INFORMATIONSHEET

July 2024

DEEP-OCEAN STEWARDSHIP INITIATIVE

The Mitigation Hierarchy: Polymetallic Nodules and Sulphides

Key Messages

- Mined deep-sea minerals will not replenish for millennia to millions of years, therefore "No Net Loss" of mineral-associated biodiversity and ecosystem functions is impossible.
- Before any deep-sea mining project goes ahead, the project-specific levels of environmental loss have to be agreed to and clearly stated.
- The mitigation hierarchy is a management tool to limit predicted environmental impacts of planned projects. The hierarchy's four levels are (1) avoidance, (2) minimisation, (3) rehabilitation/restoration, (4) offsetting.
- Avoidance and minimisation of deep-sea mining are the only measures that can maintain environmental objectives.
- The effectiveness of rehabilitation/restoration after deep-sea mining impact is unproven. Offsetting cannot replicate the unique biodiversity and mineral-associated ecosystem functions lost at mined locations.

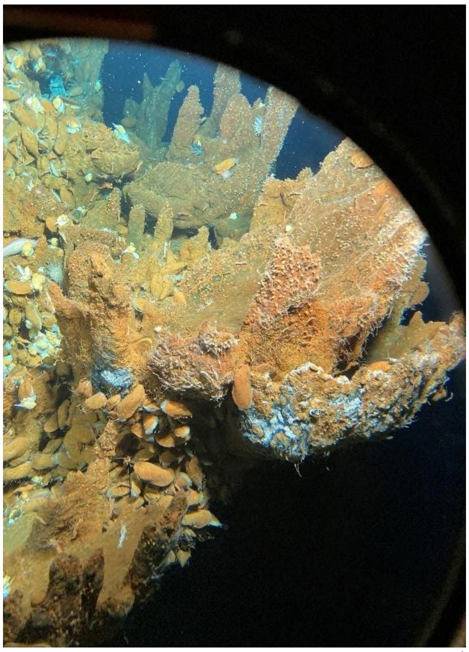

Figure 1: Minerals in the deep sea are currently under exploration for mining. The picture shows polymetallic sulphide deposits colonized by mussels and anemones at active deep-sea vents (picture by J. Sarrazin, view through the window of deep diving submersible *Nautile*).

Mitigation Hierarchy: Concept and Context

The International Seabed Authority's Mining Code regulations (e.g. ISBA/19/C/17, ISBA/29/C/CRP.1) stipulate that contractors shall apply mitigation as part of their Environmental Impact Assessment process. Here, we summarize the concept of the mitigation hierarchy and how it can be applied in a deep-sea mining context.

The concept

The mitigation hierarchy is a well-established management tool applied to terrestrial and coastal systems to reduce the environmental risks and impacts of proposed plans and projects. The tool is used to maintain systems at, or return them to, levels of pre-defined environmental status that can be expressed as variables like biodiversity and are measured against the environmental baseline prior to impact ("frame of reference"). Biodiversity management objectives can include, for example, accepted levels of biodiversity loss, no net loss, or net gain of biodiversity. Applying the mitigation hierarchy ensures that a project's negative impacts remain within the limits set by the management objectives (Figure 2a).

The mitigation hierarchy applies a tiered approach in descending priority, starting from (1) avoidance, through (2) minimization, (3) rehabilitation and restoration, and finally to (4) offsetting of impacts (Figure 2b). The first two steps are preventive, seeking to avoid and then minimize impacts as much as possible in the project design. Minimization measures reduce the duration, intensity, significance and/or extent of impacts (including direct, indirect and cumulative impacts) that cannot be completely avoided. Once these steps are exhausted, actions that support environmental recovery after impact (i.e., reverse the residual effects of an activity) can be applied. Rehabilitation focuses on repairing ecosystem functions and services, whereas restoration aims to return ecosystems to their pre-disturbance, or original, baseline conditions. As a last resort, the mitigation hierarchy allows managers to consider offsetting of impacts. Methods for offsetting impacts broadly involve protecting or restoring other environments to achieve environmental objectives as similar as possible to the losses in the directly damaged environment. According to the International Union for the Conservation of Nature (IUCN), the aim of offsetting is to achieve "No Net Loss" of biodiversity.

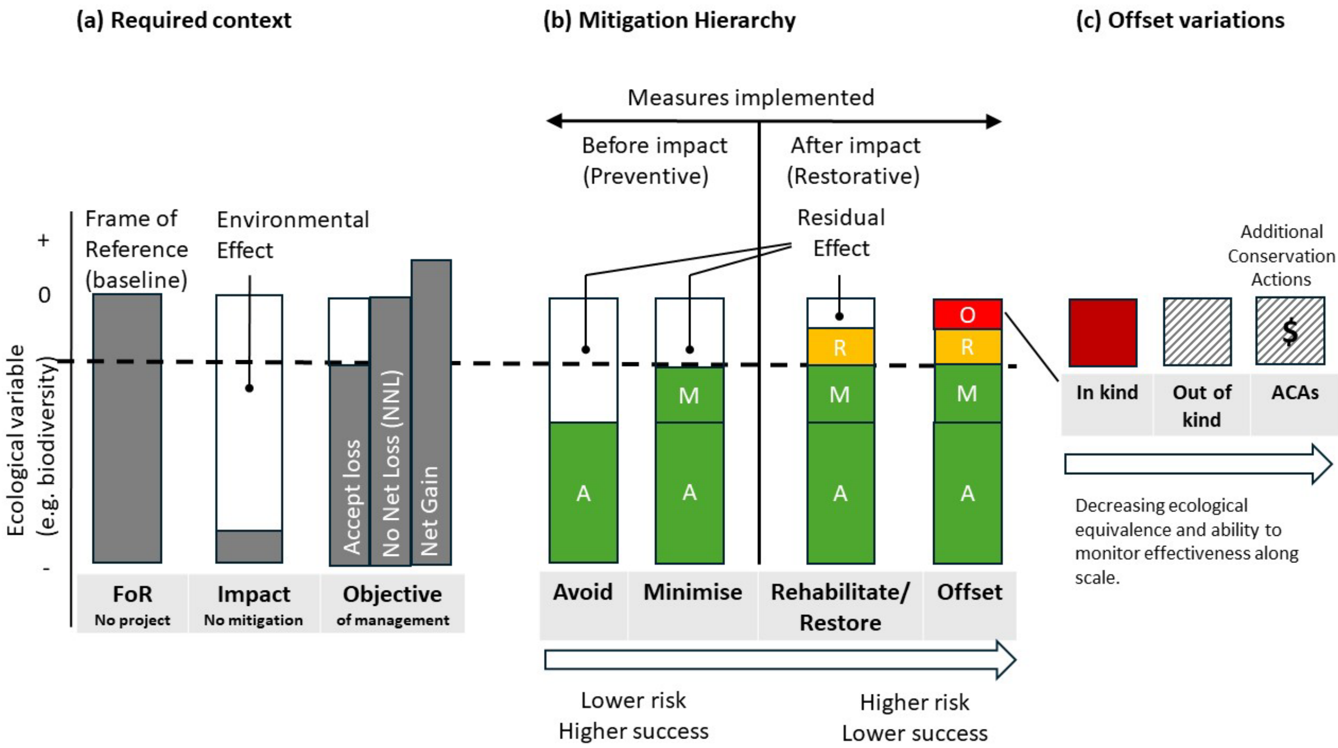

Figure 2: Mitigation hierarchy in the context of deep-sea mining. Figure based on diagram prepared by Danielle de Jonge (Joint Nature Conservation Committee) for a draft technical working document on the mitigation hierarchy for the purposes of informal intersessional work relevant to ISA Council negotiations. Diagram modified after Niner et al. 2018, Bull et al. 2016, and Ekstrom et al. 2015.

Mitigation hierarchy in the context of deep-sea mining

Insufficient knowledge on baseline conditions of deep-sea ecosystems, in combination with the inherent slow pace of biological processes in the deep ocean (Box 1) create large uncertainties about the effectiveness of rehabilitation, restoration and offsetting measures. Careful evaluation is needed to understand what types of mitigation can help managers achieve environmental objectives in the context of deep-sea mining (Supplementary table 1, 2).

It is important to recognize that any deep-sea mining project will change the environment for millions of years, as these minerals are non-renewable resources and directly associated biodiversity and ecosystem functions will be lost. The degree of any accepted loss is to be determined by management objectives before any project (black dashed line in Figure 2). With current scientific knowledge, only avoidance measures, such as areas to be protected from deep-sea mining impact, and minimization, such as vehicle design to reduce sediment plume extent, can be used to reach the set environmental objective (green color, Figure 2b).

Effectiveness of rehabilitation/restoration is currently unproven (orange color, Figure 2b), and assessment of ongoing experiments will take many years due to the slow pace of processes in the deep sea (Gollner et al. 2021). Restoration, meaning a full recovery to an ecosystem's original state, is highly unlikely because certain species and ecosystem functions depend on the minerals, which cannot be restored after mining. As a last resort, the mitigation hierarchy allows managers to consider offsetting of impacts. In-kind offsetting is practically impossible in the deep sea (red color, Figure 2b) (Niner et al. 2018). Some objectives not directly associated with deep-sea mining impacts may be reached using offsetting (Figure 2c), but those cannot replicate biodiversity and ecosystem services lost through mining. Compensating biodiversity loss in areas beyond national jurisdiction with biodiversity gains in national waters could constitute transfer of wealth (Van Dover et al. 2017).

Box 1: The ecological importance of polymetallic nodule and sulphide ecosystems

Nodules provide hard substrate for large, long-lived corals, sponges and anemones, as well as habitat for microorganisms and small animals living on and inside the nodules. Most organisms living in nodule fields are small (<1 mm) and include animals such as roundworms, bristle-worms and crustaceans that reside in the soft sediment around and under the nodules. Nodule fields provide many ecosystem services that indirectly or directly benefit humankind, such as dark oxygen production (Sweetman et al. 2024), carbon cycling, marine genetic resources, cultural heritage, and potential fisheries in the waters above (DOSI 2023, Polymetallic Nodule-rich Abyssal Plains).

Figure 3: Stalked sponge attached to a nodule

Currently known deep-sea hydrothermal vents and associated polymetallic sulphide deposits are small and globally rare. Very little is known about inactive hydrothermal vents, but they are home to long-lived, vulnerable animals, such as corals and sponges, and their biodiversity may largely exceed that of active sites. They likely also provide important ecosystem functions and services, such as *in situ* primary production (Achberger et al. 2024) or marine genetic resources. In comparison, at active vents (see Figure 1), emergent hot fluids sustain unique ecosystems. They are productivity hotspots with a high level of endemic fauna that thrives mainly on chemoautotrophic primary production. Active vents provide many ecosystem services including novel marine genetic resources, contribution to global geochemical cycles, incentive for scientific research, and inspirational value for arts and ocean education (DOSI 2023, Hydrothermal Vent Ecosystems).

Figure 4: Corals and sponges colonising a sulphide deposit at an inactive vent

For more information on mitigation possibilities, see supplementary tables below: Mitigation possibilities in polymetallic nodule (sup. Table 1, pages 6-10) and polymetallic sulphide (sup. Table 2, pages 10-15) ecosystems in the context of deep-sea mining.

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About DEEP REST:

DEEP REST is a BiodivRestore European project (GA N°101003777) gathering natural and social scientists from 8 countries to investigate two remarkable deep-sea ecosystems threatened by mining: polymetallic nodule fields and hydrothermal vents. It aims at enhancing fundamental knowledge on the faunal and functional diversity of these ecosystems and their interconnections as well as examining governance issues. Ultimately, it will develop a novel approach to improve our capacities for science-based spatial planning and propose insightful recommendations to protect these unique and vulnerable marine habitats.

DEEP REST

About DOSI:

The Deep-Ocean Stewardship Initiative is a global network of experts that integrates science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

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Information Sheet References

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Supplementary Tables

These tables show the prospects of mitigation options in polymetallic nodule (supplementary Table 1) and polymetallic sulphide-rich (supplementary Table 2) ecosystems in the context of deep-sea mining. Specific mitigation measures according to the mitigation hierarchy are given, including the responsible body (legislator, contractor), and references in case the action is already applied (no reference means that the action has not been applied in the ecosystem). Cuvelier et al. (2018) and expert knowledge were used to list specific mitigation measures. Expert knowledge was used to evaluate if a measure can be theoretically effective or if it is already effective (as of 2024), to identify gaps hindering effective implementation of an action (knowledge gaps, regulatory gaps), and to identify the time needed to close knowledge gaps and reach sufficient knowledge* (short <5 years, medium 5-10 years, long 10-30 years, very long >30 years). Comments in the tables explain the main underlying reason for rankings. 'NA' means 'not applicable.'

**Time requirements listed in the tables assume consistent research effort and will not apply if this does not occur. Slow ecological processes cannot be sped up by increased research effort or investment, limiting the speed at which some knowledge can be gained.*

Supplementary Table 1: Mitigation possibilities in polymetallic nodule ecosystems in the context of deep-sea mining

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Avoid	Complete avoidance (precautionary pause/moratorium)	Legislator		Yes | Yes			Society may invest in (i) policies to stimulate recycling, (ii) technologies that do not require metals and materials derived from deep-sea mining, and (iii) long-term actions driven by non-technological solutions that reduce demand for energy and materials.
	APEI (Areas of Particular Environmental Interest)	Legislator	ISBA/18/C/22, Blanchard & Gollner 2022	Yes | No	Insufficient baseline on regional biodiversity & function	Medium	Current APEIs only partly fulfill their purpose (Blanchard & Gollner 2022).
	PRZ	Legislator	ISA Brief 02/2018	NA | NA	NA	NA	PRZs have monitoring purpose.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Avoid	No-mining areas within contract area	Contractor		Yes | No	Insufficient regulatory framework; insufficient baseline on local biodiversity & function.	Medium	These areas should also not be indirectly impacted by mining (e.g. plumes, sound, etc.).
Minimize	Reduction of sediment removal on seafloor by mining vehicle	Contractor	EIAs (EIS: BGR, GSR, India, NORI)	Yes | partly	Lacking governance	Short	Current contractors develop vehicles that remove as little sediment as possible; still upper 5 - 10 cm sediments are removed; industries may develop alternative techniques such as picking of nodules;
	Reduction of sediment compaction by mining vehicle	Contractor	EIAs (EIS: Beijing Pioneer)	Uncertain | No	Unknown effect of sediment compaction on communities	Short	Technologically possible with positively buoyant design. Beijing Pioneer developing a flying nodule extraction vehicle.
	Reduction of vehicle plume extent (sediment)	Contractor	EIAs (EIS: BGR, GSR, India, NORI)	Yes | No	Insufficient baseline on ocean currents; unknown turbidity thresholds	Short-medium	Technologically possible, depending on machinery design (see reduction of sediment removal); plume spread also depends on topography and ocean currents; substances may be added to enhance flocculation.
	Reduction of discharge plume (toxicity)	Contractor		Uncertain | No	Unknown toxicity thresholds	Medium	Uncertain to which degree toxicity in plume can be reduced by technological processes.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Minimize	Reduction of discharge plume (sediment, toxicity)	Contractor		Yes | No	Insufficient baseline on ocean currents and distribution of discharge plume; no toxicity or turbidity thresholds for mid-water life.	Medium	Technologically possible to some degree; adapt temperature/salinity of discharge plume to match environmental conditions; no/little sediments in discharge plume; discharge near seafloor to avoid wide spread; uncertain to which degree toxicity in plume can be reduced by technological processes.
	Reduction of noise & vibration	Contractor		Yes | No	Unknown noise thresholds for invertebrates and deep-sea fish	Medium	Technologically possible to some degree (reduction of noise of vehicle, riser-lifter-system, ships)
	Reduction of light at seafloor, in water column, on surface	Contractor		Yes | No	Unknown light thresholds for deep-sea organisms.	Short	Technologically possible, as no (or little) light needed during mining operations.
	Reduction of nodule removal with visible fauna	Contractor	Impossible Metals	Yes | No	Uncertain feasibility	Short	Nodules not only harbour visible epifauna, but also smaller organisms. Nodules also offer ecosystem functions related to the mineral content.
	Intelligent track design	Contractor		Yes | No	Insufficient baseline on biodiversity, function and connectivity	Medium	Effectiveness depends on baseline knowledge and method used for 'intelligent' track design (e.g., wide gaps between tracks, 'nodules islands')
	Temporal cessation of mining operation	Contractor		Yes | No	Insufficient baseline	Medium	Baseline data on seasonality, migration & dispersal routes of benthic and pelagic species are largely missing.
	Speed restriction to avoid ship strikes with cetaceans	Contractor	NOAA	Yes | Yes	Not included in regulations	Short	Is already implemented in other industries.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Rehabilitate/Restore	Artificial nodules	Contractor	Gollner et al. 2021; NIOZ	Uncertain | No	Insufficient baseline; high uncertainty on effectiveness	Very long	Very long time needed to evaluate success due to very slow processes in the abyss; cannot restore any biodiversity or function associated to metals; unlikely that an artificial nodule can mimic natural crevices and restore its crevice fauna; very high costs.
	Sediment decompaction	Contractor	Gollner et al. 2021; UGhent	Uncertain | No	Insufficient baseline	Very long	Very long time needed to evaluate success due to very slow processes in the abyss; unknown if sediment compaction is a real mining scenario; sediment compaction impact and effect unknown; decompaction could be technologically feasible.
	Transplantation of fauna	Contractor		Uncertain | No	No single dominant species; insufficient biodiversity baseline; high uncertainty on effectiveness	Very long	Very long time needed to evaluate success due to slow processes in the abyss; difficult to predict success, possible alterations in natural community composition, and reduction of genetic diversity; very high costs.
	Organic material nourishment	Contractor		No | No	Unknown side-effects	Very long	Key nutrients could promote growth, but could also cause hypoxia and acidification, and ecosystem imbalance.
Offset	In-kind offset	Contractor/Legislator	Niner et al. 2018	No | No	90% unknown biodiversity in CCZ (Rabone et al. 2023)	Very long	Biodiversity offsets should not be applied where there is high uncertainty on the activity's impact on biodiversity (IUCN, 2016). Any biodiversity or functions associated to the metals very likely cannot be replaced.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Offset	Out-of-kind offset & ACAs	Contractor/Legislator	Niner et al. 2018	No | No		NA	Cannot replicate biodiversity and ecosystem services lost through mining; compensating biodiversity loss in areas beyond national jurisdiction with biodiversity gains in national waters could constitute transfer of wealth (Van Dover et al. 2017).

[1]after Cuvelier et al. 2018 and expert knowledge

Supplementary Table 2: Mitigation possibilities in polymetallic sulphide ecosystems in the context of deep-sea mining

A distinction is made between active and inactive vents.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Avoid	Complete avoidance (precautionary pause/ moratorium)	Legislator		Yes | Yes			Society may invest in (i) policies to stimulate recycling, (ii) technologies that do not require metals and materials derived from deep-sea mining, and (iii) long-term actions driven by non-technological solutions that reduce demand for energy and materials
	Designate active vent as SINP (Site In Need of Protection)	Legislator	Draft REMP nMAR; Blanchard & Gollner 2022	Yes | No	Insufficient delineation of 4D space, insufficient regulatory framework	Short	All active vents are classified as SINP, but no spatial scale is determined. Mining too close to active vents could disrupt the active vent communities. Effectiveness depends on implementation of spatial scale.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Avoid	Designate inactive vent as SINP (site in need of protection)	Legislator		Yes | No	Insufficient delineation of 4D space, insufficient baseline, no regulatory framework	Medium	Assessment along suites of criteria to identify vulnerable, sensitive, and ecologically or biologically significant ecosystems in need of protection shall be applied for inactive vents.
	Designate AINP (Area In Need of Protection)	Legislator	Draft REMP nMAR; Blanchard & Gollner 2022	Yes | No		Unknown	AINPs protect important habitats, but do not contribute to a set threshold specific to vents, as vents are geographically not included in AINP; currently include Kane, Vema, and Romanche fracture zones. Unsure if more AINPs would be needed.
	Precaution S: active vents (Site In Need of Precaution)	Legislator	Draft REMP nMAR; Blanchard & Gollner 2022	Yes | No	Incomplete baseline, insufficient delineation of 4D space, insufficient regulatory framework	Short	Fine-scale sites that have been predicted to have features that may give the site conservation value. The predictions could be based on various methods, including the detection of natural hydrothermal plumes. Inferred vents are classified as SINP.
	Precaution S: inactive vents (Site In Need of Precaution)	Legislator		Yes | No	Insufficient delineation of 4D space, insufficient baseline, no regulatory framework	Medium	Currently no SINP precaution considered for inactive vents.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Avoid	Precaution A (Area In Need of Precaution)	Legislator	Draft REMP nMAR; Blanchard & Gollner 2022	Yes | No	Baseline data to confirm and further feed models	Medium	Large-scale areas that have been predicted to have features that may give the area conservation value. The predictions could be based on various methods, including habitat modelling (e.g., cold-water octocorals).
	PRZ active vent	Contractor	ISA Brief 02/2018	NA | NA	NA	NA	PRZs have monitoring purpose; sufficient baseline knowledge suggests that no ecologically similar PRZ can be established for active vents, as every vent field is unique.
	PRZ inactive vent	Contractor	ISA Brief 02/2018	NA | NA	NA	NA	PRZs have monitoring purpose; insufficient baseline data on uniqueness of inactive vents; inactive vents cover a small surface area, PRZ within deposit likely impacted by mining.
	No-mining areas within contract area, inactive vent	Contractor		Uncertain | No	Insufficient regulatory framework and baseline on local biodiversity & function and connectivity within and between SMS deposits.	Medium	Maintain suitable, untouched habitats of characteristic communities at reasonable distance to ensure connectivity and larval dispersal; Likely, entire vent fields need to be designated as no-mine areas, due to the small spatial coverage of vent fields.
Minimize	Reduction of sediment removal on seafloor by mining vehicle	Contractor		NA | NA	NA	NA	Currently most of prospected deposits are hard substrate environments; Note: extinct vents are covered with sediment.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Minimize	Reduction of sediment compaction by mining vehicle	Contractor		NA | NA	NA	NA	Currently most of prospected deposits are hard substrate environments; Note: extinct vents are covered with sediment.
	Reduction of vehicle plume extent (sediment)	Contractor		Yes | No	Insufficient baseline on ocean currents; unknown turbidity thresholds	Medium	May be technologically possible, depending on machinery design.
	Reduction of vehicle plume (toxicity)	Contractor		Uncertain | No	Unknown toxicity thresholds	Medium	Uncertain to which degree toxicity in plume can be reduced by technological processes.
	Reduction of discharge plume (sediment, toxicity)	Contractor		Yes | No	Insufficient baseline on ocean currents and distribution of discharge plume; no toxicity or turbidity thresholds for mid-water life.	Medium	Technologically possible to some degree; adapt temperature/salinity of discharge plume to match environmental conditions; no/little sediments in discharge plume; discharge near seafloor to avoid wide spread; uncertain to which degree toxicity in plume can be reduced by technological processes.
	Reduction of noise & vibration	Contractor		Yes | No	Unknown noise thresholds for invertebrates and deep-sea fish	Medium	Technologically possible to some degree (reduction of noise of vehicle, riser-lifter-system, ships); sound-masking could be problem for vent species.
	Reduction of light at seafloor, in water column, on surface	Contractor		Yes | No	Unknown light thresholds for deep-sea organisms.	Short	Technologically possible, as no (or little) light needed during mining operations.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Minimize	Temporal cessation of mining operation	Contractor		Yes | No	Insufficient baseline	Medium	Baseline data on seasonality, migration & dispersal routes of benthic and pelagic species are largely missing.
	Speed restriction to avoid ship strikes with cetaceans	Contractor	NOAA	Yes | Yes	Not included in regulations	Short	Already implemented in other industries.
Rehabilitate/Restore	Substitution of inactive chimneys with artificial structures	Contractor		Uncertain | No	Insufficient baseline; uncertainty that action can be effective	Very long	Very long time needed to evaluate success due to slow live at inactive vents; very high costs (Van Dover et al. 2014)
	Transplantation of fauna	Contractor		Uncertain | No	Insufficient baseline	Very long	Very long time needed to evaluate success due to slow live at inactive vents; difficult to predict success, possible alterations in natural community composition, and reduction of genetic diversity.
	Organic material nourishment	Contractor		No | No	Unknown side-effects	Very long	Key nutrients could promote growth, but could also cause hypoxia and acidification, and ecosystem imbalance.
	Addition of colonization surfaces (inorganic/organic) at active vents	Contractor	Alfaro-Lucas et al. 2020	No | No	NA	NA	Vent fauna need fluids; wood substrata create wood-fall communities; inorganic substrata not efficient as hard substratum is not limited; existing experiments should be followed on a longer time-scale.
	Addition of colonization surfaces (inorganic/organic) at inactive vents	Contractor	Alfaro-Lucas et al. 2020	Uncertain | No	Biodiversity and functions largely unknown at inactive vents.	Very long	Very long time needed to evaluate success due to slow live at inactive vents.

Mitigation strategy	Mitigation measure[1]	Responsible body	References	Effectiveness Theoretical | Proven	Gaps	Time to reach sufficient knowledge	Comment
Offset	In-kind offset active vent	Contractor/Legislator	Van Dover et al. 2017	No | No	NA	NA	There is sufficient scientific knowledge on uniqueness of active vents (Van Dover et al. 2018; Gollner et al. 2021). Biodiversity and functions at active vents are unique and can't be replaced.
	In-kind offset inactive vent	Contractor/Legislator	Niner et al. 2018	No | No	Biodiversity and functions largely unknown at inactive vents.	Very Long	Biodiversity off-sets should not be applied where there is high uncertainty on the activity's impact on biodiversity (IUCN, 2016). Any biodiversity or functions associated to the metals very likely cannot be replaced.
	Out-of-kind offset & ACAs	Contractor/Legislator	Niner et al. 2018	No |No		NA	Cannot replicate biodiversity and ecosystem services lost through mining; compensating biodiversity loss in areas beyond national jurisdiction with biodiversity gains in national waters could constitute transfer of wealth (Van Dover et al. 2017).

[1]after Cuvelier et al. 2018 and expert knowledge