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“A Summary of Available Information in the Public Domain on the Likely Impact of Exploration and Mining Activities for Nodules on the Marine Environment” submitted on 26 August 2010

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Any human activity will impact the environment in which it occurs. The level of impact depends on the type of activity and the environment where this activity occurs. This document is a brief summary, including abstracts from the peer-reviewed literature, on the potential impact of mining for polymetallic nodules on the marine environment.

The document contains a summary of the potential impacts as reflected in the conclusions of an international workshop held by the International Seabed Authority; the names of five scientists who have experience in the assessment of the potential environmental impacts; a list of the key chapters in documents that have been published by the Authority; and some relevant peer-reviewed scientific publications with abstracts.

The information contained in this document is a sample of the information available on the potential impacts of activities associated with polymetallic nodule resources in the deep sea and is therefore not exhaustive.

Short Summary

From: Harmonisation Workshop on the Standardization of Environmental Data and Information: Development and Guidelines. Kingston, Jamaica (25-29 June, 2001), Chapter 3.

Seafloor mining of polymetallic nodules has the potential to impact vast areas of the deep-sea ecosystem. The nodule resources occur in deep oceanic waters (greater than 4000 metres) far removed from the continents (i.e., beyond major influence of coastal productivity and terrigenous sedimentation); thus, they are found in some of the least studied habitats in the biosphere. Current claims under the jurisdiction of the International Seabed Authority (ISA) include vast abyssal tracts in the North Pacific Ocean within the Clipperton-Clorion Fracture Zone (CCFZ) as well as in the north central Indian Ocean. If a substantial portion of the claim areas in the Pacific and Indian Oceans are one day exploited, nodule mining could yield one of the largest areal impacts for a single type of commercial activity on the face of the earth.

The main environmental impacts of nodule mining are expected at the seafloor, with less intense and persistent effects in the water column.

Major potential impacts include:

- 1. Removal of surface sediments, polymetallic nodules and associated biota from multiple patches tens to hundreds of square kilometres in area. Seabed sediments remaining in these patches will be compressed and broken up by passage of the mining vehicle.*
- 2. Creation of a massive near-bottom sediment plume as a consequence of nodule removal. Sediment in the plume will redeposit on the surrounding seafloor, burying the sediment/water interface and biota under sediment blankets ranging in thickness from a few grains to several centimetres. A diffuse plume will persist in the benthic boundary layer for weeks to months, potentially travelling hundreds of kilometres.*
- 3. In the surface ocean, release of bottom water entrained with lifted nodules, as well as sediments and nodule fragments, may enhance nutrient and heavy-metal concentrations,*

and reduce light levels; these alterations may affect, among other things, rates of primary production, food-web dynamics and survival of larval fish in oceanic surface waters. Settling of sediments and nodule fragments from this discharge into the oxygen-minimum zone may lead to the release of heavy metals.

- 4. The discharge of tailings from nodule processing will (by future ISA regulations) occur in the deep ocean below the oxygen minimum zone (i.e., typically below a depth of 1200 m). Once again, a large sediment plume will be formed, altering suspended particle concentrations, potentially influencing midwater food webs and yielding sediment redeposition on the underlying seafloor.*

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Selected Bibliography (ISA published)

Exploration Deep Seabed Polymetallic Exploration: Development of Environmental Guidelines, Sanya, China (1-5 June, 1998)

Most relevant chapters:

- Executive Summary
- Chapter 2 – The Biological Environment in Nodule Provinces of The Deep Sea – Professor Craig R. Smith
- Chapter 3 – The Chemical Environment in Nodule Provinces of The Deep Sea – Dr Hulayang Zhou
- Chapter 4 – The Physical Environment in Nodule Provinces of The Deep Sea – Dr Tatiana Demidova
- Chapter 3 – Review of Geochemical Impacts of Polymetallic Nodule Mining – Dr D.S. Cronan

Harmonisation Workshop on the Standardization of Environmental Data and Information: Development and Guidelines. Kingston, Jamaica (25-29 June, 2001) [Link to Full Document](#)

Most relevant chapters:

- Executive Summary
- Chapter 2 - Overview of the Authority's regulations and recommendations to ensure the effective protection of the marine environment from harmful effects that may arise from activities in the area - *Mr. Jean-Pierre Lenoble*
- Chapter 3 - Current state of knowledge of deep-sea ecosystems, proposed technologies for polymetallic nodule mining and expected impacts from mining tests during exploration - *Professor Craig R Smith*
- Chapter 4 - Priorities for environmental impact analysis of deep seabed mining - Dr Charles Morgan

Workshop on prospects for international collaboration in marine environmental research to enhance understanding of the deep-sea environment. Kingston, Jamaica (29 July - 2 August, 2002) [Link to Full Document](#)

Most relevant chapter:

- Executive Summary

Selected Bibliography (non-ISA published)

R Sharma (2005) Deep-sea impact experiments and their future requirements. *Marine Georesources And Geotechnology*, vol. 23 (4) pp. 331-338

In recent years, several experiments to assess the potential impacts due to deep-sea mining in the Pacific as well as the Indian Oceans have indicated the immediate changes and restoration patterns of environmental conditions in the marine ecosystem. The large volume of sediment (similar to 500 x 10⁷ m³ per year) estimated to be resuspended would be the major influencing factor in environmental impact in the mining area, leading to changes in availability of certain nutrients and composition of biomass, followed by gradual restoration. Important results have been obtained

from these experiments, but in order to have a better understanding of the impacts and restoration processes, it will be necessary to improvise future experiments to resemble actual deep-sea mining in terms of scale and methodology.

<http://dx.doi.org/10.1080/10641190500446698>

PAL Bharathi, BN Nagender Nath, BS Ingole, G Parthiban, SGP Matondkar, C Raghukumar, NH Khadge, AB Valsangkar, A Suryanarayana, SJ Sankar, R Sharma (2005) Impacts on surface productivity during sediment dispersal experiment in Central Indian Basin. *Marine Georesources And Geotechnology*. vol. 23 (4) pp. 315-330

It is anticipated that in the case of mining of marine minerals, sea floor sediments will be brought up along with the mineral ores and discharged on the surface. These nutrient rich sediments would create a set of different physicochemical conditions at the point of discharge thus altering the regimes of productivity in the water column. In order to assess the effects of deep sea sediment discharge on the oceanic surface water-layers (0-50M) after nodule mining, a Sediment Dispersal Experiment (SEDEX) was conducted in Central Indian Basin (CIB). A total of 675 liters of slurry prepared from 225 kg of wet sediment (330g.l⁻¹) was discharged on the surface during the experiment. Water samples were collected before and after the discharge to monitor the changes in different environmental parameters. There was a general increase in bacterial abundance and primary producers along with suspended particulate matter. Migration of zooplankton is artificially induced by the stimulatory effect of the sediment and high load of phytoplankton. An increase in diversity, both at the primary and secondary level is noticeable. Within the spatial and temporal frame of observation, waters become net-nitrifying. The influence of the dispersal is apparently more beneficial than harmful on the experimental scale. The results are interesting and warrant more intense effort with long-term observations to evolve predictive models.

<http://dx.doi.org/10.1080/10641190500446672>

H Thiel, G Schriever, EJ Foell (2005) Polymetallic nodule mining, waste disposal, and species extinction at the abyssal seafloor. *Marine Georesources And Geotechnology*. vol. 23 (3) pp. 209-220

The size of individual mining blocks for polymetallic nodule extraction seems to be rather small, not more than 100 km² in the French mining claim. Even when adding an additional resedimentation zone to the directly impacted area, the size of the affected seabed would remain below 200 km². We assume that even rare species in the abyss inhabit larger areas and propose discussions of the International Seabed Authority and other stakeholders for the different subregions on mining strategies from the perspective of exploitation versus species extinction and conservation. Although impacts of waste disposal at the abyssal seafloor are different from those of nodule mining, the 200 km concept may also be applied.

<http://dx.doi.org/10.1080/10641190500192292>

AG Glover, Craig R Smith (2003) The deep-sea floor ecosystem: current status and prospects of anthropogenic change by the year 2025. *Environmental Conservation*. vol. 30 (3) pp. 219-241

The goal of this paper is to review current impacts of human activities on the deep-sea floor ecosystem, and to predict anthropogenic changes to this ecosystem by the year 2025. The deep-sea floor ecosystem is one of the largest on the planet, covering roughly 60% of the Earth's solid surface. Despite this vast size, our knowledge of the deep sea is poor relative to other marine ecosystems, and future human threats are difficult to predict. Low productivity, low physical energy, low biological rates, and the vastness of the soft-sediment deep sea create an unusual suite of conservation challenges relative to shallow water. The numerous, but widely spaced, island habitats

of the deep ocean (for example seamounts, hydrothermal vents and submarine canyons) differ from typical deep-sea soft sediments in substrate type (hard) and levels of productivity (often high); these habitats will respond differently to anthropogenic impacts and climate change. The principal human threats to the deep sea are the disposal of wastes (structures, radioactive wastes, munitions and carbon dioxide), deep-sea fishing, oil and gas extraction, marine mineral extraction, and climate change. Current international regulations prohibit deep-sea dumping of structures, radioactive waste and munitions. Future disposal activities that could be significant by 2025 include deep-sea carbon-dioxide sequestration, sewage-sludge emplacement and dredge-spoil disposal. As fish stocks dwindle in the upper ocean, deep-sea fisheries are increasingly targeted. Most (perhaps all) of these deep-sea fisheries are not sustainable in the long term given current management practices; deep-sea fish are long-lived, slow growing and very slow to recruit in the face of sustained fishing pressure. Oil and gas exploitation has begun, and will continue, in deep water, creating significant localized impacts resulting mainly from accumulation of contaminated drill cuttings. Marine mineral extraction, in particular manganese nodule mining, represents one of the most significant conservation challenges in the deep sea. The vast spatial scales planned for nodule mining dwarf other potential direct human impacts. Nodule-mining disturbance will likely affect tens to hundreds of thousands of square kilometres with ecosystem recovery requiring many decades to millions of years (for nodule regrowth). Limited knowledge of the taxonomy, species structure, biogeography and basic natural history of deep-sea animals prevents accurate assessment of the risk of species extinctions from large-scale mining. While there are close linkages between benthic, pelagic and climatic processes, it is difficult to predict the impact of climate change on deep-sea benthic ecosystems; it is certain, however, that changes in primary production in surface waters will alter the standing stocks in the food-limited, deep-sea benthic. Long time-series studies from the abyssal North Pacific and North Atlantic suggest that even seemingly stable deep-sea ecosystems may exhibit change in key ecological parameters on decadal time scales. The causes of these decadal changes remain enigmatic. Compared to the rest of the planet, the bulk of the deep sea will probably remain relatively unimpacted by human activities and climate change in the year 2025. However, increased pressure on terrestrial resources will certainly lead to an expansion of direct human activities in the deep sea, and to direct and indirect environmental impacts. Because so little is known about this remote environment, the deep-sea ecosystem may well be substantially modified before its natural state is fully understood.

<http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=176865>

T Radziejewska (2002) Responses of deep-sea meiobenthic communities to sediment disturbance simulating effects of polymetallic nodule mining. *International Review Of Hydrobiology*. vol. 87 (4) pp. 457-477

During a benthic impact experiment (BIE) carried out during 1995-1997 by the Interoceanmetal Joint Organization (IOM) at an abyssal site in the North-East Pacific, sediment disturbance mimicking that resulting from polymetallic nodule extraction was created with a specialised device (the Benthic Disturber). The effects of the disturbance on meiobenthic communities were assessed immediately after disturbance and 22 months later. A reduction in meiobenthos abundance, observed immediately following impact, was not significant; neither were changes in composition of the meiobenthos which was dominated by nematodes and harpacticoids. The lack of any significant numerical response is probably accounted for by the moderate degree of disturbance in this study, compared with other BIE-type experiments. On the other hand, statistically significant changes in both meiofauna abundance and vertical distribution profiles in the changed sediment within the Disturber tracks were recorded. After 22 months, a significant increase in overall meiobenthos abundance was detected in that part of the test site affected by increased resuspended sediment settlement and receiving natural phytodetrital inputs. Certain taxon-specific responses on the part of nematodes and harpacticoids were noted both immediately after the disturbance and 22 months

later. They were explained by the effects of sediment physical reworking and responses to phytodetrital enrichment. The results presented should aid in developing experimental designs, on both temporal and spatial scales, of future deep-sea tests aimed at assessing the scale and consequences of man-made impacts.

<http://www3.interscience.wiley.com/cgi-bin/abstract/96015344/ABSTRACT>

H Thiel, G Schriever, A Ahnert, H Bluhm, C Borowski, K Vopel (2001) The large-scale environmental impact experiment DISCOL - reflection and foresight. *Deep-Sea Research Part II - Topical Studies in Oceanography*. vol. 48 (17-18) pp. 3869-3882

It is now accepted that environmental impact studies should accompany society's growing interest in exploiting deep-sea resources. A large-scale experiment, DISCOL (Disturbance and recolonisation experiment in a manganese nodule area of the deep South Pacific) was conducted to evaluate potential impacts from mining on the deep-sea bed. DISCOL was the first of a series of projects aimed at better understanding impacts of industrial-scale mining of polymetallic nodules upon the seafloor and its biological community. A schedule of biological work, including a disturbance scheme and sampling patterns, for another 12-year period is described that builds on the DISCOL results, but is strictly valid only for this area. However, future experiments may use estimates from the DISCOL data as a first approximation in their planning phase, but will need to conduct site-specific sampling to establish a baseline.

[http://dx.doi.org/10.1016/S0967-0645\(01\)00071-6](http://dx.doi.org/10.1016/S0967-0645(01)00071-6)

N Rodrigues, R Sharma, BN Nagender Nath (2001) Impact of benthic disturbance on megafauna in Central Indian Basin. *Deep-Sea Research Part II - Topical Studies in Oceanography* (2001) vol. 48 (16) pp. 3411-3426

Deep-sea photographs and video data were studied to evaluate the effects of benthic disturbance on megafaunal distribution in the Central Indian Basin. Xenophyophores (41 %) and holothurians (30%) are the most abundant taxa, followed by other groups in the area before the disturbance. An overall reduction (32%) in the total megafaunal population after disturbance is direct evidence of the impact on benthic environment. Different groups such as xenophyophores, sea anemones, shrimps, starfish, brittle stars, holothurians and fish show different degrees of reduction (21-48%) in their numbers, depending upon their ability to withstand increased turbidity and sedimentation rates due to disturbance. Faunal groups such as protobranch molluscs, polychaete worms, seafans and squids, observed before the disturbance, were not seen after disturbance, whereas populations of some taxa increased after the disturbance. Increased numbers of mobile taxa could be due to increased levels of organic carbon due to resedimentation, whereas increase in sessile taxa may partly reflect the difficulty in distinguishing live from dead specimens. The impact on faunal assemblages is more severe in the disturbed area than the undisturbed area. Our results indicate that monitoring of megafauna can be used effectively to evaluate the potential impacts of large-scale mining or other disturbance on the seafloor, and may therefore help in developing measures for conservation of the benthic environment.

[http://dx.doi.org/10.1016/S0967-0645\(01\)00049-2](http://dx.doi.org/10.1016/S0967-0645(01)00049-2)

K Vopel, H Thiel (2001) Abyssal nematode assemblages in physically disturbed and adjacent sites of the eastern equatorial Pacific. *Deep-Sea Research Part II - Topical Studies in Oceanography*. vol. 48 (17-18) pp. 3795-3808

The nematode assemblages of experimentally impacted and adjacent sediments in abyssal depths of the eastern equatorial Pacific were investigated 7 years after a physical disturbance. A total of 3048 nematodes belonging to 68 genera and 26 families were identified. The nematode fauna at both

disturbed and control sites was dominated by specimens belonging to the genera *Acantholaimus*, *Chromadorita*, *Thalassomonhystera*, *Desinoscolex*, *Halalaimus* and *Diplopeltula*. These genera contribute to about 55% and 50% of total nematode fauna in the disturbed and control sites, respectively. The mean relative abundance of the dominant genus *Acantholaimus* amounted to about 20%. Generic diversity, evenness and richness at the undisturbed sites do not significantly differ from the corresponding median values at the disturbed sites. Mean *k*-dominance curves show differences in community structure between treatments. Ordination of square- and fourth-root-transformed family abundances revealed groupings of the disturbed and undisturbed samples (significant at the 5% level), whereas ordination of genus abundances did not. Sample variability was investigated by inspection of the relationship between variance and mean abundance of genera and families in each sample group and by calculating the comparative index of multivariate dispersion (IMO). There is a clear increase in the standard deviation for a given mean of genus or family abundances at the disturbed sites. A higher variability among the disturbed samples, however, does not appear to be true in the multivariate sense.

[http://dx.doi.org/10.1016/S0967-0645\(01\)00068-6](http://dx.doi.org/10.1016/S0967-0645(01)00068-6)

A Ahnert, G Schriever. (2001) Response of abyssal Copepoda Harpacticoida (Crustacea) and other meiobenthos to an artificial disturbance and its bearing on future mining for polymetallic nodules. Deep-Sea Research Part II - Topical Studies In Oceanography. vol. 48 (17-18) pp. 3779-3794

Long-term effects of an anthropogenic physical disturbance on the Harpacticoida taxocene at a deep-sea site were investigated during the course of the disturbance and recolonization (DISCOL) experiment in a manganese nodule area in the southeastern Pacific. Nineteen harpacticoid copepod families were found, contributing 9-12% to the metazoan meiofauna of the experimental area (Nematoda 72-80%). Twelve families occurred in sufficient numbers to be considered representatively sampled. Dominant are the Ameiridae (17%) followed by Ectinosomatidae, Argastidae, Tisbidae, Neobryadiidae, Diosaccidae, Paranannopidae, Paramesochridae, Canthocamptidae, Cletodidae, Thalestridae and Huntmanniidae. These families are mainly distributed at random. Basic data on developmental stage composition and sex ratio of total Harpacticoida as well as vertical distribution of harpacticoid families in the sediment column are provided. Within the overall aim of the experiment, which was to assess the ecological risks of future deep-sea manganese nodule mining, we conducted multivariate community analyses based on the familial composition of the Harpacticoida assemblages immediately before and after experimental impact as well as seven years later. We were not able to detect a community response at the family level immediately after impact. An identification of the Tisbidae to species, however, revealed initial disturbance effects. After seven years we found significant differences in the assemblage composition of the directly disturbed portions of the experimental area and the secondarily disturbed areas in between, which to some extent had received blanketing from sediment plumes created during the experimental disturbance. Best discriminating families for long-term effects are the Ameiridae, Argastidae and Thalestridae. Their potential value as indicator taxa for monitoring disturbances in the deep sea is discussed, including some considerations on a cost-effective design of such monitoring programs that would include the meiofaunal Harpacticoida.

http://apps.isiknowledge.com/InboundService.do?product=WOS&action=retrieve&SrcApp=Papers&UT=000172736300018&SID=1F851F8dQ2Inn3Nm9@&SrcAuth=mekentosj&mode=FullRecord&customersID=mekentosj&DestFall=http://access.isiprproducts.com/custom_images/wok_failed_auth.html

R Sharma (2001) Indian Deep-sea Environment Experiment (INDEX): An appraisal. Deep-Sea Research Part II - Topical Studies In Oceanography. vol. 48 (16) pp. 3295-3307

Indian Deep-sea Environment Experiment (INDEX) is a multi-disciplinary study to establish baseline conditions and evaluate the possible impact of deep-seabed mining in Central Indian Basin. A disturbance was simulated to study the effects of sediment re-suspension and re-settlement in the

benthic areas. Monitoring the process of restoration and recolonisation of benthic environment and development of predictive models for environmental impact of deep seabed mining are underway. Significant information on physical, chemical, biological and geological characteristics of water column and benthic baseline conditions has been generated in the programme. Evaluation of impact of simulated disturbance on the seafloor shows vertical mixing of sediment on the seafloor, lateral migration of sediment plume, changes in geochemical and biochemical conditions as well as reduction in biomass in the benthic environment. The results obtained are useful in determining the indicator parameters and standardising the methods for assessment of effects of large-scale mining.
[http://dx.doi.org/10.1016/S0967-0645\(01\)00041-8](http://dx.doi.org/10.1016/S0967-0645(01)00041-8)

H Thiel, F Tiefsee-Umweltschutz. (2001) Evaluation of the environmental consequences of polymetallic nodule mining based on the results of the TUSCH Research Association. Deep-Sea Research Part II - Topical Studies in Oceanography. vol. 48 (17-18) pp. 3433-3452

Realising a need for increased general knowledge of the deep sea for environmental impact assessments related to the permanent storage of waste products and mining of metal resources, the German Bundesministerium für Bildung und Forschung has funded targeted research in the deep sea for more than 10 years. The research was carried out in an area in the Southeast Pacific Ocean close to and within a German mining claim, to match the interests of German deep-sea polymetallic nodule mining enterprises and the developing mining code of the Preparatory Commission for the International Seabed Authority and the International Tribunal for the Law of the Sea. The "TUSCH (abbreviation for 'Tiefsee-Umweltschutz'- deep-sea environmental protection) Research Association", with members from various university and governmental institutions, was part of the ATESEPP (Effects of Technical Interventions into the Ecosystem of the Deep Sea in the Southeast Pacific Ocean) Project between 1996 and 1998. Geotechnical, sedimentological, geochemical, hydrographic, numerical modelling and ecological studies relevant to environmental impact assessment studies of polymetallic nodule mining were undertaken. Since general oceanographic knowledge of the deep sea is rather limited, these various projects also have increased our general understanding of this region. This paper describes the potential impacts of mining processes on the seafloor and the near-bottom water layer as well as on bathyal and abyssal pelagic zones that will receive processed water, sediment and abraded nodule fines (tailings) discharged after nodule transport to the mining vessel at the ocean surface. The TUSCH Research Association defined various recommendations to keep the unavoidable impacts to a minimum, such as limited penetration of the mining system into the sediment, confining intensive resedimentation to the area behind the miner, minimising transport of sediment to the ocean surface, and discharging all tailings at great depths, ideally close to the seafloor. The recommendations are not new, but the present studies have improved them from precautionary to scientifically based statements.

[http://dx.doi.org/10.1016/S0967-0645\(01\)00051-0](http://dx.doi.org/10.1016/S0967-0645(01)00051-0)

C Borowski (2001) Physically disturbed deep-sea macrofauna in the Peru Basin, southeast Pacific, revisited 7 years after the experimental impact. Deep-Sea Research Part II - Topical Studies in Oceanography. vol. 48 (17-18) pp. 3809-3839

Long-term disturbance effects of a physical disturbance experiment on the benthic macrofauna (> 500 µm), with particular emphasis on the dominant Polychaeta, were investigated in connection with the German ATESEPP joint programme in 4150 m depth in the Peru Basin of the tropical southeast (SE) Pacific. The study site was the 10.8 km² experimental field of the disturbance and recolonization experiment (DISCOL) conducted in early 1989. This programme had the objective to simulate some of the potential disturbance effects of manganese nodule mining on the bottom-dwelling biota with a towed "plough-harrow" disturber, and subsequently to investigate the

resultant community responses with three postimpact samplings during a period of 3 years. Seven years after disturbance, in early 1996, the DISCOL site was revisited, and this study focuses on temporal development of the macrofauna over that extended period. Box core samples obtained during all post-impact expeditions from the disturber tracks (disturbed treatment) were compared with unploughed sediments from the experimental field (undisturbed treatment) and with samples from unimpacted sites of the surrounding (reference treatment). The experiment did not cause the disastrous long-term community changes in the sediment dwelling macrofauna that previously were predicted to follow large-scale disturbances. Abundance recoveries of the macrofaunal taxa were largely terminated after 7 years. Major differences in the faunal compositions at the selected taxonomic levels of higher macrofauna taxa, polychaete families and polychaete species between disturbed and control sites were not observed, but certain disturbance effects remained present over the entire 7-year period: Within-treatment data heterogeneity for the higher macrofauna taxa and the polychaete families was greater in the disturber track samples than in undisturbed and reference treatments. Enhanced heterogeneity was expressed by significantly steeper regression slopes of variance-to-mean ratios of faunal abundances ($p < 0.05$) and enhanced spatial aggregation at the levels of higher macrofauna taxa and polychaete families. Hurlbert rarefaction $E(S-n)$ and Shannon's diversity index H' calculated in non-standard ways for polychaete species revealed that patterns of diminished "diversity" in the disturbed treatments, which were observed during the later DISCOL period, were still present after 7 years, although the intensity of this signal became weaker. Recent abundance differences between treatments for the Bivalvia, Cumacea and the sigalionid polychaete species *Leanira* sp. A suggested that unploughed areas from the experimental field possibly were also affected by subtle long-term influences of particle plume settlement caused by the disturber action. A brief comparison with macrofauna abundance data from other ATESEPP sample locations in the Peru Basin revealed highest similarity between the sites located in the manganese nodule province, suggesting that similar disturbance effects can be expected for these areas. Nevertheless, the experimental impact by far did not reach industrial mining impact dimensions and interpretation of the results with regard to commercial mining requires caution.

[http://dx.doi.org/10.1016/S0967-0645\(01\)00069-8](http://dx.doi.org/10.1016/S0967-0645(01)00069-8)

BS Ingole, S Pavithran, ZA Ansari (2005) Restoration of deep-sea macrofauna after simulated benthic disturbance in the Central Indian Basin. *Marine Georesources And Geotechnology*. vol. 23 (4) pp. 267-288

Macrofaunal communities of the Central Indian Basin (CIB) were sampled with a spade before (June 1997), and immediately after (August 1997), and 44 months (April 2001) after a simulated benthic disturbance for polymetallic nodule mining. The average density recorded down to a sediment depth of 40 cm ranged from 89 to 799 ind.(.)m(-2) (mean: 373 +/- 221 SD; n = 12) and 178-1066 ind.(.)m(-2) (mean: 507 +/- 489 SD; n 3) in the test and reference area, respectively. Most of the macro-benthic animals (64%) were concentrated in the upper 0 to 2 cm sediment layers, whereas, sizeable fauna (6%) inhabited the 20-40 cm sediment section and the deepest 5 cm section from 35-40 cm contributed only about 2% to the total population density. The fauna, comprised of 12 groups, were dominated by the nematodes, which constituted 54% of the total population. The macrofaunal density in the test site showed a significant increase ($x: 400 \text{ ind.(.)m}(-2)$) in the 44 months postdisturbance sampling ($x: 320 \text{ ind.(.)m}(-2)$). The population of nematodes and oligochaetes was nearly restored after 44 months, but the polychaetes and crustaceans did not reach the baseline populations measured in June 1997. The top 0-2 cm sediment layer was severely affected by the disturber, and the study suggests that physically disturbed deep-sea macrofauna may require a longer period for restoration and resettlement than normally believed.

<http://dx.doi.org/10.1080/10641190500446573>

BS Ingole, ZA Ansari, V Rathod, N Rodrigues (2001) Response of deep-sea macrobenthos to a small-scale environmental disturbance. Deep-Sea Research Part II - Topical Studies in Oceanography. vol. 48 (16) pp. 3401-3410

To assess the possible effect of nodule mining on deep-sea environment, the Indian deep-sea environment experiment (INDEX) was undertaken in the Indian Basin. The present investigation is a part of the disturbance and recolonization study. Pre- and post-disturbance sediment samples were collected from 21 stations between 10 degrees 01 ' -10 degrees 03 'S and 75 degrees 59 ' -76 degrees 02 'E at water depths of 5300-5350 m to assess the effect of benthic disturbance. There was a significant change in the composition and biomass of macrofauna after the disturbance. Post-disturbance vertical profiles indicated a 63% reduction in the numerical count in the top 0-2-cm layer and high aggregation of macrofauna in deeper (5-10-cm) sediment layer. The impact of the disturbance was severe, as the mean biomass of macrofauna was significantly reduced in the disturbed area, probably due to the displacement and/or mortality caused by the benthic disturber. [http://dx.doi.org/10.1016/S0967-0645\(01\)00048-0](http://dx.doi.org/10.1016/S0967-0645(01)00048-0)

Charles Morgan, NA Odunton, AT Jones (1999) Synthesis of environmental impacts of deep seabed mining. Marine Georesources And Geotechnology. vol. 17 (4) pp. 307-356

A synthesis of environmental data compiled over the past 25 years is reviewed and organized. We describe the anticipated activities associated with exploration for commercial deposits, with engineering tests of recovery and mining systems, and with basic metallurgical processing. Basic description of the manganese nodule oceanographic environment is presented, including the occurrence of nodule deposits, relative sediment properties, benthic currents, and biological community. Environmental impacts from previous studies are summarized. Studies to date support the original concerns for environmental impact identified in the DOMES research, including impact on the benthic community where nodules are removed; impacts of the discharged plume on the near-surface biota; and impacts on the benthos due to deposition of suspended sediment. Future studies should address the establishment of quantitative relationships between resedimented thickness and benthic community response; integration of mining-related research efforts on benthic communities; establishment of clear guidelines for monitoring of precommercial mining test; and comparison of impacts from deep seabed mining with alternative land-based mining scenarios. <http://taylorandfrancis.metapress.com/link.asp?id=mf6y2u5hy6809155>

C Borowski, H Thiel (1998) Deep-sea macrofaunal impacts of a large-scale physical disturbance experiment in the Southeast Pacific. Deep-Sea Research Part II - Topical Studies in Oceanography. vol. 45 (1-3) pp. 55-81

Future human use of the deep sea potentially threatens benthic communities on large spatial and temporal scales. As a first approach to investigating the effects of large-scale sediment disturbance from deep-sea mining, the environmental risk assessment experiment DISCOL (DiSturbance and ReCOlonization) was started in 1989 at 4150 m depth in the tropical southeastern Pacific Ocean. A specially constructed disturber was towed 78 times through a 10.8 km² experimental field. The reestablishment of the impacted macrofaunal assemblages in the disturber tracks, with particular emphasis on the Polychaeta, was monitored three times over 3 yr. Mean macrofaunal densities (> 500 inds./0.25 m², 0-5 cm sediment depth range) in undisturbed sediments ranged from 77 to 122.8 inds./0.25 m² at the three sampling times. After the impact, the animal abundances in the plow

tracks were reduced to 39% of undisturbed densities. Polychaeta (48.6% of undisturbed densities) were less impacted than Tanaidacea (28.0%), Isopoda (18.5%), and Bivalvia (9.3%). Abundances of most higher taxa increased rapidly in the tracks, and after 3 yr were comparable to those of undisturbed sediments. Dominance shifts in polychaete families level were observed in the early post-impact phases. Significant displacement of macrofaunal depth distributions after 3 yr indicated sustained disturbance effects. Single species reactions within the Polychaeta did not allow clear interpretation of long-term disturbance effects, but Hurlbert rarefaction, used in a nonstandard way, demonstrated significantly reduced "diversity" after 3 yr. The reestablishment of a semi-liquid surface sediment layer is proposed as a potentially controlling factor for the reestablishment of the macrofaunal community after physical disturbance. Although the DISCOL experiment did not fully simulate full-scale industrial impacts, it has provided insights into macrofaunal recolonization following large-scale disturbance of deep-sea environments.

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Jung-Ho Myun, Kee Kim, HS Jung, KY Lee (1998) Potential environmental impact of deep seabed manganese nodule mining on the *Synechococcus* (cyanobacteria) in the northeast equatorial Pacific: Effect of bottom water-sediment slurry. *Marine Georesources And Geotechnology*. vol. 16 (2) pp. 133-143

Synechococcus (photoautotrophic cyanobacteria) are among the major primary producers in the oligotrophic open ocean. Potential environmental impacts of bottom water and sediment intrusion on the *Synechococcus* population in the surface water column of the northeast equatorial Pacific were investigated during the KODOS (Korea Deep Ocean Study) 95-2 cruise. The growth of *Synechococcus* was limited primarily by Fe deficit and secondarily by nitrogenous nutrients. Since bottom water and sediment are abundant in both inorganic nutrients and trace metals, the addition of bottom water-sediment slurry to surface water samples stimulated the growth of *Synechococcus*. Our results together with other experimental estimation suggest that certain impacts could occur on the photoautotrophic plankton biomass in the water column by the surface discharge of bottom water and sediment during large-scale and long-term commercial mining of Mn nodules. More quantitative estimation for those environmental aspects in the water column is necessary for the construction of environmentally affiliated mining systems in the future.

<http://links.isgloabalnet2.com/gateway/Gateway.cgi?GWVersion=2&SrcAuth=mekentosj&SrcApp=Paper&DestLinkType=FullRecord&DestApp=WOS&KeyUT=000074473100004>

H Bluhm, G Schriever, H Thiel (1995) Megabenthic recolonization in an experimentally disturbed abyssal manganese nodule area. *Marine Georesources And Geotechnology*. vol. 13 (4) pp. 393-416

The near total removal of manganese nodules during commercial deep-sea mining will destroy the habitat of the benthic hard-bottom fauna within the mined areas and result in the formation of a soft-bottom community of lower diversity. In 1989 the first large-scale and long-term experiment, DISCOL, was initiated in the abyssal tropical southeastern Pacific Ocean to study the impact of disturbances similar to ocean mining on the deep-sea fauna. The megabenthic assemblage and the recolonization of the disturbed area were monitored during three cruises of the German research vessel SONNE by use of an Ocean Floor Observation System with real-time TV and "photo-on-command" capabilities. The results of the image analyses of the baseline and three postimpact studies demonstrate not only a direct impact within the disturber tracks, but also an apparent impact on areas that were not primarily disturbed. Commercial mining will create a sediment plume, which will drift away with near-bottom currents and also affect animals outside the mined areas.

Reduction of environmental effects remains an important objective during development of future nodule collector systems. -

<http://links.isglobalnet2.com/gateway/Gateway.cgi?GWVersion=2&SrcAuth=mekentosj&SrcApp=Papers&DestLinkType=FullRecord&DestApp=WOS&KeyVT=A1995TR46200004>