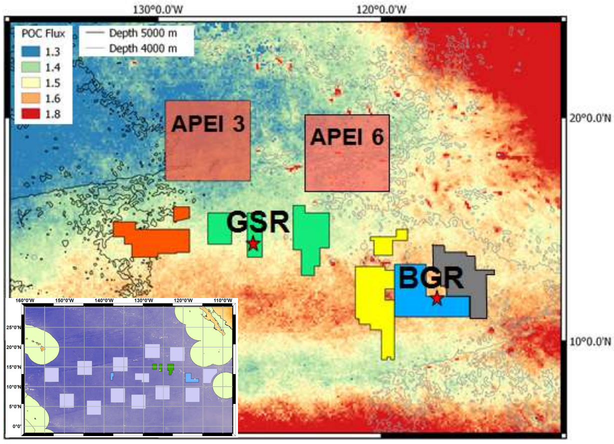
Environmental consequences of deep-seabed mining
Scientific results and recommendations

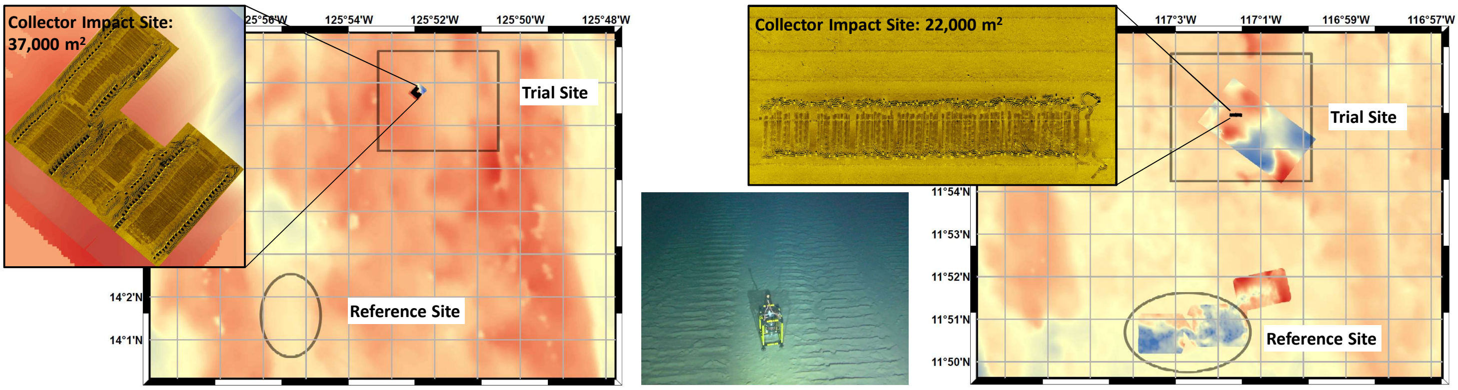
M. Haeckel and MiningImpact partners
GEOMAR, AWI, BGR, CIIMAR, DNV, IFREMER, IPMA, JUB, MPI Bremen, NIOZ, NIVA, NTNU, RBINS, Senckenberg Society, SNF, TU Delft, UNEP Grid Arendal, U Algarve, U Aveiro, U Azores, U Bielefeld, U Bremen, U Gent, U Kiel, U Lodz, U Marche, U Research, U Southampton, U Utrecht, ISA

July 2023

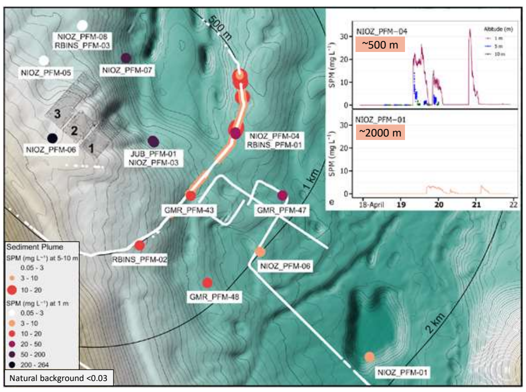
MiningImpact is a collaborative research project of 29 scientific institutions from 9 European countries. Major goals are (1) to investigate species connectivity and biodiversity of biological assemblages in the CCZ and their resilience to impacts, (2) to assess integrated effects of deep-sea mining on ecosystem functions and services, (3) to determine the dispersal of the suspended sediment plume and its effects on pelagic and benthic fauna, (4) to study potential measures for mitigation of impacts.

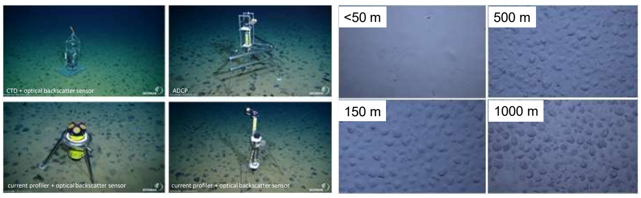
MiningImpact conducted three expeditions delivering an **independent scientific investigation of GSR's PATANIA II trials** in the contract areas of GSR and BGR: SO268 (Feb-May 2019) collected extensive environmental baseline data at the trial sites and designated reference sites, MANGAN 2021 (March-May 2021) conducted a comprehensive monitoring programme in parallel to the Patania II polymetallic nodule collector tests, and SO295 (Oct-Dec 2022) sampled the collector and plume impact sites as well as the reference sites 1.5 years after the test mining operations.



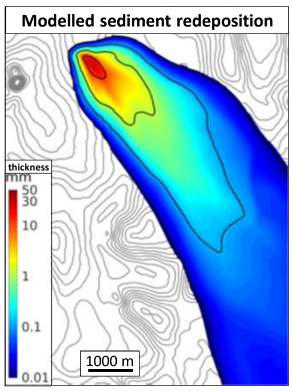


High-resolution bathymetric maps of the Reference and Trial (consisting of Collector and Plume Impact) Sites in the GSR contract area (left) and in the BGR contract area (right). Insets: AUV-based side-scan sonar images of the seafloor after the Patania-II trials: darker color indicates seafloor, where polymetallic nodules were collected (Collector Impact Sites); black dots show locations of the deposited nodule piles in the collector driving turns. Photo: An oxygen microprofiler deployed between the caterpillar tracks of Patania-II, where nodules and the bioactive sediment surface layer (top 4-8 cm including micro/meio/macro/megafauna) were removed and 2-3 cm of suspended sediment plume material was redeposited (based on geochemical data analysis).





Plume monitoring involved 50 intercalibrated acoustic and optical sensors deployed on 20 platforms that were distributed at the seafloor in the Plume Impact Site at distances of 50, 150, 500, 1000, and 2000 m from the Collector Impact Site. In addition, an AUV continuously surveyed the wider area (up to 5 km distance) at 5, 10, 30 m above the seabed. Photographic mapping of the seafloor by AUV after the trials allowed to determine the extent of sediment blanketing. The data informed numerical simulations of plume dispersal and redeposition.



Polymetallic nodule test mining removed the entire bioactive surface layer of the deep seafloor (top 4-8 cm).

The suspended sediment formed a dense particle plume with concentrations of 10-260 mg L^{-1} (i.e. 100-10,000 times natural background values).

Initial plume dynamics were driven by turbidity flow behavior, where the plume largely stayed within 10 m above seafloor.

Plume dispersal was dominated by bottom water currents at a distance of a couple of hundred metres from the test mining area.

A fine particle plume (10-100 times natural background values) was transported beyond the survey area (at 4-5 km distance).

Suspended plume material resettled at the seafloor inside the mined area and blanketed the benthic habitat more than 1000 m downstream.

A blanketing thickness of more than 1 cm covered a seafloor area 5-6 times larger than the test mining area.

Elevated metal concentrations (Mn, Co, Cu) were observed in the dense particle plume.

Acknowledgements MiningImpact received funding under the framework of the Joint Programming Initiative of Healthy and Productive Seas and Oceans (JPI Oceans) from national Research Ministries of Belgium, Germany, the Netherlands, Norway, Portugal and the partner institutes.
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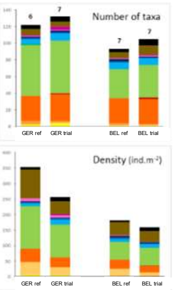
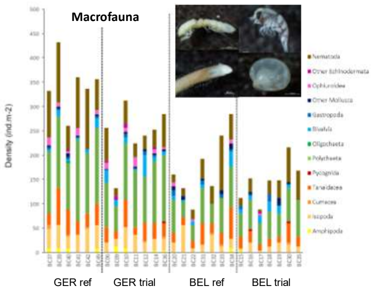
Baseline results

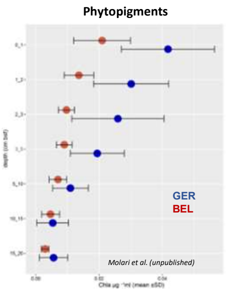
Nodule ecosystems support a highly diverse fauna of sessile and mobile species, biodiversity is currently not known for any of the faunal classes.

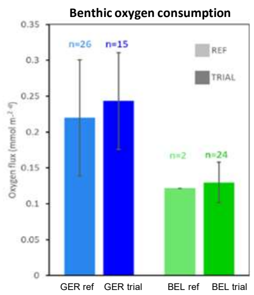
Faunal communities & environmental variables show a high variability on different spatial scales (from hundreds of metres to thousands of kilometres). Temporal variability is largely unknown.

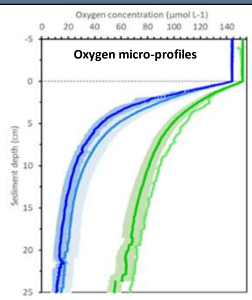
Species connectivity (across the CCZ or Pacific) and a complete ecosystem understanding remain critical knowledge gaps.





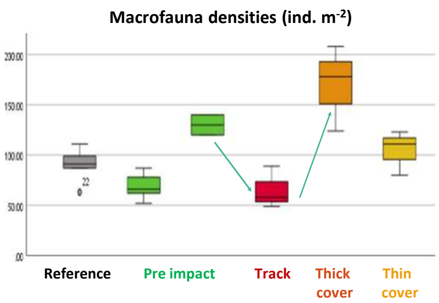


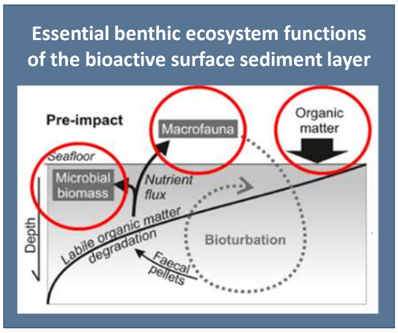


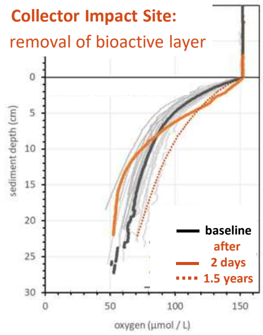


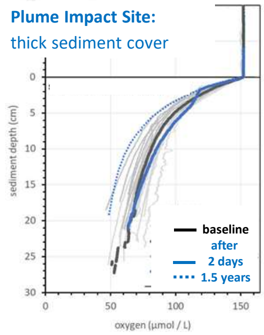
During SO268 and MANGAN 2021 (prior to the collector tests) we collected comprehensive baseline data in the Reference and Trial Sites of both working areas (BEL and GER). The data show that overall the environmental conditions differ only marginally between Reference and Trial Sites. In contrast, the BEL and GER areas exhibit considerable differences in almost all variables. This will allow us to investigate if and how this affects the response of the ecosystem to the mining disturbance.

However, within each Site considerable variability on small spatial scale of a few hundred metres are evident (e.g., macrofauna densities of individual box corer deployments (left), phytopigment Chl-a (i.e., labile organic carbon) in the sediment (center), and oxygen consumption fluxes calculated from measured in-situ oxygen microprofiles in the sediment (right) quantifying the essential ecosystem function of benthic microbial organic matter degradation.









Benthic macrofauna is actively mixing the surface sediments (bioturbation), transporting the fresh (labile) organic matter from the surface into depth and thereby increasing the reactive zone, where micro-organisms degrade the labile organic matter (by consuming oxygen), in return providing nutrients to the ecosystem. These are essential services for a healthy benthic ecosystem. Removal of the bioactive layer and its fauna during mining operations disrupts these functions.

In the Collector Impact Site loss of macrofaunal bioturbation activity and disruption of microbial activity leads to diffusion of oxygen into the sediment.

In the Plume Impact Site, where a thick sediment layer (2-3 cm) has been deposited on the unmined seafloor, macro- and meiofauna (removed during nodule collection) has been deposited with the sediment (left). Here, oxygen consumption is increased (right), indicating that the fauna has likely not survived the collection process.

Loss of seafloor integrity by nodule and seafloor removal affects all ecosystem compartments, reducing population densities and ecosystem functions. Recovery of benthic processes takes hundreds to thousands of years (on spatial scales of 200-300 km^2 per year and mining operation).

The current lack of a complete ecosystem understanding and connectivity of species hampers assessing the large-scale (regional) consequences.

Conservation areas need to match habitat characteristics of mined areas to preserve abyssal biodiversity and protect vulnerable ecosystems.

Minimizing impacts requires careful & adaptive spatial planning of mining operations (e.g. establishing network of representative PRZs) and the development of low-impact mining procedures.

Transparent and independent scientific assessment of deep-sea mining operations needs to be secured.

Total deposition thickness outside the impact area should be limited to a maximum of 1 mm.

Vertical spreading of suspended particle plume should be restricted close to the seafloor, including the return waste-water plume.

Suspended particle concentrations: needs to be developed (e.g., 2 times background values).

Contaminants in seawater (no international threshold levels exist): should be developed specifically for deep waters (quality standards for coastal waters could be used as a first approach).

Noise (sound exposure level) of <120 dB re 1 µPa2 (rms) is suggested.

Use of light in the deep ocean should be kept to a minimum. It should be assessed, if other solutions for navigation, orientation, operation and inspection can be applied.

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