BUILDING ROBUST DEEP-SEA ENVIRONMENTAL BASELINES: A FOUNDATION FOR SUSTAINABLE MINERAL RESOURCE MANAGEMENT

Summary

This policy paper consolidates current scientific and methodological knowledge on establishing robust environmental baselines in the Area. It outlines the legal and regulatory context, key data types and sampling methodologies that support the mandate of the International Seabed Authority for the effective protection of the marine environment under Part XI of the United Nations Convention on the Law of the Sea and the 1994 Agreement. The paper is intended to support contractors, Member States and scientific partners in developing consistent, data-driven approaches to environmental assessment, monitoring and management.

Introduction

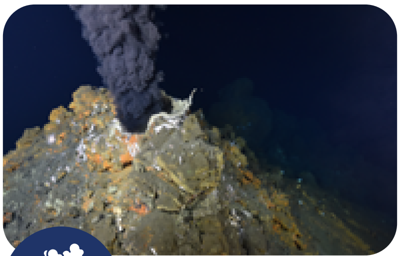
Environmental baseline data play a crucial role in expanding our understanding of the deep-sea environment and serve as a foundation for assessing the environmental impacts of various human activities. Gathering and interpreting this data often demands specialized scientific and technical expertise. This policy paper provides an overview of the process for baseline data-collection, covering key aspects such as legal and policy requirements, recommended sample types and quantities, sampling and storage methods and the practical use of the collected data in target areas for effective management of activities in the Area.

Why collect environmental baseline data?

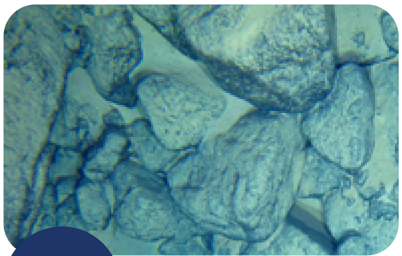
Under the United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Agreement relating to the implementation of Part XI of UNCLOS of 10 December 1982 (1994 Agreement), the International Seabed Authority (ISA) is required to regulate and control activities in the international seabed area (the Area). In this context, environmental baseline data is a key component for ensuring the effective protection of the marine environment from harmful effects that may arise from activities in the Area (UNCLOS, Article 145). In addition, ISA is mandated to promote and encourage the conduct of marine scientific research in the Area and coordinate and disseminate the results and analysis when available (UNCLOS, Article 143). Baseline studies represent both a scientific and regulatory cornerstone of ISA's environmental management framework.

The primary goal of collecting environmental baseline data is to understand the natural variability of the ecosystem and predict potential changes in the environment resulting from human activities. Environmental data also provides the foundation for assessing the potential impacts of exploration and exploitation activities on marine ecosystems before they commence. Additionally, environmental baseline data guide the development of methodologies and form the basis for long-term monitoring programmes, ensuring alignment between management plans and environmental impact assessments during future exploitation. In the context of deep-sea mining, the collection of baseline data is explicitly required under the exploration regulations for polymetallic nodules, polymetallic sulfides and cobalt-rich ferromanganese crusts (Figure 1).

Polymetallic nodules



Polymetallic sulphides



cobalt-rich ferromanganese crusts

Figure 1. Main types of deep-sea mineral resources under exploration by ISA's contractors

According to the 1994 Agreement and the exploration regulations, the following three groups have a responsibility related to environmental baselines:

- The Legal and Technical Commission (LTC) has the role to develop and implement procedures, based on the best available scientific and technical information, for determining whether proposed activities in a target area would have serious harmful effects on vulnerable marine ecosystems
- Contractors are required to gather environmental baseline data to establish the ecosystem conditions that are likely to be affected by their programmes of activities
- Contractors and sponsoring States are required to cooperate with ISA in implementing programmes for environmental monitoring and evaluation.

To support contractors and ISA Member States, the LTC has developed Recommendations to guide the contractors assessing possible environmental impacts arising from the exploration of marine minerals in the Area (2023). These recommendations are under regular review to reflect improved scientific knowledge, technical developments and technological advances. The LTC is also developing Draft guidelines for establishing baseline environmental data to guide the collection of environmental data during future exploitation activities.

What data should be collected?

A robust environmental baseline assessment is inherently multidisciplinary, integrating physical, chemical, geological and biological data to provide a comprehensive understanding of deep-sea ecosystems .

Physical oceanography: The main objectives for establishing a baseline of the physical oceanography of a contract area are to define the hydrophysical and hydrodynamic conditions, the structure of the water column, and its variability. This information is used to understand the habitats of marine organisms, to define a detailed sampling strategy for other disciplines, and to assess the potential dispersion, size and characteristics of any operational or discharge plume. Parameters to be determined include the physical properties of the water masses (e.g. temperature, depth and salinity), natural water movement (e.g. currents, tides and waves) and background physical parameters (e.g. noise and light).

Chemical oceanography and biogeochemistry: An understanding of the chemical environment of the water column and sediments (solid fraction and porewater) is required to characterize baseline oceanographic and biogeochemical conditions and assess the impacts of future mining activities, such as sediment contamination and removal and suspended sediment plumes. The latter could potentially lead to blanketing of the seafloor and turbidity in the water column, which would impact the biological communities. A suite of pre-defined measurements should be taken to determine the chemical composition of the water and the seabed.

Geological properties: In combination with biogeochemical parameters, geological properties (bathymetry and geomorphology, geological setting, sediment and stratigraphy, diagenesis, weathering and remobilization, rock substrate geochemistry and mineralogy, mineral resource geochemistry and mineralogy) are collected to characterize the habitats and to determine the heterogeneity of the seafloor and the sub-seafloor environment. These data are essential while defining the sampling locations to characterize the distribution and composition of biological communities. Measurements are taken to map large and small-scale seabed morphological features and to characterize the sediment properties and habitats.

Biological communities: When most people consider the impact of human activities on the environment, they are ultimately concerned with the impact on the biological communities, which include all living organisms on the seafloor, near the seafloor and in the overlying water column, all the way to the surface. Biological communities across different size classes, from bacteria to marine mammals, such as whales, need to be characterized to evaluate the potential impacts of human activities on them. Parameters to be determined include behaviour, biomass, functional traits, species diversity, composition and distribution, connectivity between sites and ecosystem functioning.

These parameters form the core data set required to characterize ecosystem structure and function in the Area and to support the design of environmental management tools, including regional environmental management plans.

How much data is needed?

The spatial and temporal scales of environmental variability determine the sampling effort required to establish a reliable baseline . The magnitudes and spatiotemporal variabilities of environmental factors vary across different variables and ecosystem components (e.g., pelagic or benthic). As a result, the required number of stations, replicates and the frequency of data-collection must be tailored to each specific component. To accurately characterize the environment and minimize data uncertainty within a region, data-collection should be station-oriented (local-scale) and repeated observations should be conducted to detect changes over time (e.g., seasonal and inter-annual variations) and across space (e.g., horizontal and vertical gradients at the regional scale). It is important to note that the environmental baseline is a multi-scale approach, and within each scale, different sampling methodologies are applied to address different objectives (Figure 2). Such integrated knowledge can be further used to optimize the number of samples required and to determine the most appropriate locations for new data-collection. Contractors are thus strongly encouraged to adopt the best available techniques and adhere to good industry practices to improve data acquisition and minimize unnecessary environmental impacts.

Scale	Objectives	Sampling metodology	Data collected
Basin	• Identify main oceanographic process • Detect spatial and temporal variability of those processes	Satellite images Continuous data	Surface productivity
Regional	• Describe the main habitats • Investigate habitat connectivity	Side-scans Cruise-oriented	Seafloor images
Local	• Study biological communities • Investigate the links between biological communities and environmental conditions	Samplers Station oriented	Sediment samples

Figure 2. Examples of sampling methodologies and data collected for different objectives at different spatial scales

Sampling strategies should be based on the best available research and data, and evolve as new information emerges. Regular revisions are essential to ensure these strategies remain fit for purpose and effectively capture relevant spatial and temporal variability. The exact number of samples required for baseline data depends on the type of habitat (e.g., nodules in abyssal plains, crusts in seamounts, and sulfides in mid-ocean ridges), regional heterogeneity, and the proposed mining activity (e.g., dragging, crushing or cutting). The sampling design should account for the environmental variables and the ecological processes influencing them. The final design should consider the appropriate representation of the temporal variation of the ecosystem to distinguish it from eventual changes caused by the mining operations from natural oscillations. This requires substantial sampling effort and replication, and it is better achieved by expert opinion through statistical analysis. Without this knowledge, any environmental oscillation observed during mining operations would be exclusively assigned to exploitation activities, hampering the sustainable use of the resources.

Collaborative work and integration of multiple data sets can reveal broader patterns (basin-scale), aiding the interpretation and application of baseline observations. This integrative, multi-scale approach supports the development of regional environmental management plans, helping standardize procedures across a region and optimize the work of individual contractors.

Over the past two decades, efforts to collect environmental baseline data in areas targeted for mineral exploration have increased significantly. By 2024, ISA contractors had invested approximately USD414 million in environmental baseline studies and conducted 270 research cruises. These efforts have notably expanded the availability of environmental data, particularly concerning the deep-sea environment and its biodiversity (Figure 3).

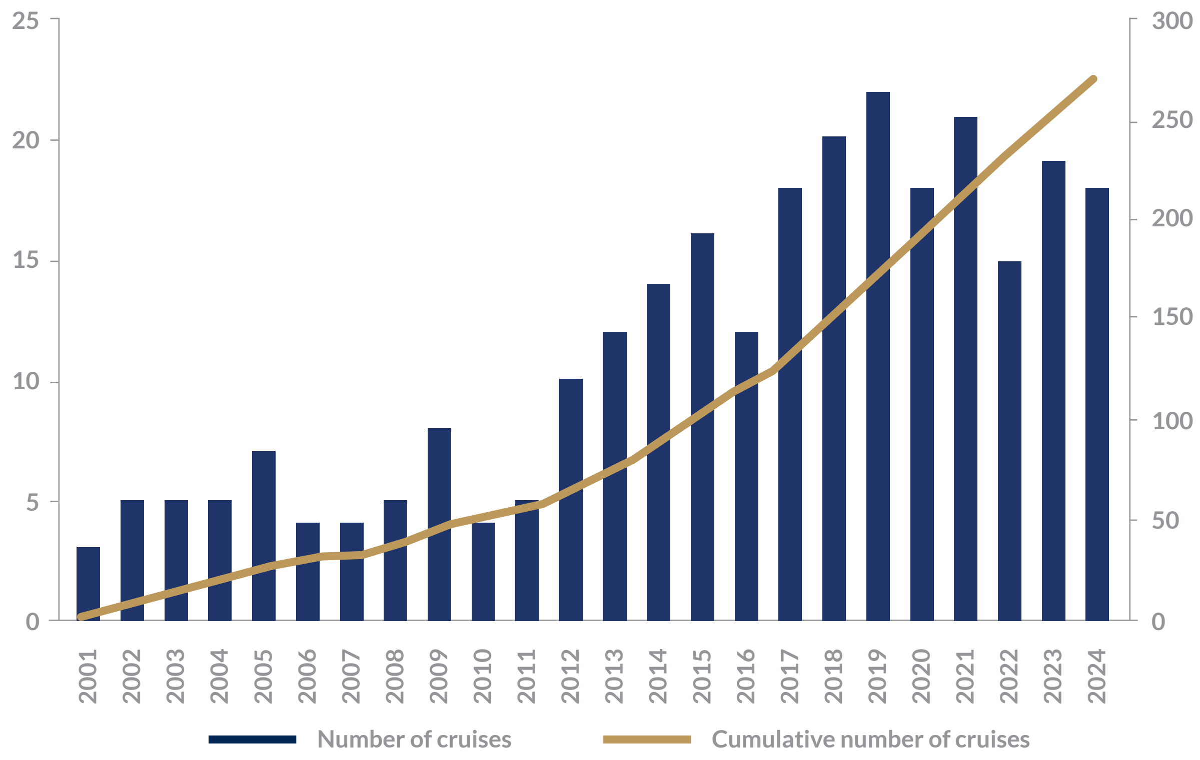


Figure 3. The annual and cumulative number of cruises conducted by ISA contractors from 2001-2024

Other multiannual scientific research projects have further advanced scientific knowledge and established requirements for baseline surveys and monitoring possible impacts. Examples of these scientific initiatives can be found in the 2024 ISA report, The contribution of the International Seabed Authority to the scientific objectives of the UN Decade of Ocean Science for Sustainable Development.

Such integrative, multi-scale approaches are central to ISA's environmental management framework and contribute directly to regional-scale assessments and policy-relevant analyses.

How should data be collected?

The environmental baseline recommendations and guidelines issued by the LTC describe the procedures to be followed for acquiring data to support collaborations, facilitate the reporting and archiving by contractors.

Sampling techniques and processes are subject to ongoing development. The best available techniques and technologies should be used to characterize the environment adequately. This requires independent feedback from relevant experts in the field to indicate suitable adjustments when needed. It is also essential to ensure that data obtained with different approaches are consistent, enabling integrated assessments of all data.

In some disciplines, technological evolution is rapid. For example, molecular techniques were rarely used in biological studies when ISA was established, yet they are now commonplace. ISA has also led the way in improving the standardization of techniques and biological classifications. The Technical Study 13: Deep Sea Macrofauna of the Clarion-Clipperton Zone contains presentations from a taxonomic standardization workshop held in Uljin, the Republic of Korea, from 23 to 30 November 2014. Finally, the ISA's Technical Study 7: Marine Benthic Nematode Molecular Protocol Handbook (Nematode Barcoding) from 2015 is the first deep-sea DNA barcoding manual ever produced. In addition, advances in DNA methodologies were discussed during the 2022 ISA workshop, Enhancing Genetic Approaches to Advance Deep-Sea Taxonomy, held in Seochon, Republic of Korea.

The sampling programmes should be adaptable to respond to increased knowledge of the mining technology to be used for resource exploitation, as well as to the natural spatial and temporal variability. Changes in sampling strategies, particularly discontinuing observations at specific sites or during certain seasons, should be implemented with caution to avoid missing episodic events, failing to capture inter-annual variability, or introducing inconsistencies that hinder temporal analysis. One challenge in collecting environmental data is the time required for both collection and processing. While some data, such as large-scale physical parameters like temperature and salinity measured by satellites, can be gathered in real time with minimal processing, other types require more effort and foresight. For instance, assessing ecosystem functioning involves biological sampling at sea, followed by extensive processing in laboratories, which demands careful planning well ahead of any mining activities.

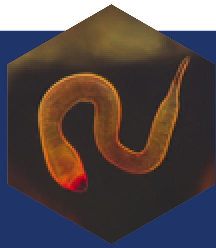
The continuous improvement of data-collection methodologies and taxonomic standards remains a central focus of ISA's technical work, ensuring comparability, transparency and scientific robustness across all contract areas.

How is the data stored and used?

To effectively monitor the marine environment and assess potential impacts from exploratory activities, the data collected must be standardized across surveys within a contract area and among various contract areas for regional-to-basin-scale comparisons. The comparisons enable the identification of common causes driving natural environmental changes and potential changes caused by future specific mining activities. It also facilitates understanding of cumulative impacts and supports the evaluation of management measures, such as the designation of areas for environmental preservation. In this regard, the ISA has undertaken efforts to standardize biological data, including the classification and naming of newly discovered species as part of its Sustainable Seabed Knowledge Initiative.

Sustainable Seabed Knowledge Initiative

In 2022, ISA launched the SSKI, which includes multiple activities whose outputs will contribute to increased knowledge on deep-sea ecosystems. In the context of baseline studies, SSKI is particularly focused on providing knowledge and tools to facilitate the biological characterization of deep-sea areas under mineral exploration. The scheme below shows SSKI outputs that can provide important contributions in the context of baseline studies.



Innovative tools

- CCZ species checklist (436 named species / 5,578 records)
- Species checklists for all regions in progress
- DNA and trait reference libraries in progres

New knowledge

"One Thousands Reasons" launched in 2024-2025 to fund taxonomy projects

- 16 projects approved
- 270,000 USD granted
- 190 new species described

Data sharing

- Improved quality control in DeepData
- New data templates with the Darvin Core principles (international standards)
- Data flow between DeepData and OBIS improved

Standardized data plays a vital role in helping ISA fulfil its mandates for marine environmental protection. These mandates include safeguarding the marine environment from potential harmful effects of mining activities in the Area, developing and reviewing regional environmental assessments and management plans, ensuring public access to environmental information and creating robust monitoring programmes.

Environmental baseline data collected in the Area are stored in DeepData, an online georeferenced database created by ISA. In accordance with the regulations, some of its information is confidential and only accessible to the Secretariat and the LTC. However, environmental data are open and freely available to the scientific community and the general public, ensuring transparency and reproducibility. The database has grown over the last few years and will continue to grow, serving as a resource both for ISA and the wider deep-sea community. At the time of writing, DeepData hosted more than 177,000 records of occurrences of biological organisms. Since 2021, ISA has been part of UNESCO's Intergovernmental Oceanographic Commission's International Oceanographic Data and Information Exchange network as an Associate Data Unit, sharing its biological data with the network's database, the Ocean Biodiversity Information System. This promoted interoperability among databases and the use of environmental data collected by the ISA contractors and the scientific community worldwide. Similar efforts are made to share the oceanographic data hosted in DeepData.

Finally, cooperative research is recognized as a valuable means of generating additional data to support the protection of the marine environment and the sustainable use of mineral resources. Collaboration between contractors and the scientific community in oceanographic research is strongly encouraged, allowing stakeholders to build on one another's findings and achieve a deeper understanding of the target ecosystems.

Policy recommendations

A comprehensive legal framework and technical guidance are already in place under ISA regulations to support the development of environmental baselines. Building on these, Member States, contractors and partners are encouraged to focus on the following policy priorities to strengthen evidence-based decision-making and ensure effective environmental protection in the Area:

1. **Sustain long-term investment in environmental baseline data-collection**
Continued financial and technical support is essential to achieve adequate spatial and temporal coverage across contract areas and regions. Sustained investment will ensure data reliability, comparability and scientific integrity, thereby enabling informed regulatory decisions.

2. **Promote the use of best available techniques and good industry practice**
Sampling design and execution should continue to follow internationally recognized standards and recommendations of the LTC, ensuring consistency and quality across all contractors' programmes.

3. **Strengthen regional and sub-regional coordination**
When standardized data sets are available, they should be leveraged to inform regional environmental management plans and cumulative impact assessments. ISA may facilitate regional cooperation mechanisms to harmonize monitoring and data-sharing.

4. **Enhance interoperability and accessibility of environmental data**
Platforms such as DeepData should be further developed for accessing high-quality environmental baseline data. Improved interoperability with international databases (e.g., OBIS) will enhance transparency, comparability and global scientific collaboration.

5. **Foster cooperation under global ocean governance frameworks**
Existing ISA resources and methodologies can contribute to the implementation of the Agreement on Biodiversity Beyond National Jurisdiction (BBNJ), including obligations related to the equitable sharing of marine genetic resources. Synergies between ISA and BBNJ mechanisms will strengthen coherence, avoid duplication and advance common objectives for the conservation and sustainable use of marine biodiversity beyond national jurisdiction.

6. **Support capacity development and technology transfer**
ISA and its partners should continue to facilitate training, data standardization workshops and collaborative research to ensure that developing States can fully participate in environmental baseline studies and benefit from new technological advances.

Collectively, these policy actions will reinforce the implementation of ISA's environmental management objectives under Part XI of UNCLOS and the 1994 Agreement. By maintaining a strong scientific foundation for regulatory decision-making, ISA and its Members can ensure that activities in the Area are conducted for the benefit of humankind as a whole and in harmony with the protection of the marine environment.

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