IMPLICATIONS OF MIDAS RESULTS FOR POLICY MAKERS:

RECOMMENDATIONS FOR FUTURE REGULATIONS

MIDAS

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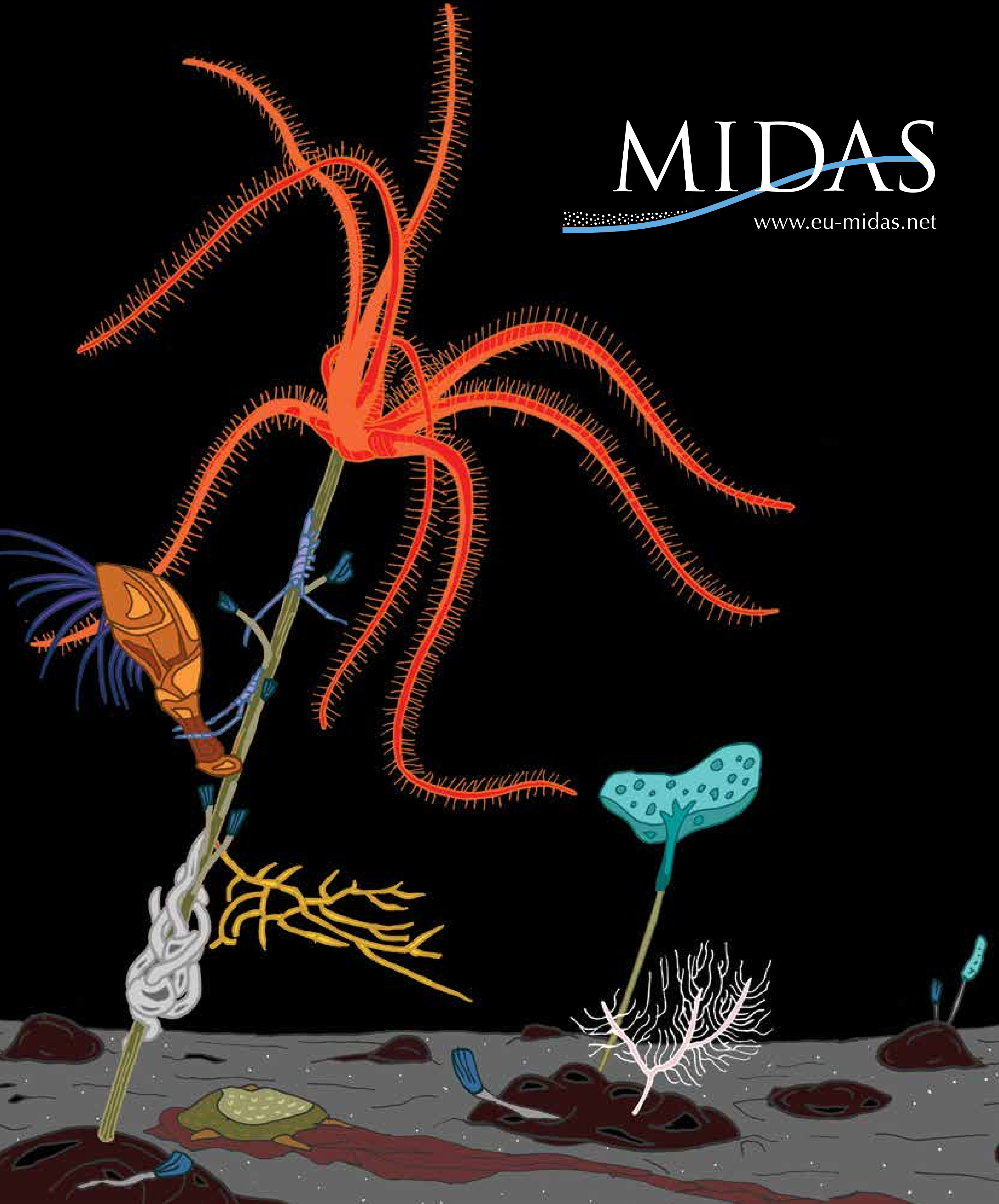

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Cover image: Manganese nodules can support increased local abundances of sessile and mobile fauna. In this illustration, a dead sponge stalk has been used as a substrate by sessile polychaete worms, a barnacle and a coral colony. Mobile isopods and starfish are also using its structure, possibly to assist in filter feeding within the faster flowing waters some centimeters from the seafloor. Illustrated by Autun Purser, based on the MIDAS / JPIO image data collected from the Peruvian Basin during Sonne Cruise SO242/2 by the AWI OFOS Launcer team.

The MIDAS project received funding from the European Union's Seventh Programme for research, technological development and demonstration under Grant Agreement No. 603418.

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December 2016

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List of acronyms

Area	The seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction
ABNJ	Areas beyond national jurisdiction
APEI	Areas of Particular Environmental Interest
AUV	Autonomous Underwater Vehicle
BAT	Best Available Technique
BEP	Best environmental practices
BIE	Benthic Impact Experiments
BPEO	Best Practicable Environmental Option
CBA	Cost benefit Analysis
CCZ	Clarion-Clipperton Zone
CHM	Common Heritage of Mankind
EBSA	Ecologically or Biologically Significant Areas
e-DNA	Environmental-DNA
EIA	Environmental impact assessment
EMMP	Environmental Management and Monitoring Plans
EMP	Environmental management plan
EMP-CCZ	Environmental Management Plan for the Clarion-Clipperton Zone
ISA	International Seabed Authority
IRZ	Impact Reference Zones
JPIO	EU Joint Programme Initiative --Oceans
LOE	Line of Evidence
LTC	Legal and Technical Commission
MIDAS	Managing Impacts of Deep-seA reSource exploitation (research project)
MPA	Marine Protected Area
NGO	Non-governmental organisation
OMCO	Ocean Minerals Company
PRZ	Preservation Reference Zones
REE	Rare earth elements
ROV	Remotely Operated Vehicle
SAR	Synthetic Aperture Radar
SEA	Strategic environmental assessment
SEMP	Strategic environmental management plan
SMS	Seafloor massive sulphides
UNCLOS	1982 United Nations Convention on the Law of the Sea
VME	Vulnerable Marine Ecosystem

1. Introduction

1.1 Purpose of this document

The MIDAS project (Managing Impacts of Deep-seA reSource exploitation) ran from 2013-2016, covering a wide array of topics all aimed at helping the nascent deep-sea mining industry, regulators and civil society to understand the potential impacts of mining on deep-sea ecosystems. The project focused mainly on the potential impacts associated with extraction of manganese nodules and seafloor massive sulphides (SMS), but also addressed environmental issues related to the exploitation of methane gas hydrates, and the potential of deep-sea muds in the North Atlantic as a source of rare earth elements (REE).

The main objectives of MIDAS were:

1. Identification of the scale of possible impacts, and their duration, on deep-sea ecosystems associated with different types of resource extraction activities;
2. Development of workable solutions and best practice codes for environmentally responsible and socially acceptable commercial activities;
3. Development of robust and cost-effective techniques for monitoring the impacts of mineral exploitation and the subsequent recovery of ecosystems;
4. Work with policy makers to enshrine best practice in international and national regulations and overarching legal frameworks.

A key aspect of MIDAS focused on the delivery of project outputs and information to policy makers, and scientific and technological results to the European Union and the International Seabed Authority to support the development of regulations for economically viable, environmentally responsible and socially acceptable deep-sea mining.

This document reviews the implications of MIDAS results for policy makers with recommendations for future regulations to be adopted by the EU and the ISA (MIDAS Report D9.6). More information can be found in the papers published by our partners (listed at the end of this document). You may also find up to date details on the MIDAS website, www.eu-midas.net). General as well as specific recommendations are provided based on the implications of MIDAS research results.

1.2 The emerging legal regime

Regulations for the exploitation of mineral resources in the deep seabed beyond the limits of national jurisdiction (the Area) are currently under development by the International Seabed Authority (ISA). Under the UN Convention on the Law of the Sea (UNCLOS), social and environmental concerns are to be a prominent feature of any future mining regime. UNCLOS designates the Area and its [mineral] resources as the "Common Heritage of Mankind" and charges the ISA with managing the Area and its resources on behalf of all humankind.

The legal status of the Area and its resources will influence every aspect of the ISA regime, including the determination of an adequate balance between facilitating mining and protecting the marine environment (Jaeckel et al., submitted). The concept of the common heritage of mankind promotes the uniform application of the highest standards for the protection of the marine environment and the safe development of activities in the Area (Jaeckel et al., submitted).

Provisions for the protection of the marine environment are defined by UNCLOS and the subsequent 'Agreement' relating to the implementation of Part XI of UNCLOS (1994). The ISA is required to adopt appropriate rules, regulations and procedures for protecting and conserving the marine environment, including preventing, reducing and controlling pollution (UNCLOS article 145), while States are obliged to protect and preserve the marine environment (UNCLOS Part XII). National rules are required to be no less effective than international rules, standards and recommended practices and procedures (UNCLOS articles 208-209).

The results of MIDAS are well timed to inform the ISA's work on the environmental and social aspects of seabed mining. A Working Draft of Regulations and Standard Contract Terms, focused on procedural and financial issues, has been issued for consultation and draft regulations for environmental components are expected to follow in early 2017. This next draft will include details of how environmental impact statements are to be prepared, submitted and assessed; processes for public participation in their review; and requirements for an environmental permit and societal license in order to proceed to exploitation. Procedures will also be elaborated for site-specific Environmental Management and Monitoring Plans (EMMP), including emergency orders to alter operations to prevent serious harm, and Closure Plans. The environmental regulations are likely to include matters such as regional-scale Environmental Management Plans (EMPs; sometimes referred to as Strategic Environment Management Plans or SEMPs). Separate regulations are likely to be required to set up and specify the responsibilities of a Seabed Mining Directorate or Mining Inspectorate.

1.3 Implications of MIDAS results for future regulations

The three years of scientific study by MIDAS have created a wealth of new knowledge and understanding to support the development of environmentally and socially responsible seabed mining regulations. MIDAS results have confirmed the importance of broad-scale regional environmental management planning, as well as the need for more finely tuned site-specific management of mining areas consistent with the broader regional plan. MIDAS results will inform the design of such plans.

A leading example is the work done by Vanreusel et al. (2016), which demonstrated that polymetallic nodule fields in the Clarion Clipperton Zone (CCZ) are hotspots of abundance and diversity for a highly vulnerable abyssal fauna. The authors also reported the high impact and lack of recovery of fauna on two old trawling tracks and experimental mining simulations carried out up to 37 years ago, suggesting that the effects of nodule mining may be very long-lasting and irreversible. Based on these observations, the researchers argued that preservation and impact reference zones should be established in areas rich in nodules. Such a finding underscores the need to include multiple preservation reference zones and impact reference zones within mining claims, as well as larger scale no-mining "areas of particular environmental interest" across nodule fields.

MIDAS researchers also explored and elaborated the importance of connectivity and larval distribution patterns for hydrothermal vent and other communities along mid-ocean ridges, with a focus on the Mid-Atlantic Ridge. These results fed directly into scientific work towards the development of a regional environmental management plan for the Mid-Atlantic Ridge with a scientifically justified array of protected bands along the ridge that takes into account key features of the ridge and its flanks. Such a plan would have significant conservation benefits and provide flexibility in the location of eventual SMS mine sites set within a regional context.

Yet many questions remain and new questions have arisen. For example, MIDAS research has confirmed the importance of constraining plumes (and any resulting resedimentation) to the smallest possible area due to their impact on the smothering and clogging of tissues, interference with feeding mechanisms of pelagic and benthic biota, and the potential ecotoxicity of operational and discharge plumes. Without test mining, however, and an evaluation of the impacts of test mining prior to licensing full-scale commercial mining, it will be impossible to determine the full spatial extent and impact of plumes.

In addition, long-term studies are required to gauge the full range of impacts of mining on benthic and deep ocean biodiversity and ecosystem services and their potential for recovery. Few studies with repeated, precision and statistically robust sampling have been carried out to date. Considerable effort is needed to understand the complexity of deep-sea ecosystems, particularly in manganese nodule areas where recovery is likely to be prolonged.

Such quandaries of timing underscore the need to start small, and to ensure that test mining occurs as part of the exploration phase of a contract and before an exploitation contract is granted. This would allow a better understanding of the scale and potential severity of mining-impacts before a long-term exploitation licence is issued, and enable technological and regulatory modifications to be made at an early stage to ensure effective environmental protection.

The Moose at Snake Pit vent field, 23°N, along the mid-Atlantic ridge. Image courtesy Ifremer/ Victor 6000, Bicose cruise (2014).

2. Summary of key MIDAS results

The main direct impacts of deep-sea mining include: (1) mortality of fauna living on mined substrates; (2) removal of substrate and thus habitat loss; (3) habitat fragmentation; (4) habitat modification (i.e. change of mineral and sediment composition, geomorphology, chemical regimes); and (5) diverse other smaller scale direct impacts. Indirect impacts comprise: (6) the formation of near-seabed sediment plumes by the activity of crawlers and other seabed installations; (7) the returned water plume from dewatering on the vessel, in addition to any leaks along the riser system (MIDAS Report D6.6); (8) the trans-shipment plume when dewatered ores are rewetted for transfer to transport barges; and (9) potential release of toxic substances into the water column and Benthic Boundary Layer by the mining process (for SMS deposits). MIDAS did not work on the release of mid-water plumes or their impacts on the pelagic environment.

MIDAS scientific work addressed the scale of the potential impacts from deep-sea mining - for example, the size of the areas to be mined, the spread and influence of plumes away from the areas directly mined and the potential toxic nature of the material in these plumes - and how these impacts would affect ecosystems, for example by impeding connectivity between populations, interrupting the life cycles of species, loss of habitat, and impacts on ecosystem functioning. A key topic studied concerned the ability of ecosystems to recover once mining has ceased.

Estimates of the scale of the area impacted for individual nodule mining operations have been developed as part of the scenarios developed by MIDAS (Report D.7.3 Section 2.2). A nodule mining scenario was developed that represents an 'average' case, based on intermediate values for 1) production rate (2.5 million tonnes per annum) and 2) the abundance of nodules (15 kg m-2). In this 'intermediate' scenario, nodules were collected over an area of 167 km2 each year (the area affected directly by mining). The amount of sediment disturbed and released by the mining system at the seabed varied between 4 and 8 million tonnes per year depending on factors such as the speed of the mining system over the seabed and the thickness of the sediment layer extracted. This also created an annual dewatering discharge in the water column of between 0.5 and 0.9 million tonnes. The sediment load in the potential plume created by transhipment to the transport barges is unknown. Most of the sediment disturbed by mining is expected to settle within the area of the footprint impacted directly by mining. However, resedimentation will occur over a wider area. MIDAS Report D7.3 used sediment plume modelling outputs to calculate the areas affected by annual sedimentation thicknesses of 0.1mm, 1mm and >1mm. Figure 1 shows the indicative area affected by an annual sedimentation of 1mm or more, over a 30-year mining operation within a licence block awarded typically by the International Seabed Authority. The three parts to the figure show the areas affected directly by mining and resedimentation in relation to three different mining scenarios.

The outputs of MIDAS indicate that the loss of specific habitats within some areas (nodule fields and inactive hydrothermal vents) will persist in the long term; for nodule fields this change can be considered permanent for nodule-attached fauna owing to the very slow rate of nodule growth (Vanreusel et al., 2016). The impacts of direct habitat loss are compounded by long-term changes to physical conditions, such as altered sediment structure, caused by mining and resedimentation

There is variation in recovery rates after disturbance for different species of fauna found within nodule- and vent-associated habitats: some species are found to colonise sites within a few years while others have not been recorded returning to sites after more than 35 years (for nodule areas). It should also be noted that observed recovery rates are mostly known from relatively small-scale disturbance experiments; the potential for deep-sea environments to recover after disturbance on the scale of full-scale mining operations is not known.

The overall conclusion is that for most seabed areas that experience direct mining impacts, recovery to a state similar to the baseline environment (in terms of the abundance, diversity and composition of the community) is likely to occur only in the very long term, if at all. The exception may be fast spreading ridges with active hydrothermal vents, where it was shown that after a volcanic eruption new vents formed relatively fast and the initial community recovery was relatively quick but incomplete four years after eruption (Gollner et al, 2015). Industry consultation indicates that inactive vents are currently expected to be the main targets of SMS extraction. Long-lived benthic fauna in these areas, such as black corals, may take a long time to recover.

The impacts and effects of mining surrounding the directly mined area are poorly understood. This is partly due to uncertainty of the scale of the area that might be affected. Models developed by MIDAS estimated the extent of sediment plumes that might be generated during the extraction of both nodules and SMS. It is evident that the size and behaviour of plumes is determined by numerous factors that will vary greatly between mining operations and sites. In addition, there is limited understanding of the responses of most fauna to particular sediment concentrations or deposition thicknesses.

Based on current evidence, it is not possible at this stage to suggest effective thresholds for density of plumes and the distance of their spread away from the mined areas. Therefore, even where an area of physical impact may be estimated, based on a number of assumptions, this cannot be linked to a definitive effect on individual species, populations or ecosystems.

Effects of mineral extraction outside of the areas affected directly by mining or by sediment plumes, but that arise as a result of loss or degradation of seabed habitat or effects on populations of deep-sea fauna within the directly affected areas, include changes to ecosystem functioning, recoverability, connectivity and recruitment. These effects are likely to be particularly relevant where large areas of habitat are affected by a mining operation (as may be the case for nodule extraction) or where incremental loss of habitat occurs over a region as a result of numerous simultaneous or consecutive mining operations.

Current understanding of ecosystem functioning, recoverability, connectivity and recruitment in the deep sea is limited. There is considerable uncertainty about the effects of mining on these processes. The risk registers developed by MIDAS (Report D7.3) provide an overview of the main impacts and effects of extraction of polymetallic nodules and SMS.

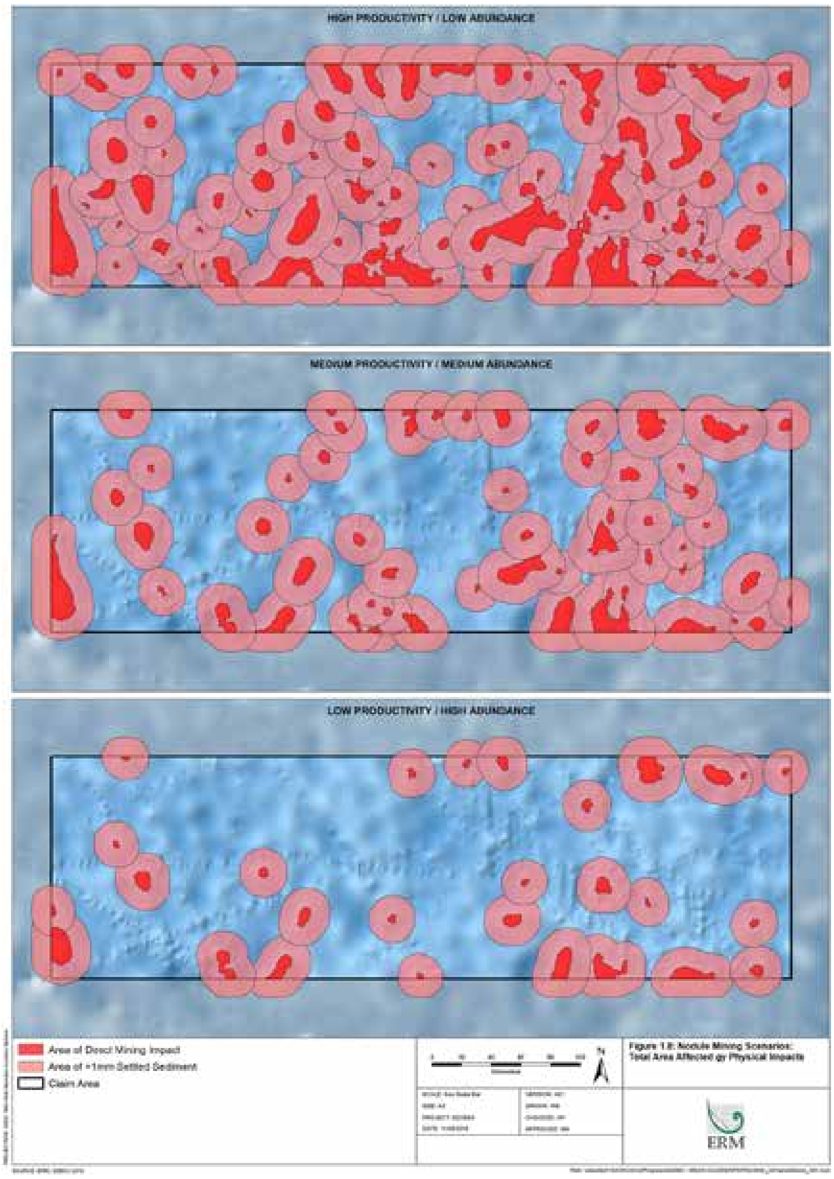


Figure 1: Indicative total area of physical impact for nodule mining scenarios. Image courtesy ERM.

Implications and recommendations

3.1 Geological and geochemical impacts

3.1.1 Areal impacts

Manganese nodules exist as thin layers, a few centimetres thick, lying on the seabed, which means that any mining will require the stripping of very large areas of seabed – in the order of 200 km2 per year per operator. Thus mining for nodules will be unlike any metal mining conducted today in the extent of its environmental footprint. It will also be carried out in some of the least studied areas of the planet - areas that are very remote and thus difficult for scientists to access. These issues of the large aerial impact and difficulty in obtaining new scientific information need to be borne in mind when reading the following sections. Sulphide deposits form three dimensional ore bodies, similar to those in terrestrial environments and direct footprints here for single mines may be on the order of a few km2.

3.1.2 Role of geo-microbial processes in SMS mining

The mining of SMS will expose ‘fresh’ sulphide mineral surfaces to seawater, resulting in the oxidation of these sulphides and the release of heavy metals into seawater. The results show a positive correlation between the abundance of microorganisms on the mineral surfaces and the degree of weathering, suggesting that geo-microbiological processes play an important role in the degradation of sulphide minerals in SMS deposits. Geo-microbiological processes may also be important in reductive processes that scavenge metals from solution.

Loss of, or change to, bacterial communities may therefore affect ecosystem functions that determine local conditions at vent sites (MIDAS Report D7.3). This indicates that assessments of the potential environmental impact of mineral dissolution during deep-sea mining activities should include biogeochemical processes in addition to abiotic geochemical leaching.

3.1.3 Some SMS minerals may remain reactive

MIDAS results showed that release of metals from fresh sulphides at the seafloor varies depending on the mineral exposed. Release begins very quickly on exposure to seawater, meaning that mining sulphides at the seafloor will immediately release dissolved metal ions into the environment, decrease pH and lower oxygen, which may have an impact on the ecosystems (Knight and Roberts, 2014). Residence time for toxic material is important to understanding the impacts of any waste plume or storage of mined materials on the seafloor. Chalcopyrites from SMS were found to remain reactive for at least 73 hours after exposure with no signs of slowing down. Thus ore stockpiling either on the seabed or in a wet state on ships or barges should be avoided, as it could continue to leach toxic metals into the water.

3.1.4 Recommendations

- Further research and environmental impact assessment processes will need to include both biogeochemical processes and abiotic geochemical leaching, especially for SMS deposits.
- Stockpiling of ore containing chalcopyrite on the seafloor pending its uploading should not be permitted.
- The interaction between ores and seawater should be assessed at all stages including crushing processes at the seabed, flow through the riser pipe, dewatering on the surface vessel, the consequent discharge plume, and transport to shore in barges.

3.1.5 Gas hydrates and potential slope failures

MIDAS research revealed that gas production from methane hydrates could lead to subsidence of the seafloor and potentially induce local slope failures. Some portions of gas hydrate may be more prone to dissociation under specific environmental change scenarios than others. Slope stability or instability may vary based on a number of factors that will need to be further understood and considered when selecting potential extraction sites.

3.1.6 Gas hydrate leakage to atmosphere unlikely

Another MIDAS research project demonstrated that should leakage of methane gas into the water column occur during gas production from gas hydrates, it will not reach the atmosphere. The methane gas will dissolve and be oxidized in the water column (i.e. within ~200 m above the gas hydrate stability zone, which is located in water depths of ~360 m at Svalbard and ~720 m in the Black Sea). Evidence that any methane leakage from gas hydrates production will not reach the atmosphere is relevant for regulations on accounting of greenhouse gas emissions into the atmosphere.

3.1.7 Recommendations

- Guidelines should be developed to inform future research and environmental impact assessments of potential gas hydrate production.

- Advanced field and laboratory characterization of the physical properties and thermo-hydro-mechanical behaviour of gas hydrate-bearing and free gas-bearing sediments are also needed to enable an informed decision on subsea development.
- Similarly, potential slope failures and run-out distances of landslides possibly triggered by the dissociation of gas hydrates in the surroundings of the production site should be analysed.
- Any production operation should be continuously monitored to assess gas leakage and seafloor subsidence.

3.2 Plumes in a dynamic environment

3.2.1 Source of plumes

Plumes present perhaps the most significant potential source of environmental impact from deep-sea mining. Mining will produce sediment plumes on the sea floor, as well as in the water column following dewatering of the ore slurry on board the support vessel. The ores will be stored in a dry condition on the mining surface vessel until they are transferred to transportation barges. For transferal the ores may need to be recharged with water leading to a secondary discharge plume from the barge. MIDAS only studied the characteristics of seafloor plumes. The spread of a plume will be determined by the amount of material released, the characteristics of the release – flow rate, height above seabed, exhaust size, etc. - and the currents into which the plume is released.

3.2.2 Potential impacts of near-seabed plumes

Natural sedimentation rates on abyssal plains are very low, in the order of one to two mm per thousand years. Therefore, the impact of plumes that can add particles at rates orders of magnitude greater can have significant effects, through smothering organisms, clogging of filter-feeding mechanisms (e.g. corals and sponges) and causing alterations in sediment characteristics for deposit-feeding fauna. It is unknown the distance over which plumes will travel but estimates have been made that this could be up to 100 km from mining sites. Differential settling rates of grains in the plumes will lead to changes in sediment structure that can lead to changes in community composition (e.g. effects on recruitment, burrowing, meiofauna distribution). Plumes may also be toxic, due to enhanced mineral content from the crushing/breaking of minerals during extraction and from fractioning processes on the support vessel. This will be particularly the case for SMS deposits where exposure to oxygen during the mining process may release toxic chemicals.

3.2.3 Potential impacts of returned-water plumes

Returned-water plumes from ore dewatering may alter ambient temperature, pH and oxygen affecting animals in the water column.

3.2.4 Potential impacts of surface discharges

The potential impacts of surface discharges and plumes need to be better characterized and assessed and incorporated into section [37] of the Annex to the ISA "Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area" (ISBA/19/LTC/8) issued by the Legal and Technical Commission (LTC). The release of surface water plumes has not been investigated within MIDAS, but large predators, fish, micronekton, zooplankton and phytoplankton will all be potentially affected. If discharges occur near the sea surface they may cause nutrient enrichment (MIDAS Report D6.6) impacting algal species and photosynthetic processes.

3.2.5 Thresholds

The thresholds at which 1) smothering by high-particle concentrations settling within the water column, and 2) toxicity of the plume material would lead to significant impacts remain poorly known. Thresholds are needed for determining the boundary between where the plume has a significant impact and where an impact that can be discounted. This may depend on the particular taxa and size of organism affected and the dilution effect of physical oceanographic mixing processes. Long-term chronic effects need to be studied because plume releases may continue in the same area for many years. . The tolerance may be very low of organisms adapted to negligible particle loads in oceanic waters.

3.2.6 Baseline measurements of currents

For some sites, a long (1+ year) time series of currents will be needed to provide a realistic assessment of the role of eddies and to identify extreme current events.

3.2.7 Modelling advances and limitations

Accurate models constructed for the specific environment they represent, and with an appreciation of the limitations of their inherent assumptions, can be vital tools for predicting and understanding plume impacts. The challenge is to verify their accuracy.

3.2.8 Scales

Plume behaviour will need to be modelled across a broad range of temporal and spatial scales. Current state-of-the-art models of flow dynamics cannot cover all appropriate scales. This is a highly challenging problem. Confidence in the results will vary with scale.

3.2.9 Metrics for turbulence and current speed

The role of turbulence and current speed in plume models is highly sensitive to the exact metrics of the impact being studied. It is extremely important that these are clarified with respect to ecological impacts in the deep sea.

3.2.10 Monitoring

Models predicting the fate of suspended matter and chemical plumes will be crucial tools for designing monitoring strategies and interpreting monitoring results of 1) mining equipment tests and 2) full-scale mining operations. Plume monitoring during mining activity should anticipate that plumes are complex in shape (possibly sinuous, layered and patchy). A broad range of temporal and spatial scales will be needed. If plume monitoring is not carried out with enough spatial or temporal coverage, and not taking into account predictions by plume modelling, its validity could be questioned.

3.2.11 Mid-water plumes

MIDAS has only partially dealt with mid-water discharges and their potential impacts on the pelagic ecosystem. MIDAS has not dealt with plumes caused by the transfer of the ore from the surface mining vessel to transport barges. Studies of both will be essential for understanding the full impact of seabed mining.

3.2.12 Recommendations

- A metric-based decision tree may enable operators to draw conclusions from the probable fate of discharged contaminants from deep-sea mining activities, but this needs to be tested and will always need to be backed by additional site-specific information.
- Baseline studies will need to assess current and eddy regimes, geomorphology, seasonality, etc. Long-term time series will be needed for complex sites.
- Models are vital tools for predicting and understanding plume impacts. More work is needed to enable precise modelling of plumes in order to assess the footprint of operations and the spread of environmental impacts.

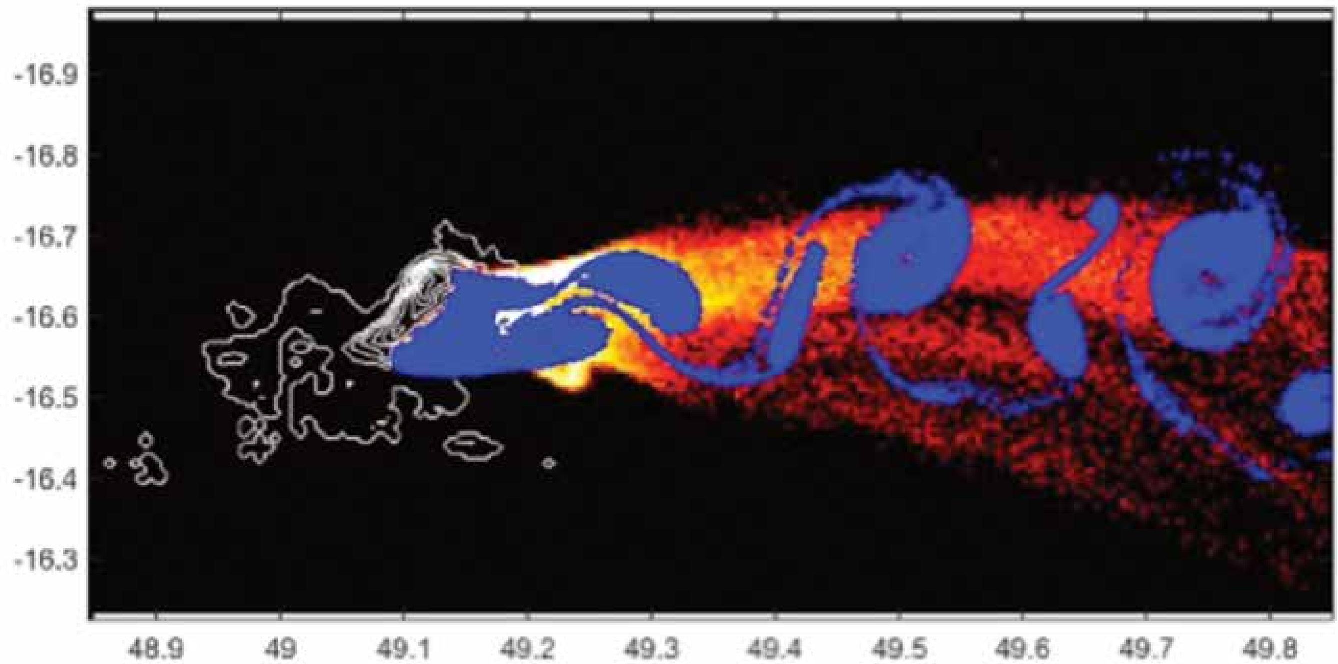


Figure 2: The simulated sediment plume (blue) downstream of an abyssal hill in conditions that lead to shedding of vortices. The cumulative depth of sediment is shaded. Image courtesy SAMS.

- Models need to be constructed with an understanding of the environment they represent. The limitations of the inherent assumptions of different models need to be appreciated. Models need to cover all appropriate spatial and temporal scales and related to species- and ecosystem-specific thresholds.
- It is difficult to recommend broadly applicable models because no single model will apply to all conditions. Therefore, modelling approaches must be applied intelligently in any given context with an understanding of the complexities likely to be encountered at that site.
- More research is needed on how particle-dense plumes will behave initially in the immediate vicinity of mining machinery and discharges. This information will provide the key initial conditions for larger-scale plume models. Model studies coupled with different design options of mining systems may provide solutions for plume mitigation.
- Thresholds are lacking for determining when a plume will have a significant adverse impact. Research in the establishing plume thresholds is needed.
- The impacts of plumes crossing the boundaries between adjacent contractor areas will need to be considered in impact assessments and exploration regulations.
- Oceanographic and plume model data and methodologies will need to be independently validated. These should be shared as "environmental data" because different assumptions can lead to varying conclusions and results.
- MIDAS recommends that the text of paragraph 37 of the ISA "Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area" (ISBA/19/LTC/8)) is amended as follows:

  37. If there is potential for surface discharge, the pelagic community in the upper 200 m of the water column should be characterized. Depending on plume modelling studies, it may be necessary to study pelagic communities, especially gelatinous plankton, over a wide depth range. The pelagic community structure 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 pelagic trawls or remotely operated vehicle techniques. Measurements should be made of phytoplankton composition, biomass and production, zooplankton composition and biomass, bacterial plankton biomass and productivity, micronekton, fish and large predators. Temporal variation of the plankton community in the upper surface waters on seasonal and inter-annual scales should be studied. Remote sensing should be used to augment field programmes. Calibration and validation of remote-sensing data are essential.

3.3 Ecotoxicology

3.3.1 Potential sources of exposure

Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process. Minerals extracted from the seafloor are likely to be broken up into smaller pieces so that the ore can be pumped to the sea surface as a slurry. The exposure of newly mined sulphide ores to oxygen will produce toxic chemicals. Nodules and crusts however, which formed and are found in oxic environments may not release chemical toxins.

3.3.2 Limits of traditional toxicity testing

'Traditional' toxicity testing in shallow-water aquatic organisms has usually considered one metal ion at a time, in a fixed oxidation state, under standard laboratory conditions of temperature (usually 20 oC) and hydrostatic pressure (normally 0.1 MPa) using well-established 'indicator species'. Standard toxicity tests are also usually applied over short time intervals, for example 48 or 96 hours. These conditions poorly represent the environmental conditions that will prevail for deep-sea mining. Environmental conditions at a mining site will be typified by low temperate (5-10 oC), high hydrostatic pressure (> 10 MPa). In addition mining will continue for many months to years.

MIDAS results show that it will not be possible to extrapolate toxicity information and practices from shallow water areas to deep-sea situations. Instead, the toxicity of individual minerals deposits, specific to each mine site, should be assessed independently to identify potential toxic risks during mining. Under controlled ecologically-relevant conditions it may be possible to determine the bulk lethal toxicity of an ore deposit and of the return waters. It may be necessary to test the bulk lethal toxicity of an ore deposit in a number of different physical phases (e.g. in solution, as particulates and as adsorbed elements onto the surface of particulates) using a number of different biological proxy organisms. A toxicity test of the bulk resource will be more useful than trying to predict toxicity from knowledge of the individual metals of the resource. Consequently, the bulk resource should be processed as anticipated during exploitation, and the toxicity of the resulting aqueous solution and particulate material should be assessed both independently and in combination under ecologically-relevant environmental conditions (temperature, hydrostatic pressure, oxygen concentration, carbon dioxide concentration) over time-scales representing a range from acute (e.g. 24 h, 48 h, 72 h, 96 h) to chronic (e.g. seasonal and reproductive cycles) timescales for key species present in the area of impact.

Results from MIDAS ecotoxicology experiments indicate that sensitivity to potential toxicants may be differentially moderated by both temperature and hydrostatic pressure, and that significant bioenergetic impacts may be incurred at sub-lethal concentrations of toxicants. Accumulation of toxicants quantified during chronic sub-lethal exposure experiments may then be compared with the accumulation of toxicants in samples taken from the environment whilst performing, and after, specific mining activities.

3.3.3 Alternative to traditional toxicity testing

The Weight of Evidence approach used in some MIDAS experiments proved to be a useful method to characterize the environmental hazard of deep-sea mining to biological species and communities. Using this approach, multiple 'Lines Of Evidence' (LOE), including a characterisation of the mineral content of the resource (chemical composition, grain size), the accumulation of metals within organism tissues, the organism tissue biomarker response, and additional bioassays were assessed to determine the risk. Using this approach, and applying the LOE to relevant 'canary' or proxy species in the vicinity of the mining site, could provide a mechanism to develop a holistic overview of the toxic risk of mining and of the resource. (MIDAS Report D3.6). However, further testing and validation of the LOE at bathyal and abyssal depths is required before this approach can be universally recommended to the ISA.

3.3.4 Recommendations

- Knowledge on the ecotoxicological limits of deep-water species to certain chemicals (or mixtures) is helpful to assess their tolerances and define the limits of ecotoxicological impact from a mining site.
- Chronic sub-lethal toxic impacts and cumulative impacts should be considered by contractors and by the ISA in regulating exploitation activities. These will need to include the cumulative impacts of plumes created from mining adjacent plots over extended periods on the physiology and performance of the surrounding biological communities as well as the potential impacts of avoidance behaviour by fauna adjacent to mining plots.
- The bulk toxicity of each prospective resource should be established in advance, and at different times during biological and seasonal cycles, for a suite of organisms relevant to the region surrounding the area of immediate impact. Such an approach should also be adopted to assess the potential toxicity of discharge waters from any dewatering of the ore slurry. This assessment should be conducted as part of the baseline studies phase before an exploitation contract is granted and as a component of the routine ship-board monitoring during mining activity.
- Rapid assessment of ore and plume toxicity on board the survey/support vessel is recommended with an approved assay during both the exploration phase and the exploitation phase.
- Regulators should consider setting spatial limits for the influence of the plumes produced and their metals content.
- A precautionary approach should be adopted during test mining and initial exploitation in the absence of field-validated data of chronic impacts generated at the scale of commercial exploitation. Operators and regulating bodies should consider continuing to work with environmental scientists during the early phases of exploitation to iterate regulations for impact monitoring and the designation of exposure limits based on new research.
- As larval stages are more susceptible to toxic effects, knowing the reproductive and spawning seasons of species, if relevant, may permit the identification of times of the year when mining should be suspended for a particular location/resource (i.e. it may be necessary to introduce 'mining seasons' to avoid key reproductive events. This may be included in adaptive management plans.
- Operations will need contingency plans if/when discharge waters exceed toxicity thresholds, as determined during EIAs.

3.4 Impacts on species connectivity

3.4.1 Why connectivity is important

Mining may impact species connectivity through habitat loss (loss of substrate, including the mineral itself); habitat fragmentation; habitat modification (this includes habitat smoothing or roughening, organic enrichment by decay of organisms, modification of vent fluid regimes) as well as ecotoxicological and physical effects of sediment plumes (MIDAS Report D6.6). Understanding the distribution of species at local and regional scales and the extent of gene flow among populations is key for the development of strategies for biodiversity conservation.

3.4.2 Challenges of assessing connectivity

Connectivity studies rely on understanding the life cycle of species including the distribution of adults, seasonality in reproduction, quantity and behaviour of eggs and larvae and larval dispersion. This information is almost completely lacking for nodule areas. In addition, most seabed samples contain more undescribed new species than known species and the vast majority of species are known by only a few specimens for which we have little or no information on their reproduction. Similar challenges could be said to exist for SMS deposits: while the life history characteristics are known for several key hydrothermal vent fauna there is very little information on species that may be affected by inactive vent/ SMS mining.

3.4.3 Biogeography

Our current level of biogeographic knowledge is not sufficient to make accurate predictions of the consequences of mining, which may continue for many decades. Biogeographic information is critical in: 1) assessing whether the Areas of Particular Environmental Interest (APEI) designated by the ISA in the CCZ nodule province represent suitable areas from which recovery could take place after mining has finished, and 2) in the selection of Preservation Reference Zones (PRZs) for comparison with Impact Reference Zones (IRZs), such that the PRZs are representative of the mining area and will provide information relevant to judging impacts.

3.4.4 Connectivity scales

Quantifying the scales of population connectivity is crucial to predicting population responses to environmental disturbance and to developing efficient conservation strategies.

3.4.5 Implications for recovery

It is difficult to measure connectivity between populations. Small numbers of individuals passing from one area to another can transfer a lot of genetic material giving the impression of well-connected populations. However the immigration of small numbers of individuals may not be sufficient for recolonisation to occur. Therefore, a precautionary approach to genetic estimates of connectivity must be considered.

3.4.6 Reproduction and larval traits

Deep-sea species have a range of reproductive life histories. This makes the development of mitigation strategies difficult at local scales. Lack of knowledge of the reproductive cycles and early development of most species adds to the challenge of developing appropriate mitigation measures, and understanding the resilience and recovery potential of species. For example, avoiding mining activity at key points of a seasonal cycle of one species will not necessarily reduce adverse effects on species with continuous reproduction. (MIDAS Report D4.8)

3.4.7 Distribution of larger fauna across local and basin scales using imagery

MIDAS researchers used still and video images collected by Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and towed high-resolution camera systems to assess the distribution of larger fauna across local and basin scales. This may be a promising approach for charismatic fauna, such as octopi, fish, larger crinoids and corals, because relatively large areas can be covered in a relatively short time (Vanreusel et al., 2016, Purser et al., in press). It should be noted, however, that the results are restricted to higher taxonomic levels and often address morphotypes without taxonomic validation before a faunal atlas of the target region has been developed. Such an atlas should be based on a comprehensive set of voucher specimens collected in the area. This is a crucial requirement for ground-truthing.

3.4.8 Readiness for Rapid Biodiversity Assessments

Rapid biodiversity assessments, such as environmental-DNA (e-DNA) surveys, are frequently suggested as a suitable method for baseline and impact studies. Despite recent advances, much of the existing state-of-the art technology and methodologies are still at the pilot test stage, and cannot be used on an industrial scale for rapid biodiversity assessment. This is especially true for assessments based on environmental DNA, which may have the potential for fast biodiversity screening in the future but are clearly not yet sufficiently mature to be suggested for monitoring in the context of deep-sea mining. There is currently no methodology available that can 1) rapidly assess biodiversity across the whole size range from megafauna to microbes, 2) provide information on genetic connectivity and 3) the dispersal potential of species. State of the art molecular (genomic, proteomic) methods applied to specimen extracted from samples, however, have the potential to speed up the assessment of e biodiversity found in an area. Similar to image-based Rapid Biodiversity

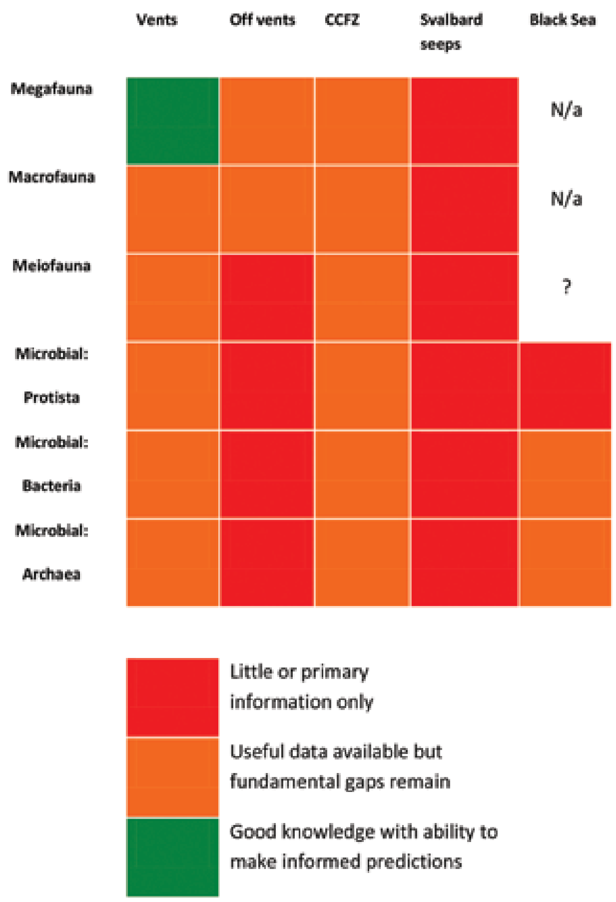
Assessments (section 3.4.7) a proper identification of species requires the creation of an archive of vouchered specimens that are properly described and identified using traditional taxonomic methods. Only after this has been achieved for a particular region can the rapid identification of taxa be based on molecular tools alone.

3.4.9 Molecular and modelling approaches

Molecular and modelling approaches may provide valuable insights into patterns of differentiation and connectivity in marine systems where direct observations of larvae and reproductive traits are not possible. However, lack of knowledge leads to the use many assumptions in such endeavours.

3.4.10 Limit of knowledge

Baseline knowledge of the deep-sea in general, and in particular the CCZ and mid ocean ridges is still too incomplete to enable reasonable mitigation advice to be given with regard to connectivity and biogeography (MIDAS Report D4.8). Until contractors publish detailed plans of the scale of potential impacts it will not be possible to offer advice on how these impacts may be mitigated to ensure biological connectivity.



3.4.11 Recommendations

- Standardized baseline should include DNA taxonomy and address gaps in the knowledge of life history, functional traits and physical oceanography.
- Genetic connectivity studies (MIDAS Report D4.8) should include:

  a. Improved coupling of physical oceanographic and population genetic models for more accurate predictions of dispersal pathways

  b. Additional processes that at present are not fully understood, such as:

  i. The importance of stepping stone dispersal pathways;

  ii. Larval dispersal patterns which follow different patterns in successive years; and

  iii. The role of large-scale episodic events in driving intermittent genetic connectivity between localities.
- Protected areas (should be designed to optimize gene flow between different populations. This will avoid isolation of populations leading to: i) the loss of genetic diversity and ii) a high rate of inbreeding and increased homozygosity.
- Based on MIDAS results, two types of protected areas are envisaged: a number of small PRZs within the mining claim areas to maintain local populations, and larger protection zones (e.g. APEIs) at the regional scale to maintain regional biodiversity.
- Until more informed predictions on impacts of mining can be made accurately, a precautionary approach should be implemented to avoid global extinctions.
- A reliable, open source list of species in the proposed impacted region will provide the basis for effective management recommendations.
- Contractors should be required to publish a list of taxa (preferably to species names, but including at the very least genus names) linked to openly accessible museum-vouchered specimens fixed and preserved in 80% ethanol.
- DNA taxonomic studies on ethanol preserved samples taken by contractors should be undertaken by experienced scientists. Field guides to the abundant fauna should be available for all contractor licence blocks to enable all workers in these regions to identify species.

Figure 3 (left): Assessment of biogeographic knowledge in deep-sea habitats with mineral or gas hydrate potential. Vents and off-vent sites are threatened by mining for massive sulphide deposits; the CCZ in the NE Pacific is the main target for polymetallic nodule mining; Svalbard seeps and the Black Sea are associated with gas hydrates. Image courtesy IMAR.

- Management strategies and impact assessment studies should incorporate studies of the reproductive biology, ecology and population demographics of habitat-forming species. Information on spawning, fertilization and larval biology, such as information on larval duration, behaviour and dispersal, are essential in order to understand the current level of connectivity among local coral populations and determine potential impacts on meta-population dynamics. (MIDAS Report D4.8)
- More research on the functionality of PRZs and IRZs for hydrothermal vents and inactive vent areas is needed. Initiatives such as the SEMPIA workshops (initiated by MIDAS), are addressing these issues for the Mid-Atlantic Ridge but further developments are needed.
- More knowledge on deep-sea species connectivity and biogeography is required before general predictions on post-mining recolonisation and recovery can be made.
- New approaches to connectivity studies should be developed combining data from a range of disciplines, such as functional traits (e.g. to establish connectivity amongst a range of trait parameters) and physical oceanography (e.g. currents and modelled currents).

3.5 Impacts on ecosystem function

MIDAS has addressed the potential impact deep-sea resource extraction may have on ecosystem functioning through desktop modelling studies, laboratory-based disturbance experiments and in situ studies of habitats heavily modified by mining activities in the past. These sites can be used as partial analogues of the sorts of disturbances that are likely to be experienced at deep-sea mining sites.

3.5.1 Impacts on benthic ecosystem functioning

Overall, MIDAS results show that deep-sea ecosystems, particularly in abyssal nodule fields, continue to be impacted for decades after a disturbance, and recover extremely slowly from even small-scale disturbance events. Commercial-scale mining is therefore likely to significantly impact seafloor ecosystems over much longer timescales.

3.5.2 Uncertainties

The disturbances imposed on the seafloor by the DISCOL experiment at an abyssal nodule site off Peru using a plough harrow, and by Benthic Impact Experiments (BIE) in the CCZ by a variety of mechanisms, are not comparable to the level of disturbance that will occur during commercial mining, where much larger areas of seafloor will be disturbed. We therefore urge caution when generalising the results of small-scale disturbance experiments described in MIDAS to the recovery dynamics of faunal communities in areas where commercial mining will take place.

Figure 4: Autonomous Integrated Sediment Disturber deployed at the HAUSGARTEN site. In the lower left, push cores used for sampling by ROV are visible. The dark circle indicates one of three disturbed areas. Image courtesy MARUM/U.Bremen and T.Soltwedel, AWI.

3.5.3 Role of microbial communities

While it is clear that microbial communities play an important role in benthic ecosystem functioning (e.g. carbon and nutrient cycling) over regional scales in the CCZ and in the deep sea in general, longer term analyses of the composition and functions of microbial communities including observations of their activity, e.g., in terms of oxygen uptake, organic matter turnover, and growth of the disturbed sediments, remain necessary. Investigations carried out at experimental disturbance tracks at the seafloor in the CCZ and the Peru Basin (DISCOL Experimental area) indicate that minor disturbances effect microbial communities and impair their functions. More investigations are needed to better characterise disturbance effects on microbial communities and microbially-driven ecosystem functions and to investigate the potential of microbial community characteristics to serve as indicators for assessing the status of the ecosystem and the level of disturbance.

3.5.4 Variability

Abyssal environments can suffer periodic and cyclic events (e.g. El Nino cycles) and may be subject to impacts from climate change. Baseline studies will need to capture longer-term variability in faunal communities to distinguish mining impacts from climate-induced environmental variability.

3.5.5 Potential role of autonomous ecosystem monitoring

Monitoring by autonomous systems for assessing ecosystem function should be developed further, particularly to make the methods suitable for routine application by mining contractors.

3.5.6 Recommendations

- It will be important to establish ecological baselines at the appropriate spatial and temporal scales.
- Multiple reference sites both in the near and far field from intended mining sites should be established and monitored, for at least 2 years in advance of mining to capture a snapshot of natural variability.
- Long-term ecosystem monitoring will enable assessment of impacts on ecosystem functions. There is potential for further development of autonomous monitoring systems.
- In nodule fields, the mining footprint should be constrained to the smallest possible area, so as to limit sediment disturbance and compaction, both of which may inhibit ecosystem recovery.

3.6 Ecosystem resilience and recovery

Extraction of deep-seafloor minerals will have the potential for wide-scale and long-term adverse effects on the benthic communities. It is important therefore to study and predict the potential and mode of deep-sea ecosystem recovery. Within MIDAS a variety of anthropogenic and natural disturbance events were investigated to determine the potential impact of industrial mining on benthic organisms associated with 1) nodules from abyssal plains, 2) hydrothermal vents associated with seafloor massive sulphides, and 3) gas hydrates on continental margins. Research expeditions, field experiments, literature reviews and meta-analyses were carried out to (1) assess mode and timing of ecosystem recovery, (2) identify the factors influencing ecosystem recovery, and (3) propose possible restoration and/or mitigation actions, which may enhance ecosystem recovery and/ or minimise mining disturbance effects.

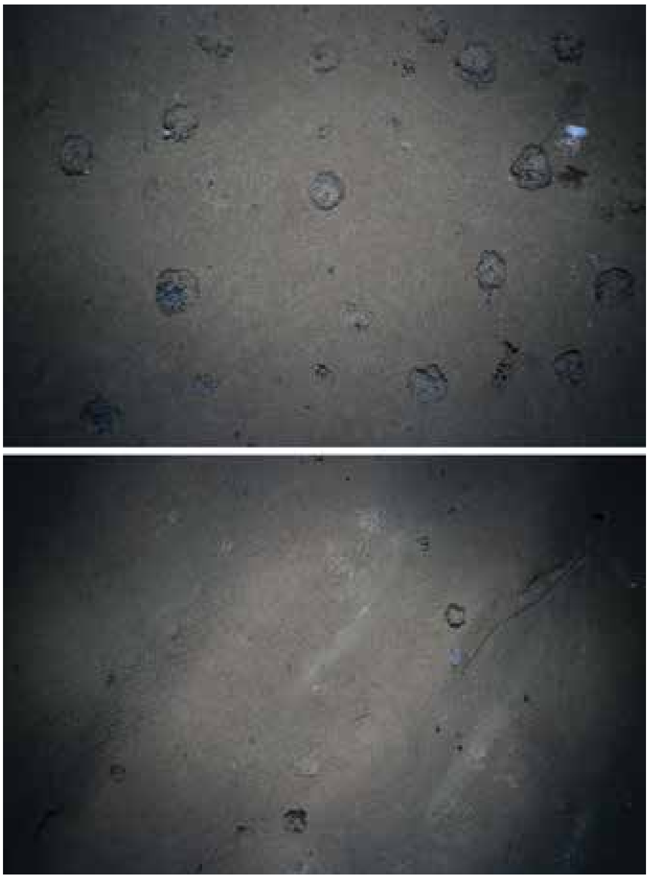


Figure 5: Contrast between undisturbed (upper) and disturbed (lower) seafloor in the DEA, 26 years after experimental disturbance; photo credit: AWI OFOS-Launcher SO242-2.

3.6.1 Faunal recovery rates vary greatly across ecosystems, and community composition may not return to its original state for a very long time

Following a local submarine volcanic eruption at El Hierro (Canary Islands), organisms with opportunistic life history traits were able to recolonise disturbed seafloor areas within a period of a few months to a few years. However, a return to the original community would take much longer. Another study at the Palinuro Seamount in the Eastern Tyrrhenian Sea showed that after seven years following localized disturbances the composition of the benthic community had not returned to its original community, although the abundance, biomass and diversity of microscopic meiofauna had recovered fully. Another study revisiting an experimental disturbance created in 1989 in a manganese nodule area in the Peru Basin (DISCOL experimental area) seven years after disturbance showed that while densities of smaller infauna had recovered, differences remained in terms of diversity and community composition. Sessile megafauna were still absent in the disturbance area and partly sessile megafauna showed reduced abundances. Preliminary results obtained during a follow-up study in 2015 showed that even 26 years after the impact, benthic communities did not recover. High-resolution sampling by ROV revealed reduced abundances of meiofauna and microorganisms in disturbance tracks especially where the disturbance removed or buried the biogeochemically active surface layer. Similarly, differences in megafauna were prominent in high-resolution megafauna surveys.

These findings were confirmed by a metadata analysis on recovery rates that revealed high variability between and within ecosystems as well as across size classes and taxa. While densities and diversities of certain taxa can, in some areas, recover to pre-disturbance conditions or even exceed them, community composition remains distinct even decades after disturbance. The loss or change of hard substrate composition may cause substantial community changes, such as of nodule-attached fauna, persisting over geological timescales at directly mined sites.

3.6.2 Recovery rates

The recovery of ecosystems in the Pacific nodule area is extremely slow. Nematode communities within and outside tracks at the 26-year old Ocean Minerals Company (OMCO) disturbance site in the CCZ show differences. The close proximity of the samples taken within and adjacent to the tracks of sampling dredges suggests recovery is not only a function of dispersal ability but also the availability of suitable habitat. In another study nematode recovery in a 36-year old disturbance experiment is evident in the top 1cm of sediment only. Lower depths showed depleted abundances and diversity compared to the control site. Bioturbation is probably important in the process of recovery by creating a thicker layer of active sediment. Areas that have been mined will either reveal a deeper more consolidated layer or be subject to the deposition of centimetres of unconsolidated sediment – in both cases the sediment will have a very different structure to that present before. No experiments have been carried out on recolonisation in the unconsolidated material, but its nature may make it more difficult for animals to colonise. It is expected that recovery will be faster and greater in the higher productivity areas of the eastern and central CCZ relative to the lower productivity western areas.

3.6.3 Polymetallic nodules are important to preserve biodiversity of abyssal epifauna

Communities of sessile fauna in nodule-rich areas are similar across the CCZ, but the nodule-poor areas show much lower diversity and abundance (up to 3 times lower) of fauna typically found on nodules. Work by the EU Joint Programme Initiative –Oceans (JPIO) project and related MIDAS research highlighted the importance of nodules in maintaining epifaunal biodiversity in the CCZ (Vanreusel et al., 2016). Analysis of ROV video footage showed that nodule-bearing areas have higher diversity and densities of epifaunal taxa compared to nodule-free areas. Communities of mobile fauna show the same trends. These findings have consequences for the designation of potential preservation reference zones in the CCZ and should be incorporated into conservation management plans.

3.6.4 Potential mitigation and restoration actions

Typically, industries apply a structured approach to mitigation and apply a mitigation hierarchy for actions(Ekstrom et al. 2015). This suggests that mitigation should be done in the strict order of: Avoid, Minimise, Restore and Offset. MIDAS reviewed a set of mitigation and restoration actions that could facilitate recolonisation of impacted substrates and accelerate the rates of recovery of biodiversity and function. It should be noted, however, that a proof of concept and feasibility of restoration actions, especially for application on larger spatial scales, is largely missing. Offsetting is unlikely to be effective as there are no comparable ecosystems that are in need of restoration.

3.6.5 Accounting for cumulative effects

Three major impacts of mining activities have been identified for mitigation and restoration actions: 1) mining operations at seafloor, 2) resource (substrate) removal and 3) plume discharges. These impacts can lead to the following effects on the ecosystem: mortality of the fauna, habitat loss, habitat modification, habitat fragmentation and other direct impacts or a combination of these effects. Often these effects are interlinked; for example, habitat loss leads to habitat fragmentation, and, depending on the scale, to local mortality and/or extinction of entire populations. Alternatively, habitat modification, fragmentation and in some severe cases habitat loss, leads to (partial) mortality of fauna, thus shifting the faunal presence and composition to locally more adapted organisms, which are not specifically representative for the ecosystem (MIDAS Report D6.7).

3.6.6 Multiple approaches necessary

No single action will allow an ecosystem to recover, instead combined mitigation/restoration actions need to be considered. Such sets of combined actions should facilitate and eventually accelerate the rates of recovery of biodiversity and ecosystem function and will depend on the specific characteristics of the different mining habitats and the resources hosted (polymetallic nodules, ferromanganese cobalt rich crusts, sulphides, gas hydrates). Suggested actions range from the deployment of artificial substrates to enhance faunal colonisation /survival to habitat recreation to artificial eutrophication. These actions will all need to include spatial and temporal management of mining operations. Mitigation might also include altering the design and construction of mining equipment to minimise environmental effects, such as plume containment, eliminating toxicity and sediment compression reduction.

3.6.7 Uncertainties

Whether mitigation and restoration actions can facilitate the recovery of deep-sea ecosystem structure and functioning requires much greater study. The deployment of artificial colonisation substrata has been proposed as a restoration action in mined ecosystems to support local communities. Within MIDAS, patterns of colonisation of organic and inorganic substrata were assessed at active and inactive vents at the MAR as well as the use of artificial substrata in the deep sea in general. At the Mid-Atlantic Ridge, different larval types and juveniles were found on the artificial substrata, highlighting its potential for increasing local recruitment and thus aiding the survival of local populations. MIDAS Report D6.6 reviewed the few natural or anthropogenic disturbance studies available, although the type of impact and extent (scale) are not comparable to actual mining impacts. Hence a large degree of uncertainty remains in predicting the success of proposed mitigation and restoration actions.

3.6.8 Restoration

Restoration is considered plausible/possible in only a limited number of scenarios, and is generally regarded as highly uncertain. In cases where restoration is impossible a set of mitigation measures should be taken in order to avoid potentially irreversible damage to the local populations and which might lead to extinction.

3.6.9 Challenges to mitigation and restoration actions

It should be borne in mind that most deep-sea ecosystems have great spatial and (often) temporal variability making it difficult to design mitigation measures that have a high chance of success. Much more knowledge is needed especially in areas other than active vents where species distributions are poorly known in time and space.

3.6.10 Initial thoughts on mitigation and restoration options

A combined set of mitigation and restoration actions can be envisioned, dependent on and adapted to the local environment and ecosystem characteristics. During a workshop, several mitigation or restoration actions were proposed. These are listed below together with their advantages and disadvantages (MIDAS Report D6.7):

(i) Designation of refuge areas/set-aside areas/no-mining areas is likely to be the most effective action. The main difficulties are the selection of truly representative areas that will not be impacted by any mining activities (including plumes). This implies the use of effective, and possibly large, buffer zones. There are insufficient data on ecosystems and habitats in the APEIs of the CCZ to understand if they are representative of the mining licence areas, and therefore if they are truly refuge areas for biodiversity conservation. The distances between the mined areas and the current CCZ APEIs may be too great for the APEIs are to provide a source for recolonisation. The APEIs are important but should not be the only conservation measure in the CCZ.

(ii) Deployment of artificial colonisation substrata can be used to provide additional suitable habitats for recolonisation when the original habitat has been removed by mining. They can also contribute to maintaining connectivity between sites separated by large distances. This method is probably only applicable to SMS mining and prerequisites to guarantee success, such as maintenance of active venting and seepage, will need to be taken into account. Overall, knowledge is still limited to fully appreciate the potential of this action, although it represents an affordable and straightforward experiment that could be carried out during the exploration phase.

(iii) The transplant of fauna. The main issues are 1) the location of the sites for transplanting fauna into and 2) the selection of sites as sources for restoration. These will need to respect the natural distribution patterns and local community composition so as not to cause ecosystem imbalances at receptor sites as well as reducing genetic diversity or the introduction of invasive species. Transplant experiments could be used for the mitigation of potential impacts and /or to test the in situ ecotoxicological and mechanical effects of mining activities. This could be implemented during the impact assessment and/or in the monitoring phases.

(iv) Implant larvae (larvae showering/seeding). By showering a site with larvae, the re-colonisation of the benthic community will be enhanced by promoting the presence of early life stages. This method has low predictability because settlement success depends on local environmental conditions, geomorphology and presence of other organisms. Risks of alterations to the original community or reduction of genetic diversity are main threats of this action.

(v) Guarantee food availability by adding organic material or bait to attract fauna from all different size classes. Increased food availability favours growth and reproduction and can accelerate succession, however, if input of organic matter is too high there are risks of hypoxia, acidification and eutrophication. Furthermore, the addition of food does not necessarily favour the recovery of communities that resemble (in terms of biodiversity, species composition, and function) those that have been damaged by mining, at least in the early period of recovery.

(vi) Reduce plume and its extent. Engineering solutions may be possible to reduce the seabed plume to a minimum. This could have a major beneficial effect, since unconstrained plumes will have serious impacts for tens of kilometres beyond the mined sites. Careful management of the returned water in the dewatering and transhipment plumes could also reduce environmental impacts, e.g. by releasing them as deep as possible in the water column and reducing particle size to a minimum.

Guidelines could be provided to the industry for straightforward and affordable experiments (MIDAS Report D6.7). Such early stage experimentation would allow more knowledge to be gathered on specific ecosystems and their peculiarities. More importantly, it would allow the possible success of proposed mitigation or restoration actions to be assessed. Such experiments could include disturbance studies resembling actual mining actions, and the deployment of artificial substrates to estimate recolonisation potential and assess the composition and settlement potential of the regional species pool on these surfaces. This applies mainly to SMS mining.

Figure 6: Colonisation experiments on the Eiffel Tower hydrothermal vent at Lucky Strike vent field, Mid-Atlantic Ridge, where artificial substrata were deployed and recovered after two years. Image courtesy Ifremer.

3.6.11 Recommendations

- The resilience of a community or organisms (i.e. degrees of resistance and recovery) should be assessed against each type of ecological risk from extractive activities. The data can be used in an environmental impact assessment (EIA) of the extractive activities (See MIDAS Report D8.5).
- Mitigation of mining effects should be designed to make sure that tipping points or points beyond which no ecosystem or community recovery is possible are avoided. These actions will need to include spatial and temporal management of mining operations as well as engineering and operational designs able to minimize, for instance, plume size on the sea floor, toxicity of the return plume and sediment compression (MIDAS Report D7.5).
- A set of combined mitigation and restoration actions, different for each ecosystem and/or locality and related abiotic and biotic conditions should be considered, rather than reliance on one type of action.
- Mitigation management actions would include spatial and temporal management of mining operations, as well as technologically advanced mining machine construction to minimise plume generation at the seafloor, to reduce toxicity of the return plume and minimise sediment compaction (MIDAS Report D6.7).
- Mitigation actions could also be designed to stimulate or at least not impede long-term recovery, including, if proven feasible, deployment of artificial substrates, nutrient enhancement, propagation-and-transplant to stimulate recovery (MIDAS Report D6.6).

- To counteract the uncertainties or fill in knowledge gaps specific to SMS mining, be it only for a specific locality, colonisation experiments could be mandatory as part of the exploration and pilot mining phase.

3.7 Working with industry

MIDAS set out to work closely with industry in order to identify the most likely scenarios for the industrial activities involved in extraction of deep-sea minerals, as well as the potential mitigation and management practices to control the environmental impacts of these activities. Industry involvement was particularly important because there is limited information in the public domain on commercial scale mining, although considerable equipment development is underway. The information gathered was disseminated to the MIDAS research community to inform the development of suggested industry guidelines and protocols.

3.7.1 Main impacts and causative factors

A register of the main potential environmental impacts of deep-sea mining was created for nodules and for SMS drawing upon industry consultations and MIDAS research results. For both ore types MIDAS identified two areas of impact – the directly mined area where habitat would be completely lost, and the area of seabed and water column surrounding this where other effects of mining may be experienced, ranging from full loss to partial habitat loss.

i. Scientific results from MIDAS showed that ecosystem recovery in the directly mined nodule areas will be extremely slow, or not at all for those faunas attached to nodules. Recovery would be more rapid for directly mined SMS areas.

ii. The impacts and effects of mining in the areas adjacent to the directly mined area will be mainly linked to plumes of sediment-laden and potentially toxic material which will be generated by the mining process at the seabed, or created when water and sediment are discharged after separation of the minerals at the sea surface.

3.7.2 Mitigation and management approaches

Since deep-sea mining has not yet begun there is very limited information about the environmental performance of the proposed technologies and about the environmental management practices that may be used in the industry. This was highlighted as a gap during our industry consultation, and the need was identified for high-level guidance to assist in conducting Best Available Technique (BAT) and Best Practicable Environmental Option (BPEO) assessments, as well as the need to develop and implement mitigation measures.

The main focus of mitigation for deep-sea mining for industry and regulators will be:

- Limiting the directly mined area within a region to a level that does not threaten ecosystem integrity; and
- Limiting the size of the area that is affected by secondary impacts (e.g. from plumes and sediment deposition) outside of the mined area by managing the disturbance of sediment.

3.7.3 Best Available Technique (BAT) and Best Practicable Environmental Option (BPEO) assessments

While BAT assessments focus on technology development and selection, BPEO assessments relate to other decision-making aspects of projects, e.g. where to mine first, rates of extraction, number of mining tools and the locations of discharges.

3.7.3.1 Guidance for BAT and BPEO Assessments

MIDAS Work Package 7 (WP7) produced a generic high level framework to guide the consistent application of future BAT and BPEO assessments in deep-sea mining (MIDAS Report D7.4 'Report of the BAT and BPEO Assessments,'). BAT and BPEO assessments can be regarded as key approaches to demonstrating how mitigation has been built into a project. They underpin the information presented in the Environmental Impact Assessment (EIA) process.

The objective of the BAT assessment is to prevent, reduce and, as far as possible, eliminate impacts by giving priority to intervention 'at source' and ensuring the prudent management of natural resources in line with the 'polluter pays' principle and the norms of pollution prevention. 'At source' refers to how a piece of technology makes its primary interaction with the environment, but could equally refer to the inception stage in the development of that technology.

Challenges: While the concept of BAT is well defined and well applied to many industries, full BAT assessments of the current technology for deep-sea mining are not possible because most of the technology to be used is currently in development with limited testing carried out to date in relevant environments. Alternatives for comparison or assessment are therefore not yet available. BAT assessment will be more readily applicable when a specific technology (component or system) is proven in an operational environment and can be compared against other similar alternatives.

Role of BPEO: The BPEO study is an important tool in the decision making process for stakeholders, regulators and mining concession holders. BPEO assessments provide a platform for determining the best environmental solutions for a specific project, taking into consideration a number of factors in addition to the performance of the technology, such as regulatory compliance, public acceptance and cost.

Content of BPEO: BPEO applies to the overall approach of a project (i.e. not just the techniques/technology used) and includes topics such as the mine plan, extraction and collection methods, location where sediment is first separated from the minerals, location of dewatering discharge and any use of chemicals, including the types of chemicals. BPEO provides an auditable basis for the selection of the 'best' option and the basis of explaining key project decisions to the public in the course of conducting an EIA.

Caveat: Each BAT or BPEO assessment will be unique, and the general methodology provided in the MIDAS Report D7.4 will need to be adapted to suit a particular project.

3.7.3.2 Recommendations

- An ultimate environmental management aim should be to avoid all negative effects, for example by changing or modifying an activity or method. In reality this is not usually possible (especially in primary extractive projects), often for economic or technical reasons. However, a 'mitigation hierarchy' can be applied in an attempt to minimise the impacts and effects.
- BAT and BPEO assessments should be developed to demonstrate how a project has sought to avoid and reduce impacts at source and to minimise impacts on receptors.
- Each BAT and BPEO assessment should be considered individually and tailored to 1) the technology being considered and 2) the environment it will operate in.
- The assessments should be based on verified information, where possible, and documented for transparency. The assessment of impacts should be supported where possible by scientific evidence including academic research, modelling studies or the results of monitoring of similar activities/technologies, noting that at the present time understanding of the impacts and effects is at an early stage of development. Additional studies may be necessary.
- Once BAT has been established it should be reviewed at appropriate intervals. Triggers for review could include: (i) a change in regulation; (ii) technological step changes in the industry; and (iii) evidence that the environmental performance/impacts are materially different from those expected.
- 'BAT Reference Notes', as developed within the European Union, or something similar (e.g. ISA Recommendations and Guidance documents) can provide a mechanism for sharing and encapsulating good practice and precedent around environmental performance and other BAT considerations.
- BPEO assessment is often a case of comparing alternatives and can be aligned with, and be informed by, the early stages of an EIA, including 'Scoping'.
- Where appropriate, a preliminary stakeholder consultation can be undertaken to enable options to be identified that are important to external parties. A diverse range of options presented helps provide consultees and regulators with a degree of confidence that the identification of a preferable option has been based on a thorough and transparent process. At this stage innovative options could be considered alongside more traditional ones. Although deep-sea mining projects probably do not have traditional methods, there may be examples of BPEO from other industries that could be considered.
- A new EIA should be required each time operations move to a new area within a licence block, and when the original assessment criteria change, such as changes to mining operations, the technology used, or new scientific information becomes available.

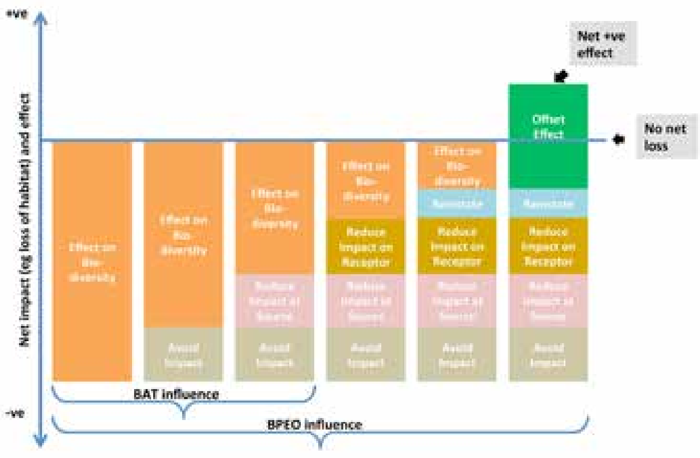


Figure 7: Mitigation hierarchy

3.7.4 Mitigation and management approaches

The overall objective of mine planning and operations should be to minimise the direct footprint wherever possible and to work in the most efficient manner possible to maximise recovery in a given target area and therefore to minimise the overall footprint required per unit volume of nodule recovered or SMS mined. However, in some circumstances there may be environmental benefits in spreading mining over a wider area, but leaving suitably sized patches of nodules intact.

3.7.4.1 Challenges

It is the more specific and unique elements of DSM that will present the main mitigation challenges. Although these elements are relatively few they are a source of considerable uncertainty, not least:

1) in how technologies will interact with the environment to cause impacts;
2) how the environment will respond to those impacts in terms of tolerance, resilience and ability to recover; and
3) the scale of mining activities and the extent to which the activities, by virtue of their scale, could threaten the integrity of marine ecosystems.

Although a major simplification, it is likely that the focus of mitigation for DSM will come down to two closely-linked elements:

1) limiting the extent of the area of exploitation within a defined region to a level that can be sustainably absorbed without threatening ecosystem integrity; and
2) limiting the extent of the area which is affected by secondary impacts (e.g. from plumes and sediment deposition) (MIDAS Report D7.5).

3.7.4.2 Guiding principle

A guiding principle of environmental management is to avoid affecting the integrity of ecosystems. Both nodules and seafloor massive sulphides are integral parts of their environment and the ecosystems they support. Therefore, it is not practicable to avoid negative impacts on individual elements of ecosystems. Assessments of proposed DSM should therefore identify the best practical mitigation options to ensure that there are no adverse effects on the overall integrity of the wider ecosystem in areas targeted by mining. This should be achieved by reducing impacts and/or considering reinstatement of key species, to the extent these are feasible and do not themselves lead to further negative effects.

In addition,, the selective removal of nodules from areas with different levels of nodule abundance might also be considered. It is suspected that some specific and distinct species assemblages associated with different abundances of nodules may be identified (it has been observed that nodule rich areas have higher densities of both sessile and mobile fauna than areas that are nodule-free; in addition there may be differences between areas containing nodules at different abundances). Where this is the case mitigation may require that only a proportion of an area with a given density of nodule is removed. In such cases, efficient operations within each designated mining area will be required, and operations will have to be strictly controlled to keep them within target areas. This type of approach is common to typical licence conditions of shallow water sand and aggregate dredging operations.

3.7.4.3 Importance of EIAs and BPEO studies:

The primary vehicles for identifying impacts and developing appropriate mitigation options are EIA and BPEO studies. These present a defined framework for analysis of impacts, mitigation and the significance of residual effects of projects. Using these methods it should be possible to identify and implement mitigation and management measures which reduce the significance of residual effects to as low as reasonably practicable.

3.7.4.4 Potential role of offsets

Where avoidance and reduction is not feasible, and reinstatement potentially not practical (e.g. where a nodule habitat has been removed and cannot be replaced by artificial nodules) the concept of restoration and offsetting activities may sometimes be considered. Offsetting would typically be proposed at other locations that are potentially valuable in terms of their biodiversity and ecosystems, and usually for areas with the same or similar ecosystems to the mining area. Offsets in other industries may be achieved via a range of measures commonly focussed on preservation, protection and enhancement of sites and their ecosystem integrity in the long term. However, this will be difficult to achieve in the deep sea where equivalent impacted ecosystems do not exist.

3.7.4.5 Mitigation from environmental management practices

The practicalities and efficacy of restoration/reinstatement at a commercial exploitation scale would need to be fully evaluated before committing to such approaches. For SMS there have been proposals to consider restoration/

reinstatement through the installation of artificial structures at hydrothermal vents following extraction. Any such measures would need to be included in the EMMP.

3.7.4.6 Recommendations

The following are based on MIDAS Report D7.5.

- Within each target mining area operations should maximise the level of recovery of nodules, e.g. 50% efficiency versus 100% efficiency would double the area impacted by the mining system for the same production rate.
- Sufficiently large areas of hard substrate (nodules or SMS) that are not significantly affected by sediment deposition from plumes need to be left in place at appropriate spatial intervals to maintain ecosystem functions. This may be through the creation of 'mining exclusion areas'. In nodule areas the focus should be on preserving areas of high nodule abundance. These will include the PRZs, but further set aside areas are likely to be required.

3.8 Protocols and standards

We have taken the knowledge generated in the MIDAS project and examined best practice in other sectors to create a range of protocols that could be used to improve environmental management of deep-sea mining. This has involved reviewing current guidance from deep-sea mining and allied industries and seeking input from a range of stakeholders, including representatives from the mining industry, environmental managers, policymakers, regulators and scientists.

3.8.1 Review of Best Practice

A major review of best practice in environmental management in deep-sea industries was brought together in 'Review of existing protocols and standards applicable to the exploitation of deep-sea mineral resources' (MIDAS Report D8.2). The report includes information on corporate approaches to optimise company environmental performance, focusing on the company itself, including the corporate structure, governance, environmental codes of conduct and internal processes that encourage an environmentally sustainable operation. The report reviewed protocols and standards for environmental management that could be applicable throughout a deep-sea mining project. This includes protocols and standards for environmental impact assessment and reporting, environmental risk assessments, baseline assessment and monitoring and environmental management and monitoring plans. Environmental operations across multiple mining projects are covered, with a particular focus on strategic environmental assessment. The review also covers stakeholder assessment of deep-sea mining sustainability, including the protocols and standards used by direct stakeholders, such as financial institutions, contractors and state sponsors. MIDAS identified gaps and areas for future development. Emphasis is placed on protocols and standards directly relevant for the extraction of seafloor massive sulphides, polymetallic nodules and cobalt-rich ferromanganese crusts. Allied industries, such as aggregate extraction, industrial deep-sea bottom trawling and hydrocarbon exploitation, which have developed their own protocols and standards, are included in the review where appropriate.

3.8.2 Testing, validation and review

The protocols and tools developed within MIDAS have been scrutinised and improved by stakeholders including contractors, the ISA and scientists (see 'Report on outcomes of practical implementation of protocols and standards, including refinements and lessons learned' (MIDAS Report D8.3). This process included practical trials and peer-review. The practical trial of protocols was carried out at a scenario workshop at the National Oceanography Centre in Southampton, UK in June 2016. As deep-sea mining in areas beyond national jurisdiction has not yet happened, it is challenging to effectively test environmental approaches. We applied a scenario workshop methodology, used commonly in other industries in order to stimulate discussion, provide specific guidance including alternative approaches and gather the viewpoints of a range of stakeholders.

The protocols also passed through a working group review process including commercial mineral extraction equipment manufacturers, extraction companies, environmental survey companies, NGOs and academics. The review process ensured that the outputs represent, to the best possible level, the agreement of the entire MIDAS project.

3.8.3 Environmental management framework

Our proposed environmental management framework for deep-sea mining is based on the precautionary approach, which incorporates adaptive management into its design. It includes aspects of environmental management systems from other well-developed industries, such as the onshore and offshore oil and gas industries, but it is tailored to the unique challenges of deep-sea mining. It is focused on the phases of a single mining project; regional and claim-scale management issues are integrated. The adoption of such an environmental management framework by the ISA and national regulators for deep-sea mining would have three main benefits:

1) The technical aspects of the process will assist the ISA in its requirement to protect the marine environment from impacts of mining, both with respect to managing impacts from an individual project, and the cumulative impacts of multiple projects. It will also be of benefit to national regulators.
2) The implementation of a standard process will benefit contractors by reducing uncertainty in planning, applications, and undertaking exploitation and extraction activities, while providing certainty of process to financiers.
3) It will ensure fairness and uniformity in the application of environmental standards, with equal responsibility and liability between contractors.

3.8.3.1 Environmental Impact Assessment and management planning

The EIA approach is an important mechanism by which the ISA can operationalise several key principles, including the precautionary approach, the protection of the common heritage of mankind and protection of the marine environment from harmful effects. The EIA process allows identification and assessment of risks, and the development of plans to mitigate harmful effects in the associated EMMP. We have developed protocols for this EIA process for deep-sea mining, including a detailed approach for carrying out an EIA. MIDAS focussed effort also on understanding the mitigation hierarchy, evaluating the potential efficacy of mitigation approaches in the context of deep-sea mining.

3.8.3.2 Regional assessment

Regional environmental management is an important process to improve the sustainability of deep-sea mining. This process has already begun, with the development of the environmental management plan for the CCZ. MIDAS has developed guidelines for extending this approach to a full regional environmental assessment. Using best-practice approaches from other industries, MIDAS developed a series of recommendations for regional assessment and management planning. These are being tested in the development of a SEMP for deep seabed mineral exploration and exploitation in the Atlantic basin (SEMPIA). The regional-scale risks of deep-sea mining have been assessed using an expert-based risk assessment process, carried out in summer 2016. This process will further guide the scoping and development of regional assessments, so they can focus on and mitigate the key environmental risk sources.

3.8.3.3 Environmental Monitoring and Management Plans

EMMP and associated regulations and permit requirements should aim to prevent or avoid adverse impacts on the environment. Where prevention is not possible, the EMMP should identify ways to minimise or mitigate against adverse impacts. Compensation, or offset (e.g. the conservation of the environment elsewhere) should be considered only as a last resort. Where significant impacts are unavoidable then spatial planning at a regional scale using networks of marine protected areas could complement site-specific measures to reduce impacts, especially in the deep sea.

3.8.3.4 Gaps in existing knowledge

Important gaps and areas for development of protocols and standards include standards for environmental management, strategic environmental assessments (SEA), EIA criteria, baseline assessment methods and monitoring requirements. More specifically, gaps were identified in considering 1) how to reduce potential impacts at an early stage during the design phase of mining, 2) the specification of robust indicators of impacts and thresholds, 3) transparency standards, 4) optimal corporate structuring for sustainability, 5) scoping EIAs, 6) data standards, 7) methods for assessing cumulative and multi-sectoral impacts, 8) developing regional environmental management plans, 9) standards for baseline biodiversity data collection, 10) terms for defining good ecological status, 11) the design and protection of protected areas, and 12) methods to monitor and assess of the impacts of plumes.

3.8.4 Recommendations

- All plans need to be adaptive and include provisions for regular reassessment.
- Clear, well-defined terminology is required - for example, the different types of areas impacted by mining (primary and secondary impact areas).
- A nested approach to management planning is suggested, with three levels: 1) large-scale regional assessment/plan, 2) medium scale assessment/plan for the license block and 3) local assessment/plan for the mined area(s).
- Regional planning is required as part of the SEAs and should be undertaken by the regulating body, such as the

ISA for 'The Area'.

- Collaboration between operators/contractors to share environmental data is the only way to build up a regional assessment. The regional assessment can be used to validate smaller-scale oceanographic and ecosystem models proposed by individual contractors.
- Mining protocols and mining legislation should be iterative - early experiences should inform improvements of regulations.
- Precise definitions of PRZs and IRZs are required in relation to the exploitation of deep-sea minerals, including their size, number and relationship to the mined areas.

3.9 Impact Reference Zones and Preservation Reference Zones

As deep-sea mining moves towards exploitation there are two priorities for environmental management: 1) mitigating the impacts and effects of activities where possible, and 2) optimising approaches for monitoring of impacts. The ISA Mining Code stipulates the creation of two types of zones for local monitoring within a licence area - IRZs and PRZs. The environmental management plan for the CCZ states that a PRZ might also be used for "ensuring preservation … of biological communities impacted by mining activities". The approach used for allocating and assessing IRZs and PRZs, therefore, is important in understanding and managing the impacts of mining activities for these multiple requirements. The recommendations below will help ensure robust environmental management of mining and will ultimately help the ISA meet its requirement to protect the marine environment.

3.9.1 Recommendations

- PRZs should be of a suitable size to ensure sufficient separation from direct impacts and plumes to allow for long-term monitoring and to provide a biodiversity protection function.
- PRZs and IRZs should be defined objectively following best-practice and statistically robust approaches. The designation of multiple PRZs and IRZs in each licence area will be necessary to ensure statistically robust comparisons.
- Sediment plumes are important and should be considered in the design of PRZs and may need additional IRZs to monitor their effects.
- PRZs should be representative of the mined area, and thus should contain high quality resource. It may be necessary for additional PRZs to be designated in areas that represent other habitats that are likely to be affected by mining, for example seamounts.
- The impacts of mining may extend beyond the boundaries of a licence area, so transboundary effects should be considered. Contractors with adjacent claims may consider sharing PRZ design, placement, and monitoring; however, this may have disadvantages for conservation and monitoring and should be assessed carefully.
- Test mining activities are distinct from commercial mining and may require additional PRZs.
- The results of monitoring are important to the perception of DSM projects and ultimately to obtaining the licence to operate. It may important that monitoring plans and results are verified independently.

3.10 Review of existing ISA Recommendation for the guidance of contractors in baseline studies

The ISA Recommendations for the guidance of contractors during the exploration phase, issued by the LTC, were reviewed through the lens of MIDAS research results. A full review was made of the LTC's "Recommendations for the guidance of contractors for the assessment of possible environmental impacts arising from the exploration of marine minerals" (ISBA/19/LTC/8), hereafter referred to (in italics) as the 'LTC Recommendations'. The LTC Recommendations (including an Annex to the document) informs potential contractors of requirements for best practices in acquiring baseline data and for environmental impact assessments (EIAs). The MIDAS Recommendations may be useful to update the LTC Recommendations, and inform the development of future guidance for EIAs for test mining and commercial exploitation.

General findings: The MIDAS review revealed that monitoring strategies will need to include more specific and often more extensive temporal and spatial dimensions. Detailed protocols for contractors are needed to enable robust statistical analyses and these should include definitions of standards and specified type, quality, and extent of information for baseline studies. The review highlighted the critical need for enhanced sharing of data across contractors and scientists to improve mutual research efforts and ensure fundamental questions are considered.

Further work needed: The MIDAS review was not exhaustive and further work will be needed to inform the updating of the LTC Recommendations, which are anticipated to be reviewed at least every five years. As envisaged in the LTC Recommendations the ISA should convene an expert workshop for updating, revising and extending the LTC Recommendations taking into account broad knowledge of current scientific knowledge and information, as well as improved technologies. Such a workshop could be guided by recent publications, technical reports and peer reviewed articles that have been generated by different scientific communities, for instance the South Pacific Commission (SPC), MIDAS, JPI Oceans, the recent book on "Biological Sampling in the Deep Sea" (Clark et al. 2016) and reports from other projects such as the EU Blue Mining and Blue Nodules projects.

3.10.1 Recommendations

- The most basic datasets for understanding the deep-sea environment should include: bathymetry, seafloor backscatter, hydrodynamics, physical biological samples and imagery (at an appropriate spatial/temporal scale), particulate carbon flux, reproductive biology, time series (c. 10 years). These should be aggregated at a regional scale in order to form the basis for sound biogeography and regional environmental planning. Data collected by contractors should be aggregated into a regional assessment
- Monitoring strategies for baseline studies for exploration should include both temporal and spatial dimensions, including epipelagic, mesopelagic, bathypelagic, abyssopelagic and benthopelagic environments, as necessary.
- Environmental baseline studies should be linked precisely to the information required for EIAs and vice versa.
- A handbook to ensure consistent interpretation and application of the LTC Recommendations is needed. Such a handbook could include minimum reporting standards for environmental baseline and monitoring studies for each mineral type. The handbook would include the principles of environmental baseline survey design, including how to generate cost-effective and statistically robust results.
- Environmental studies should be undertaken at scales relevant to the scale of the potential impact in both space and time. The LTC Recommendations lack a definition of the relevant scale and area of study. These issues are particularly important for physical oceanography in environmental baseline studies.
- Temporal and spatial scales should be specified throughout the baseline survey process (see MIDAS Reports D8.3 and D8.5). This is very important because some physical oceanographic, chemical and biological phenomena are time- and spatial-scale dependent.
- The temporal duration of environmental studies should be relative to the setting. They should be of a long enough duration with regular sampling to understand seasonal variation, inter-annual variation, and other relevant, potentially episodic and extreme, events. MIDAS results for instance showed that tidal movements affect sediment plume settling patterns, especially in areas characterised by significant changes in geomorphology (see LTC Recommendations III.15.a.ii). Episodic events, occurring on much larger time scales, e.g., the passage of deep-reaching eddies, may also affect plume settling.
- The LTC Recommendations should be explicit in how contractors should treat Vulnerable Marine Ecosystems (VMEs), Ecologically or Biologically Significant Areas (EBSAs), and other areas of importance to other stakeholders.
- Delineation of potential IRZs and PRZs is a crucial step during the exploration process. Further work will be necessary to clarify the definitions, locations, size and spacing of test mining sites, IRZs and PRZs. The optimal distance from the impacted area should be based on connectivity and the nature and extent of the expected impacts, including plumes (see MIDAS Report D8.5).
- Multiple IRZs and PRZs may need to be established as standard practice.
- PRZs should include areas rich in nodules (i.e. these areas would be directly comparable to high nodule abundance mining sites). Evidence from MIDAS research shows that nodule density relates to species density, diversity and community structure (Vanreusel et al. 2016; see MIDAS Report D8.5).

3.11 Societal and legal frameworks

A key aspect of MIDAS was a focus on the legal and societal dimensions of deep-sea mining and the delivery of project outputs and information to policy makers. In addition to communicating the best available science and understanding to policy-makers and other stakeholders, MIDAS sought to facilitate and integrate wider civil society perspectives into other on-going discussions within MIDAS, such as work with industry.

3.11.1 The international legal framework for deep-sea mining

The United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Implementing Agreement provide the overarching framework for deep seabed mining. These are supplemented by rules, regulations, and guidance as they are developed by the International Seabed Authority (see MIDAS brief, 'The international legal framework for deep sea mining' available online on the MIDAS website). Under UNCLOS Articles 133, et sec., the Area and its [mineral] resources are designated as the Common Heritage of Mankind. The ISA manages the Area and its resources on behalf of humankind as a whole. As part of its suite of obligations, the ISA has to ensure that measures are taken to ensure effective protection of the marine environment from the 'harmful effects' of mining activities. Key issues considered by MIDAS included an analysis of core environmental concepts such as "serious harm" and 'harmful effects", fundamental principles such as the "precautionary approach", "common heritage of mankind", and transparency.

3.11.2 Defining Serious Harm

Defining "serious harm" will be an important topic in the context of the draft exploitation regulations currently being formulated by the ISA. In relation to mining activities which may cause serious harm the ISA has the mandate under UNCLOS to: (i) set-aside areas where mining will not be permitted; (ii) deny a new application for a contract to conduct seabed mineral activities; (iii) suspend, alter or terminate operations; and iv) hold the contractor and its sponsoring state liable for any environmental harm (Levin et al., 2016). As described in Levin et al. 2016, mechanisms to assess significance will need to include: 1) the identification of ecological thresholds based on long-term average baseline conditions; 2) the application of key metrics for biodiversity, abundance, habitat quality, population connectivity, heterogeneity levels, and community productivity; and 3) the application of other indicators that address species-, community- or ecosystem-level impacts. MIDAS has contributed knowledge to these areas, but major gaps persist. Measures that reflect key ecosystem services and can quantify their loss are also needed. Levin et al. (2016) underscore the need to assess the potential for cumulative, significant adverse changes and serious harm across multiple sectors. They suggest actions to advance understanding of these impacts.

3.11.3 Role of precaution in decision making

Given the significant uncertainties, limited knowledge and the risk of serious harm, it is widely appreciated that any future deep-sea mining will need to adopt a precautionary approach. There is a significant challenge in how the precautionary approach might be implemented in practice, especially in the deep sea where knowledge is limited and where, therefore, a more rigorous approach to precaution might need to be taken. There is an imperative to gain more scientific knowledge in order to ease restrictions that might be imposed by a strict precautionary approach. MIDAS Report D9.5 on 'Policy options and associated valuation and appraisal needs and methods for deep-sea mining' investigates best practices for applying the precautionary approach and environmental valuation techniques. As with other new industries, the dominant policy questions are whether, why, where and how to authorise or even encourage deep seabed mining, and how to ensure that any deep seabed mining contributes to fulfilling societal needs, including economic development.

A combination of the two strategies represented in blue in Figure 8 may be the most socially acceptable way forward for deep seabed mining today. Resources with lower risks in a limited number of small sites could be first exploited to facilitate in-situ learning. Subsequently it could be decided whether or not to continue exploiting and to exploit in other areas, based on a deliberate adaptive strategy in combination with good baseline data, environmental impact assessments, site specific management plans and SEMPs/REMPs (MIDAS Report D9.5). Other precautionary mechanisms include 1) identifying gaps in knowledge, 2) recognising uncertainties, 3) looking for signals indicating potential harm, 4) enabling research to address knowledge gaps through a targeted funding mechanism, 5) installing procedures to integrate new knowledge as it becomes available and 6) strictly enforcing the burden of proof to require sufficient evidence that mining activities will not cause serious harm. The report underscores the importance of reflection in terms of needs of current and future generations and of intra- and intergenerational equity.

3.11.4 Limited applicability of standard valuation and appraisal methods

While MIDAS has made a significant contribution to improving our knowledge of deep-sea ecosystems, and the likely impacts of mining activities, much greater knowledge is required on species distributions, abundances and life history characteristics in order to quantify changes that may occur in ecosystem services. A full cost benefit analysis (CBA) including ecosystem services is not feasible at present. This produces an asymmetry in decisions whether, or not, to engage in deep-sea mining. While cash flow and profitability might indicate that deep-sea mining is feasible, knowledge on impacts, their effects and ecosystem values are not sufficiently well known for a true CBA to be conducted in support of deep-sea mining decision taking.

Figure 8: Strategies for DSM: scaling and timing of action. Source: D9.5 (Tinch & van den Hove, 2016)

3.11.5 Conserving the Common Heritage of Humankind

The principle of the Common Heritage of Mankind (CHM) for the development of resources in the Area and how it might be implemented in international waters is complex. The International Seabed Authority manages the Area and its resources on behalf of humankind as a whole. It is appropriate therefore, in line with the CHM principle, that public opinions are taken into account regarding the risks, benefits and alternatives of seabed mining, the value of marine ecosystems and their ecosystem services, and the sharing of benefits intra-generationally and inter-generationally. MIDAS contributed to a paper (Jaeckel et al., submitted) examining options for operationalising CHM. It proposed a number of actions that might be considered including: 1) funding marine scientific research to increase knowledge for humankind, 2) ensuring public participation in value-based decisions, 3) assessing the need for, and alternatives to, deep seabed mining, 4) setting conservation targets, 5) limiting environmental impacts (e.g. through site-specific measures, systems of no-mining areas and regional limits on the magnitude of cumulative activities), 6) preserving options for future generations including access to minable sites, 7) a compensation system for environmental harm, and 8) effective enforcement mechanisms that enable States to act on behalf of humankind in the event of environmental harm.

3.11.6 Role of transparency

MIDAS also focused on issues of transparency, in particular in relation to the collection and dissemination of environmental baseline information and the evaluation of potential environmental impacts. One study associated with MIDAS compared decision-making and public engagement processes at the ISA with the current practices in regional fisheries management organisations (Ardron, 2016). The study suggested that decision-making processes could benefit from an explicit ISA policy concerning transparency. A number of recommendations were made that might be considered by the ISA including 1) a presumption that information generated in the Area is non-confidential unless otherwise determined, 2) making mining contracts publicly available, 3) allowing greater observer access to some meetings of the LTC and Finance Committee, and 4) publishing the annual reports of the Contractors' including compliance in seabed exploration and exploitation operations and their associated environmental impacts (Ardron, 2016). Best practices associated with transparency and recommendations are discussed in MIDAS Report D8.5.

3.11.7 Input from stakeholder workshops

Annual meetings to highlight MIDAS findings and to interact with the EU decision-makers and stakeholders have been an important part of the MIDAS science-policy interface mechanisms. Policymakers, non-governmental organisations (NGOs) and industry representatives were brought together to showcase the latest MIDAS results and facilitate open discussions on key issues. Key observations from the MIDAS science-policy meeting held in December 2015 included 2) the importance of the continued interaction and better communication between industry and other stakeholders to assist industry as it progresses towards the exploitation of mineral resources and 2) the need share standardised environmental information between contractors for regional planning within which the activities of individual contractors can be set. It was emphasised that despite significant progress on deep-sea mining-related science via MIDAS, there was still a long way to go in understanding ecosystem impacts and the rate and extent of ecosystem recovery. Participants noted the need for continued research to take this work forward and to preserve momentum.

3.11.8 Value of MIDAS outreach

MIDAS outreach has served to inform and greatly enhance the quality of NGO input in discussions on commercial seabed mining. MIDAS results have fed into stakeholder consultations and related discussions, such as the EU's Marine Strategy Framework Directive, Blue Growth and Circular Economy initiatives. A MIDAS Report 9.7 on 'two rounds of consultations with NGOs including a summary of views and recommendations' reflects the deliberations of two NGO-sponsored workshops held in November 2014 and April 2016 at which the work of MIDAS was presented. Many at these workshops stressed the importance of the precautionary approach and the need for comprehensive regional environmental management plans prior to any approval of seabed mining contracts.

3.11.9 Recommendations

- The uncertainties and potential impacts of deep-sea mining require the precautionary approach to be applied until more is understood about deep-sea ecosystems, and to be refined as more knowledge is gained.
- Mining regulations should identify and incorporate thresholds and triggers to *inter alia,* indicate a potential likelihood for serious harm, in order to enable the ISA to take pre-emptive action to prevent such harm from occurring.
- Procedures for assessing the potential for cumulative, significant adverse changes and serious harm across multiple sectors should be developed.
- Policies should be developed concerning transparency and public participation.
- Independent research outside contractor areas is necessary to address conservation issues that are beyond the responsibility of individual contractors to address (e.g. cumulative impacts, regional impacts, etc.).
- Test mining and the sharing and evaluation of results should be a required part of the exploration contract. Requirements for long-term monitoring studies should be included.
- Independent review by scientists should be included in assessing the results of test mining, potentially via an independent scientific body.
- A European level organization for promoting, improving, engaging, and coordinating knowledge of deep-sea ecosystems should be considered.

3.12 Technologies to assess the impacts of deep-sea mining and their environmental effects

Deep-sea mining will require comprehensive monitoring of the marine environment. Determining the key variables to measure and monitor will be a critical step in the development of exploitation regulations. Identifying equipment to provide environmental information in a reliable and cost-effective manner will be a critical step.

3.12.1 Towards routine ecosystem monitoring throughout the lifetime of mining projects

All phases of deep-sea mining projects need ecosystem monitoring technologies, from baseline studies as part of the EIA to mining operations, including the assessment of Preservation Reference Zones (PRZs), Impact Reference Zones (IRZs) and other spatial planning measures such as Areas of Particular Environmental Interest (APEIs). Prior to resource extraction, ecosystem status and natural variability need to be characterised, particularly within the licence areas. Once resource extraction has commenced, monitoring should quantify the impacts, including their spatial extent, and ensure these meet regulatory requirements. Following mining activities, continued monitoring is required to address long-term effects and ecosystem recovery.

Figure 9: Recovery of a benthic platform ('lander') after measurements of fluxes of oxygen and other solutes at the seafloor of nodule areas in Peru Basin. Image: Alfred-Wegener-Institut / Johannes Lemburg.

3.12.2 Review of monitoring technologies available in science and industry

Scientists and industry partners within MIDAS, in collaboration with external experts, published a 'Compilation of existing deep-sea ecosystem monitoring technologies in European research and industry sectors' (MIDAS Report D10.1). Monitoring needs were identified for a suite of environmental parameters. Technologies for each of the parameters were assessed in terms of readiness, potential for automation, and appropriateness for deep-sea mining. The report identified a large range of platforms and instruments. Some monitoring technologies are being used currently by science, but have not yet been applied routinely by industry, such as molecular tools for biodiversity assessment and in situ methods to measure biogeochemical processes for quantifying ecosystem function.

While methods for baseline observations and monitoring are available and are mostly operational in science, important gaps were identified in the monitoring of plumes, particle and solute dispersion, sedimentation and associated ecological impacts at a variety of spatial scales.

3.12.3 Challenges in monitoring plumes

Knowledge on the fate of plumes generated by mining is needed to assess the true footprint of mining operations. MIDAS researchers have monitored plumes generated by experimental disturbances of the seafloor in a shallow water system (Portmán Bay) and in the Clarion Clipperton Zone (CCZ) in the equatorial eastern Pacific Ocean. They demonstrated that the quantification of suspended sediments is possible with optical and acoustic sensors. However, plume monitoring in the context of industrial mining operations requires the coupling of hydrodynamic modelling with observations using stationary and moving platforms - an approach which has not yet been demonstrated at an appropriate scale.

3.12.4 Habitat mapping technologies

Efforts to apply and improve acoustic and optical technologies for mapping seafloor habitats was described in MIDAS Report D10.2 on 'Integrative habitat mapping technologies for identification of different deep-sea habitats and their spatial coverage'. Habitat mapping technologies allow the non-invasive assessment of extensive areas of the seafloor and are particularly suitable for the environmental monitoring of deep-sea mining.

AUV investigations have proved useful in the rapid characterisation of seafloor morphology. They delineated plough marks of < 50 cm depth created by seabed disturbance experiments decades prior to the AUV surveys. AUVs equipped with Synthetic Aperture Sonar (SAR) were used to characterise complex habitats at Mid Atlantic Ridge sites in the Arctic (Denny et al., 2015). MIDAS also made considerable progress in the development of software tools for the analysis of seafloor imagery. For example, novel mosaicking and 3D reconstruction methods were applied to images.

Expert knowledge is still required for the high-level analyses of acoustic and optical images and the generation of derived products. However, non-invasive habitat mapping technologies clearly offer great potential for the development of automated systems to monitor the environment in an industrial setting.

3.12.5 Technologies for rapid biodiversity assessment

The identification and quantification of marine fauna are essential for the assessment of biodiversity, and to measure recolonisation and recovery rates post-mining. MIDAS Report D10.4 'Tools for rapid biodiversity monitoring across size classes' focused on the potential of both novel image-based technologies and molecular methods to speed up biodiversity assessments and their use in routine applications by industry. Investigations based on ROV video surveys have proved successful in resolving the relationship between nodule abundance and the effects of seafloor disturbance on the density and composition of communities of large sessile and mobile fauna in the CCZ (Vanreusel et al., 2016). High resolution imaging surveys carried out with towed still cameras achieved a resolution of fauna down to sizes of 1cm.

3.12.6 Value and limitations of molecular methods

Molecular methods have the potential to speed up the process of identification of organisms of many taxa and of different faunal sizes (from microbes to megafauna). For example, DNA-based genomic analyses were successfully applied to samples from the CCZ to assess macrofaunal biodiversity and to resolve the distribution patterns of several polychaete and isopod crustacean species (Janssen et al., 2015). Similar methods applied to microbial communities in samples from nodule areas within the Peru Basin have indicated that experimental disturbances carried out 26 years ago are still having an impact on microbial communities today (Boetius, 2015).

3.12.7 Further challenges to using molecular or image-based tools

Before routine industrial applications of molecular and image-based methods for rapid biodiversity assessment can be carried out, a detailed database of voucher specimens from the region, their morphology and genomic sequences, and their appearance in images needs to be set up. Investigations based only on morphotypes or genomic information will not be suitable without proper validation and archiving of voucher specimens. This is also an issue for genomic investigations based on environmental DNA (eDNA) approaches. While eDNA may allow fast and low-cost biodiversity monitoring in the future, the science is not yet mature enough for its application. Apart from the necessity of building species inventories, greater development is required of methods (e.g. the development of primers that select for long DNA sequences from intact organisms).

3.12.8 Technologies for monitoring ecosystem function

The functions and services of ocean ecosystems, such as productivity, remineralisation, bioturbation and genetic resources are, as yet, not addressed by environmental monitoring techniques even though they provide information on ecosystem status. We have characterised methods for monitoring ecosystem function with a focus on in situ observations and experiments, many of which have been field-tested for the first time in the context of monitoring deep-sea mining. For example, a suite of autonomous landers and ROV modules equipped with incubation chambers and microsensors were deployed in the Peru Basin nodule province. They provided strong indications of the long-term impacts of simulated mining disturbances on biogeochemical processes at the seafloor. At the same site, 'food pulse experiments' were carried out successfully with autonomous and ROV-manipulated equipment to quantify organic matter remineralisation by microbes and larger organisms in areas with polymetallic nodules. A summary of methods is provided in MIDAS Report 10.3 on 'Integrated modular systems for monitoring of ecosystem functions in deep-sea habitats with relevance for mining'.

3.12.9 Limitations of tools to observe ecosystem function

Approaches used by scientists to observe ecosystem function are not yet readily transferrable for routine application by industry for monitoring deep-sea mining at present. More detailed investigations of mining-related impacts on ecosystem functions are needed before advice can be given on which environmental parameters should be adopted for monitoring, and which technologies should be used.

3.12.10 Assessing suitability for routine monitoring by industry and the transfer of knowledge

Two critical steps for the development of exploitation regulations are 1) to determine the key variables to measure and monitor and 2) to identify equipment that can provide the necessary environmental information in a reliable and cost-effective manner. The identification of technologies that are best suited for use in the context of routine industrial monitoring was a key MIDAS goal. Figure 10 summarises some aspects of an analysis of the relevant strengths and weaknesses of molecular and image-based technologies for rapid biodiversity assessment.

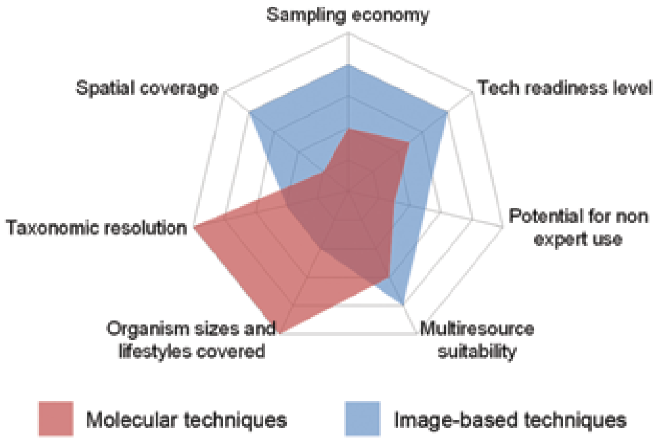


Figure 10: Characterisation of molecular and image-based biodiversity assessment technologies regarding scientific significance and feasibility for cost-effective routine application. Simplified representation of the assessment carried out in MIDAS report 'Tools for rapid biodiversity monitoring across size classes' Graphics: Autun Purser & Felix Janssen / AWI.

3.12.11 Recommendations

- Tools are needed for the selection of the indicators and technologies for environmental monitoring in a structured and formalized manner (e.g., in form of a decision matrix).
- Monitoring strategies and technologies need to be standardized, quality controlled, and validated in order to ensure that baseline data and monitoring results can be integrated across licence areas and during the life of a mine site.
- ISO 9001 should be adopted by the International Seabed Authority and its contractors for reporting on and documenting technologies and procedures.
- The selection of monitoring strategies needs to take into account the temporal and spatial scales of impacts, the characteristics of the local environment and the expected timescales for the recovery of faunal communities.
- A greater variety of in situ monitoring of ecosystem functions at the seafloor should be part of baseline studies. Seafloor ecosystem functions (e.g. organic matter remineralization, energy and element transfer in food webs, bioturbation) provide integrated information on activities of seafloor biota and are key to assess ecosystem services (e.g., nutrient regeneration, carbon burial / biological pump).
- An open access taxonomy reference database of benthic and pelagic specimen is required at a regional scale (i.e., across license areas) to enable future rapid biodiversity

studies. The database needs to include genomic information, the collection and archiving of voucher specimens

- A regional atlas of in situ different images of larger epifauna should be compiled to ensure a standardised approach to seabed imaging surveys between contractors.
- Plume monitoring will require the coupling of hydrodynamic modelling with in situ observations from stationary and moving platforms to build and validate models of plume behaviour.
- Non-invasive habitat mapping technologies offer great potential for the development of automated systems to monitor the environment but still face significant limitations.
- Genomic investigations based on eDNA may have the potential for fast and low-cost biodiversity monitoring in the future, but the science is not yet mature enough for its application.

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Appendix I: Summary of MIDAS recommendations

3.1 Recommendations related to geochemical impacts

- Further research and environmental impact assessment processes will need to include both biogeochemical processes and abiotic geochemical leaching, especially for SMS deposits.
- Stockpiling of ore containing chalcopyrite on the seafloor pending its uploading should not be permitted.
- The interaction between ores and seawater should be assessed at all stages including crushing processes at the seabed, flow through the riser pipe, dewatering on the surface vessel, the consequent discharge plume, and transport to shore in barges

3.1 Recommendations related to gas hydrates on continental margins

- Guidelines should be developed to inform future research and environmental impact assessments of potential gas hydrate production.
- Advanced field and laboratory characterization of the physical properties and thermo-hydro-mechanical behaviour of gas hydrate-bearing and free gas-bearing sediments are also needed to enable an informed decision on subsea development.
- Similarly, potential slope failures and run-out distances of landslides possibly triggered by the dissociation of gas hydrates in the surroundings of the production site should be analysed.
- Any production operation should be continuously monitored to assess gas leakage and seafloor subsidence.

3.2 Recommendations related to plumes

- A metric-based decision tree may enable operators to draw conclusions from the probable fate of discharged contaminants from deep-sea mining activities, but this needs to be tested and will always need to be backed by additional site-specific information.
- Baseline studies will need to assess current and eddy regimes, geomorphology, seasonality, etc. Long-term time series will be needed for complex sites.
- Models are vital tools for predicting and understanding plume impacts. More work is needed to enable precise modelling of plumes in order to assess the footprint of operations and the spread of environmental impacts.
- Models need to be constructed with an understanding of the environment they represent. The limitations of the inherent assumptions of different models need to be appreciated. Models need to cover all appropriate spatial and temporal scales and related to species- and ecosystem-specific thresholds.
- It is difficult to recommend broadly applicable models because no single model will apply to all conditions. Therefore, modelling approaches must be applied intelligently in any given context with an understanding of the complexities likely to be encountered at that site.
- More research is needed on how particle-dense plumes will behave initially in the immediate vicinity of mining machinery and discharges. This information will provide the key initial conditions for larger-scale plume models. Model studies coupled with different design options of mining systems may provide solutions for plume mitigation.
- Thresholds are lacking for determining when a plume will have a significant adverse impact. Research in the establishing plume thresholds is needed.
- The impacts of plumes crossing the boundaries between adjacent contractor areas will need to be considered in impact assessments and exploration regulations.
- Oceanographic and plume model data and methodologies will need to be independently validated. These should be shared as "environmental data" because different assumptions can lead to varying conclusions and results.
- MIDAS recommends that the text of paragraph 37 of the ISA "Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area" (ISBA/19/LTC/8)) is amended as follows:

  > 37. If there is potential for surface discharge, the pelagic community in the upper 200 m of the water column should be characterized. Depending on plume modelling studies, it may be necessary to study pelagic communities, especially gelatinous plankton, over a wide depth range. The pelagic community structure 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 pelagic trawls or remotely operated vehicle techniques. Measurements should be made of phytoplankton composition, biomass and production, zooplankton composition and biomass, bacterial plankton biomass and productivity, micronekton, fish and large predators. Temporal variation of the plankton community in the upper surface waters on seasonal and inter-annual scales should be studied. Remote sensing should be used to augment field programmes. Calibration and validation of remote-sensing data are essential.

3.3 Recommendations related to ecotoxicology

- Knowledge on the ecotoxicological limits of deep-water species to certain chemicals (or mixtures) is helpful to assess their tolerances and define the limits of ecotoxicological impact from a mining site.
- Chronic sub-lethal toxic impacts and cumulative impacts should be considered by contractors and by the ISA in regulating exploitation activities. These will need to include the cumulative impacts of plumes created from mining adjacent plots over extended periods on the physiology and performance of the surrounding biological communities as well as the potential impacts of avoidance behaviour by fauna adjacent to mining plots.
- The bulk toxicity of each prospective resource should be established in advance, and at different times during biological and seasonal cycles, for a suite of organisms relevant to the region surrounding the area of immediate impact. Such an approach should also be adopted to assess the potential toxicity of discharge waters from any dewatering of the ore slurry. This assessment should be conducted as part of the baseline studies phase before an exploitation contract is granted and as a component of the routine ship-board monitoring during mining activity.
- Rapid assessment of ore and plume toxicity on board the survey/support vessel is recommended with an approved assay during both the exploration phase and the exploitation phase.
- Regulators should consider setting spatial limits for the influence of the plumes produced and their metals content.
- A precautionary approach should be adopted during test mining and initial exploitation in the absence of field-validated data of chronic impacts generated at the scale of commercial exploitation. Operators and regulating bodies should consider continuing to work with environmental scientists during the early phases of exploitation to iterate regulations for impact monitoring and the designation of exposure limits based on new research.
- As larval stages are more susceptible to toxic effects, knowing the reproductive and spawning seasons of species, if relevant, may permit the identification of times of the year when mining should be suspended for a particular location/resource (i.e. it may be necessary to introduce 'mining seasons' to avoid key reproductive events. This may be included in adaptive management plans.
- Operations will need contingency plans if/when discharge waters exceed toxicity thresholds, as determined during EIAs.

3.4 Recommendations related to species connectivity

- Standardized baseline should include DNA taxonomy and address gaps in the knowledge of life history, functional traits and physical oceanography.
- Genetic connectivity studies (MIDAS Report D4.8) should include:
    a. Improved coupling of physical oceanographic and population genetic models for more accurate predictions of dispersal pathways;
    b. Additional processes that at present are not fully understood, such as: the importance of stepping stone dispersal pathways; larval dispersal patterns which follow different patterns in successive years; and the role of large-scale episodic events in driving intermittent genetic connectivity between localities.
- Protected areas (should be designed to optimize gene flow between different populations. This will avoid isolation of populations leading to: i) the loss of genetic diversity and ii) a high rate of inbreeding and increased homozygosity.
- Based on MIDAS results, two types of protected areas are envisaged: a number of small PRZs within the mining claim areas to maintain local populations, and larger protection zones (e.g. APEIs) at the regional scale to maintain regional biodiversity.
- Until more informed predictions on impacts of mining can be made accurately, a precautionary approach should be implemented to avoid global extinctions.

- A reliable, open source list of species in the proposed impacted region will provide the basis for effective management recommendations.
- Contractors should be required to publish a list of taxa (preferably to species names, but including at the very least genus names) linked to openly-accessible museum-vouchered specimens fixed and preserved in 80% ethanol.

3.5 Recommendations relating to ecosystem function

- It will be important to establish ecological baselines at the appropriate spatial and temporal scales.
- Multiple reference sites both in the near and far field from intended mining sites should be established and monitored, for at least 2 years in advance of mining to capture a snapshot of natural variability.
- Long-term ecosystem monitoring will enable assessment of impacts on ecosystem functions. There is potential for further development of autonomous monitoring systems.
- In nodule fields, the mining footprint should be constrained to the smallest possible area, so as to limit sediment disturbance and compaction, both of which may inhibit ecosystem recovery.

3.6 Recommendations relating to ecosystem recovery

- The resilience of a community or organisms (i.e. degrees of resistance and recovery) should be assessed against each type of ecological risk from extractive activities. The data can be used in an environmental impact assessment (EIA) of the extractive activities (See MIDAS Report D8.5).
- Mitigation of mining effects should be designed to make sure that tipping points or points beyond which no ecosystem or community recovery is possible are avoided. These actions will need to include spatial and temporal management of mining operations as well as engineering and operational designs able to minimize, for instance, plume size on the sea floor, toxicity of the return plume and sediment compression (MIDAS Report D7.5).
- A set of combined mitigation and restoration actions, different for each ecosystem and/or locality and related abiotic and biotic conditions should be considered, rather than reliance on one type of action.
- Mitigation management actions would include spatial and temporal management of mining operations, as well as technologically advanced mining machine construction to minimise plume generation at the seafloor, to reduce toxicity of the return plume and minimise sediment compaction (MIDAS Report D6.7).
- Mitigation actions could also be designed to stimulate or at least not impede long-term recovery, including, if proven feasible, deployment of artificial substrates, nutrient enhancement, propagation-and-transplant to stimulate recovery (Midas Report D6.6).
- To counteract the uncertainties or fill in knowledge gaps specific to SMS mining, be it only for a specific locality, colonisation experiments could be mandatory as part of the exploration and pilot mining phase.

3.7.3 Recommendations relating to Best Available Technique (BAT) and Best Practicable Environmental Option (BPEO) assessments

- An ultimate environmental management aim should be to avoid all negative effects, for example by changing or modifying an activity or method. In reality this is not usually possible (especially in primary extractive projects), often for economic or technical reasons. However, a ‘mitigation hierarchy’ can be applied in an attempt to minimise the impacts and effects.
- BAT and BPEO assessments should be developed to demonstrate how a project has sought to avoid and reduce impacts at source and to minimise impacts on receptors.
- Each BAT and BPEO assessment should be considered individually and tailored to 1) the technology being considered and 2) the environment it will operate in.
- The assessments should be based on verified information, where possible, and documented for transparency. The assessment of impacts should be supported where possible by scientific evidence including academic research, modelling studies or the results of monitoring of similar activities/technologies, noting that at the present time understanding of the impacts and effects

is at an early stage of development. Additional studies may be necessary.

- Once BAT has been established it should be reviewed at appropriate intervals. Triggers for review could include: (i) a change in regulation; (ii) technological step changes in the industry; and (iii) evidence that the environmental performance/impacts are materially different from those expected.
- 'BAT Reference Notes', as developed within the European Union, or something similar (e.g. ISA Recommendations and Guidance documents) can provide a mechanism for sharing and encapsulating good practice and precedent around environmental performance and other BAT considerations.
- BPEO assessment is often a case of comparing alternatives and can be aligned with, and be informed by, the early stages of an EIA, including 'Scoping'.
- Where appropriate, a preliminary stakeholder consultation can be undertaken to enable options to be identified that are important to external parties. A diverse range of options presented helps provide consultees and regulators with a degree of confidence that the identification of a preferable option has been based on a thorough and transparent process. At this stage innovative options could be considered alongside more traditional ones. Although deep-sea mining projects probably do not have traditional methods, there may be examples of BPEO from other industries that could be considered.

3.7.4 Recommendations relating to mitigation

- Within each target mining area operations should maximise the level of recovery of nodules, e.g. 50% efficiency versus 100% efficiency would double the area impacted by the mining system for the same production rate.
- Sufficiently large areas of hard substrate (nodules or SMS) that are not significantly affected by sediment deposition from plumes need to be left in place at appropriate spatial intervals to maintain ecosystem functions. This may be through the creation of 'mining exclusion areas'. In nodule areas the focus should be on preserving areas of high nodule abundance. These will include the PRZs, but further set aside areas are likely to be required.

3.8 Recommendations relating to management and planning

- All plans need to be adaptive and include provisions for regular reassessment.
- Clear, well-defined terminology is required - for example, the different types of areas impacted by mining (primary and secondary impact areas).
- A nested approach to management planning is suggested, with three levels: 1) large-scale regional assessment/plan, 2) medium scale assessment/plan for the license block and 3) local assessment/plan for the mined area(s).
- Regional planning is required as part of the SEAs and should be undertaken by the regulating body, such as the ISA for 'The Area'.
- Collaboration between operators/contractors to share environmental data is the only way to build up a regional assessment. The regional assessment can be used to validate smaller-scale oceanographic and ecosystem models proposed by individual contractors.
- Mining protocols and mining legislation should be iterative - early experiences should inform improvements of regulations.
- Precise definitions of PRZs and IRZs are required in relation to the exploitation of deep-sea minerals, including their size, number and relationship to the mined areas.

3.9 Recommendations related to impact and preservation reference zones

- PRZs should be of a suitable size to ensure sufficient separation from direct impacts and plumes to allow for long-term monitoring and to provide a biodiversity protection function.
- PRZs and IRZs should be defined objectively following best-practice and statistically robust approaches. The designation of multiple PRZs and IRZs in each licence area will be necessary to ensure statistically robust comparisons.
- Sediment plumes are important and should be considered in the design of PRZs and may need additional IRZs to monitor their effects.
- PRZs should be representative of the mined area, and thus should contain high quality resource. It may be necessary for

additional PRZs to be designated in areas that represent other habitats that are likely to be affected by mining, for example seamounts.

- The impacts of mining may extend beyond the boundaries of a licence area, so transboundary effects should be considered. Contractors with adjacent claims may consider sharing PRZ design, placement, and monitoring; however, this may have disadvantages for conservation and monitoring and should be assessed carefully.
- Test mining activities are distinct from commercial mining and may require additional PRZs.
- The results of monitoring are important to the perception of DSM projects and ultimately to obtaining the licence to operate. It may important that monitoring plans and results are verified independently.

3.10 Recommendations related to baseline studies

- The most basic datasets for understanding the deep-sea environment should include: bathymetry, seafloor backscatter, hydrodynamics, physical biological samples and imagery (at an appropriate spatial/temporal scale), particulate carbon flux, reproductive biology, time series (c. 10 years). These should be aggregated at a regional scale in order to form the basis for sound biogeography and regional environmental planning. Data collected by contractors should be aggregated into a regional assessment
- Monitoring strategies for baseline studies for exploration should include both temporal and spatial dimensions, including epipelagic, mesopelagic, bathypelagic, abyssopelagic and benthopelagic environments, as necessary.
- Environmental baseline studies should be linked precisely to the information required for EIAs and vice versa.
- A handbook to ensure consistent interpretation and application of the LTC Recommendations is needed. Such a handbook could include minimum reporting standards for environmental baseline and monitoring studies for each mineral type. The handbook would include the principles of environmental baseline survey design, including how to generate cost-effective and statistically robust results.
- Environmental studies should be undertaken at scales relevant to the scale of the potential impact in both space and time. The LTC Recommendations lack a definition of the relevant scale and area of study. These issues are particularly important for physical oceanography in environmental baseline studies.
- Temporal and spatial scales should be specified throughout the baseline survey process (see MIDAS Reports D8.3 and D8.5). This is very important because some physical oceanographic, chemical and biological phenomena are time- and spatial-scale dependent.
- The temporal duration of environmental studies should be relative to the setting. They should be of a long enough duration with regular sampling to understand seasonal variation, inter-annual variation, and other relevant, potentially episodic and extreme, events. MIDAS results for instance showed that tidal movements affect sediment plume settling patterns, especially in areas characterised by significant changes in geomorphology (see LTC Recommendations III.15.a.ii). Episodic events, occurring on much larger time scales, e.g., the passage of deep-reaching eddies, may also affect plume settling.
- The LTC Recommendations should be explicit in how contractors should treat Vulnerable Marine Ecosystems (VMEs), Ecologically or Biologically Significant Areas (EBSAs), and other areas of importance to other stakeholders.
- Delineation of potential IRZs and PRZs is a crucial step during the exploration process. Further work will be necessary to clarify the definitions, locations, size and spacing of test mining sites, IRZs and PRZs. The optimal distance from the impacted area should be based on connectivity and the nature and extent of the expected impacts, including plumes (see MIDAS Report D8.5).
- Multiple IRZs and PRZs may need to be established as standard practice.
- PRZs should include areas rich in nodules (i.e. these areas would be directly comparable to high nodule abundance mining sites). Evidence from MIDAS research shows that nodule density relates to species density, diversity and community structure (Vanreusel et al. 2016; see MIDAS Report D8.5).

3.11 Recommendations related to societal issues

- The uncertainties and potential impacts of deep-sea mining require the precautionary approach to be applied until more is understood about deep-sea ecosystems, and to be refined as more knowledge is gained.

- Mining regulations should identify and incorporate thresholds and triggers to inter alia, indicate a potential likelihood for serious harm, in order to enable the ISA to take pre-emptive action to prevent such harm from occurring.
- Procedures for assessing the potential for cumulative, significant adverse changes and serious harm across multiple sectors should be developed.
- Policies should be developed concerning transparency and public participation.
- Independent research outside contractor areas is necessary to address conservation issues that are beyond the responsibility of individual contractors to address (e.g. cumulative impacts, regional impacts, etc.).
- Test mining and the sharing and evaluation of results should be a required part of the exploration contract. Requirements for long-term monitoring studies should be included.
- Independent review by scientists should be included in assessing the results of test mining, potentially via an independent scientific body.
- A European level organization for promoting, improving, engaging, and coordinating knowledge of deep-sea ecosystems should be considered.

3.12 Recommendations related to monitoring the marine environment

- Tools are needed for the selection of the indicators and technologies for environmental monitoring in a structured and formalized manner (e.g., in form of a decision matrix).
- Monitoring strategies and technologies need to be standardized, quality controlled, and validated in order to ensure that baseline data and monitoring results can be integrated across licence areas and during the life of a mine site.
- ISO 9001 should be adopted by the International Seabed Authority and its contractors for reporting on and documenting technologies and procedures.
- The selection of monitoring strategies needs to take into account the temporal and spatial scales of impacts, the characteristics of the local environment and the expected timescales for the recovery of faunal communities.
- A greater variety of in situ monitoring of ecosystem functions at the seafloor should be part of baseline studies. Seafloor ecosystem functions (e.g. organic matter remineralization, energy and element transfer in food webs, bioturbation) provide integrated information on activities of seafloor biota and are key to assess ecosystem services (e.g., nutrient regeneration, carbon burial / biological pump).
- An open access taxonomy reference database of benthic and pelagic specimen is required at a regional scale (i.e., across license areas) to enable future rapid biodiversity studies. The database needs to include genomic information, the collection and archiving of voucher specimens
- A regional atlas of in situ different images of larger epifauna should be compiled to ensure a standardised approach to seabed imaging surveys between contractors.
- Plume monitoring will require the coupling of hydrodynamic modelling with in situ observations from stationary and moving platforms to build and validate models of plume behaviour.
- Non-invasive habitat mapping technologies offer great potential for the development of automated systems to monitor the environment but still face significant limitations.
- Genomic investigations based on eDNA may have the potential for fast and low-cost biodiversity monitoring in the future, but the science is not yet mature enough for its application.

Appendix II: List of MIDAS reports

The following documents and reports were produced as internal deliverables during the course of the MIDAS project. Some are publicaly available via the MIDAS website (www.eu-midas.net) but most are confidential dicuments since they contain as yet unpublished scientific data. For more information please contact the MIDAS project manager, Dr Vikki Gunn (vikki.gunn@seascapeconsultants.co.uk).

D1.1 Inventory of sulphide mineralogy and trace metal content, and review of sulphide oxidation rates determined for seafloor systems, including contrasting sulphide mineralogy and experimental designs

D1.2 Data report on 'Evaluation of the geological processes relevant to assessing the scale of the impact of mining Europe's seafloor REE resources'

D1.3 Report on batch experiments into sulphide oxidation and trace metal release

D1.4 Data report on 'Evaluation of techniques for the extraction of REE's and their potential for the remobilisation of other potentially harmful elements'

D1.5 Report on seismic and geotechnical characterisation of hydrated sediments in a sand-rich setting: field work and lab experiment results.

D1.6 Report on potential impacts of gas hydrate exploitation on slope stability and sediment deformation.

D1.7 Report on assessment of changes in methane release and sediment physical properties of sites after drilling in the Svalbard area

D2.1 Report on the effects of a range of characteristic hydrodynamic regimes on the three discharge methodologies in terms of near-field dilution

D2.2 Report on the near-field hydrodynamic modelling of three case study sites: MAR, DISCOL, CCZ

D2.3 Report on model simulations of a far-field dispersion effects under a range of future climate and extreme future scenarios

D2.4 Analysis of data requirement for near-field model validation

D2.5 Report on variance and persistence of hydrodynamic conditions at three case study sites

D2.6 Report hydrographic measurements made at two sites: MAR and DISCOL

D2.7 Report containing metric-based decision tree to enable operators to draw conclusions from the probably fate of discharged contaminants

D3.1 Database of existing ecotoxicological data and quality assessment established from a desk study of the literature

D3.2 Report on the lethal and sub-lethal toxicity of selected metals and REEs to planktonic and benthic meio-, macro- and megafaunal life history stage at low temperatures and high pressures

D3.3 Assessment report on the use of avoidance behaviour monitoring for real time impact assessment of mining activity, to feed into WP10

D3.4 Database of new ecotoxicological data of selected metals and REEs in meio- to megafauna of relevance to deep-sea mining, collating D3.1, D3.2 and D3.3 to feed into WP7 and WP8.

D3.5 Validation report on the response of biological indices to toxicant exposure in macro- and megafauna from exposures to contaminant complexes collected, including field exposures, to feed into WP7 and WP8

D3.6 Report on the biological response of bathyal and abyssal fauna to toxic exposure to selected metals and REEs

D4.1 Database on reproduction and larval ecology from selected study regions (CCZ, MAR, Arctic gas hydrates)

D4.2 Gap analyses of existing data to determine what future sampling is required and to provide support for ecological modelling from the selected study regions

D4.3 Synthesis of reproduction and larval ecology key functional species from the selected study regions (CCZ, MAR)

D4.4 Report on scales of population connectivity based on genetic analyses

D4.5 Meta-analyses of biogeographic patterns based on existing and new data from planned cruises to produce a synthesis of patterns of biogeography and connectivity at scales from local to province

D4.6 Analyses and modelling of key species dispersal and population connectivity at different spatial scales and under different disturbance scenarios at the fragmented habitats of MAR

D4.7 Delivery of appropriate data and associated metadata to WP6 and WP8 as well as accessing information on monitoring technologies with WP10

D4.8 Report summarising all information from WP4 relevant to the production of a document with recommendations for management practices and mitigation activities to enhance or preserve species.

D5.1 Report on the assessment of the severity of methane release from gas hydrate extraction activities and potential impacts on deep-sea ecosystems

D5.2 Report impacts of deep-sea sediment disturbance on abyssal seafloor ecosystem processes and ecosystem recovery.

D5.3 Report on the impact of long-term effects of sediment burial on benthic biodiversity, community structure and ecosystem functions and services, based on lab and in situ studies

D5.4 Report on the results from the modelling assessments

D6.1 Report on timescales of recovery of abyssal communities after disturbance (DISCOL)

D6.2 Report on recovery of communities on Palinuro Seamount

D6.3 Report on recovery of benthic communities from sediment burial and exposure to acidic waters at El Hierro

D6.4 Report on disturbance experiment at Portman Bay

D6.5 Report on early colonisation processes at active and inactive vent of the mid-Atlantic Ridge

D6.6 Report on the resilience of benthic deep-sea fauna to mining activities

D6.7 Synoptic report on colonisation of artificial substrates by deep-sea fauna and potential restoration actions in the deep sea including literature and new data

D7.1 Information pack for industry stakeholders

D7.2 Project definitions and bases for assessment

D7.3 Register of main impacts and causative factors

D7.4 Report of the BAT and BPEO assessments

D7.5 Register of proposed mitigation and environmental management practices and measures

D8.1 Initial outline of key areas for development of protocols and standards identified from stakeholder consultation

D8.2 Review of existing protocols and standards applicable to the exploitation of deep-sea mineral resources

D8.3 Report on outcomes of practical implementation of protocols and standards, including refinements and lessons learned

D8.4 Report on outcomes of review of protocols and tools, including suggested amendments

D8.5 Protocols, tools and standards for environmental management of exploitation of deep-sea mineral resources

D9.1 Policy briefs to inform the Science-Policy Panel on preliminary findings from MIDAS and the implications for policymakers

D9.2 Report of a comparative review of indicators for the descriptor on seafloor integrity

D9.3 Report on ISA workshops in the first two years of MIDAS on scientific issues of importance to the development of international regulations for the exploitation of polymetallic nodules

D9.4 Report on applying the results from MIDAS to update ISA's guidance document

D9.5 Report on policy options and associated valuation and appraisal needs and methods for DSM.

D9.6 Report on the implications of MIDAS results for policy makers with recommendations for future regulations to be adopted by the EU and the ISA

D9.7 Report on the two rounds of consultations with NGOs including a summary of views and recommendations

D10.1 Compilation of existing deep-sea ecosystem monitoring technologies in European research and industry. Assessment of applicability, and identification of gaps in existing technologies

D10.2 Integrative habitat mapping technologies for identification of different deep-sea habitats and their spatial coverage

D10.3 Integrated modular systems for monitoring of ecosystem functions in deep-sea habitats with relevance for mining

D10.4 Tools for rapid biodiversity monitoring across size classes

D10.5 Report on appropriateness of the testing of the protocols and standards developed in WP8

D11.1 Project website

D11.2 Project handbook

D11.3 Project brochure

MIDAS

For more information about MIDAS please visit

www.eu-midas.net

The MIDAS project received funding from the European Union's Seventh Programme for research, technological development and demonstration under Grant Agreement No. 603418