides and accompanying mineral resources in the Area, which contain concentrations of metals including copper, lead, zinc, gold and silver.
Pore water	The water present within the spaces between sediment particles; also called “interstitial water”.
Preservation reference zone	For exploration, a preservation reference zone is identified as part of test-mining. The zone selected should be comparable to the test-mining area. The preservation reference zone should be carefully located and large enough not to be affected by testing activities, including the effects from seabed-disturbance and discharge plumes. For test-mining, a preservation reference zone should be within the contractor’s area, if possible. The aim of this zone is to act as a control area.
Pycnocline	A layer of water in which there is a steep gradient in density with depth. It separates the well-mixed surface waters from the dense waters of the deep ocean. Density of the water is a function of temperature, salinity and, to a lesser extent, pressure.
Rain of fines	Far-field component of the seabed disturbance plume that consists mainly of fines: sedimentary particles that drift with the bottom current and slowly settle to the sea floor, generally outside the specific mining area.
Redox system	One essential chemical reaction is oxidation (giving electron) and reduction (removing electron). The chemical tendency (environmental strength) of oxidation can be expressed by redox potential (mv) that can be measured by an Eh/Ph meter. Eh is strongly correlated to the dissolved oxygen concentration in the sediment.

Scavenger	An animal that eats waste products and dead remains of other animals and plants that they did not kill themselves.
Seamounts	Isolated topographic features, usually of volcanic origin, of significant height above the sea floor.
Serious harm	Any effect from activities in the Area on the marine environment that represents a significant adverse change in the marine environment, determined according to the rules, regulations and procedures adopted by the International Seabed Authority on the basis of internationally recognized standards and practices informed by the best available scientific evidence.
Spatial scale	Scales characteristic of dimensions in space, as of oceanic phenomena, for example, the diameter of an eddy or the length of a wave. Also pertains to the geographical arrangement of sampling stations.
Stable isotope analysis	The identification of isotopic signature: the distribution of certain stable isotopes and chemical elements within chemical compounds. When applied to food webs it can be used to draw direct inferences regarding diet, trophic level and subsistence. Variations in isotope ratios from isotopic fractionation are measured using mass spectrometry, which separates the different isotopes of an element on the basis of their mass-to-charge ratio.
Subhabitat	A visually recognizable component of a larger habitat, for example, tubeworm and mussel beds may be subhabitats of a specific active polymetallic sulphide field; an operational term that facilitates an understanding of the habitat as a whole.
Symbioses (chemosynthetic)	Associations between bacteria (symbionts) and invertebrates or vertebrates (hosts), in which the symbionts are chemosynthetic and provide nourishment to the host. The bacteria may be either endosymbiotic (living within the host tissues, such as tubeworms, clams, mussels) or episymbiotic (living on the outside of the host, such as bresiliid shrimps, alvinellid polychaetes).
Synoptic scales	Scales of hydrodynamic variability or events encompassing temporal scales ranging from one to two weeks to one to two months and spatial scales of one to several hundred kilometres. A typical feature is synoptic eddies 100–200 km in diameter passing through the north-east tropical Pacific from east to west and often penetrating to the sea floor.
Taxonomy	Orderly classification of animals or plants according to their presumed natural relationship.
Test-mining	The use and testing of a fully integrated and functional mining system including collection systems and water discharge systems.
Testing of mining components	The use and testing of recovery systems and equipment and the component parts of a mining system, including seafloor collectors, riser systems and equipment and discharge systems and equipment.

Thermocline	A layer of water in which there is a rapid change of temperature with depth.
Transect	The vertical plane (reference for all the measures and sampling taken during the survey), from surface to the sea bottom, of the route of a survey oceanographic vessel, from point A to point B.
Zooplankton/ animal plankton	Unlike phytoplankton, these organisms cannot produce organic matter on their own and thus feed on other organisms.

Annex III

Environmental impact statement template for reporting an environmental impact assessment undertaken during exploration

The purpose of the environmental impact statement is to document and report the results of the environmental impact assessment process. The assessment of impacts should be appropriate to the nature and extent of the activity being considered. The environmental impact statement documents the project's parameters and the way in which the environmental assessment has been undertaken, including the predicted impacts of the project, proposed measures for mitigation, the significance of residual effects and the uncertainties that affect the predictions and how to address them, as well as concerns raised in consultations and how they have been addressed. The contractor should use the major headings set out below, as appropriate to the activity, and introduce subheadings or text divisions in order to present the information in a logical and coherent manner.

Template

Executive summary

1. Introduction
2. Policy, legal and administrative context
3. Description of the proposed activity
4. Description of the existing physico-chemical environment
5. Description of the existing biological environment
6. Assessment of impacts on the physico-chemical environment and proposed mitigation
7. Assessment of impacts on the biological environment and proposed mitigation
8. Accidental events and natural hazards
9. Environmental management, monitoring and reporting
10. Consultation
11. Glossary and abbreviations
12. Study team
13. References
14. Appendices