# APPLICATION OF HIGH-RESOLUTION IMAGING SURVEY FOR RAPID MAINTAINING OF BIODIVERSITY IN THE AREAS IMPACTED BY DEEP-SEABED NODULE MINING

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***ABSTRACT***
*Deep-sea mining of polymetallic nodules is expected to cause the destruction of the abyssal ecosystem processes and biodiversity. Responsible environmental management involves balancing resource use with maintaining and conservation of 30-50% of available habitat to prevent losses of biodiversity. To establish baseline megafaunal diversity and habitats in the area perspective for nodule mining total of 32140 seafloor high-resolution images are analyzed, and the mean megafauna's abundance and composition are estimated. Application of time-series imaging survey of the seafloor allows to monitor and assess the possible losses in biodiversity during mining operations, as well as to identify any post-mining recolonization.*
***Keywords:*** *Deep seabed mining, megafauna, polymetallic nodules, Clarion-Clippertone Zone, biodiversity.*

## Introduction

The deep-sea floor beyond national jurisdiction, along with Antarctica, remains today the only large area on Earth that is not being used for the extraction of mineral resources of any kind [1, 2]. In the past several years, however, interest in deep-sea minerals such as polymetallic nodules (or manganese nodules), seafloor massive sulphides (or polymetallic sulphides) and Co-rich ferromanganese crusts has resurged. These deposits contain metals at economically interesting concentrations such as copper, nickel, cobalt, manganese, lithium, indium, gallium, germanium, REE's, which are needed for renewable energy production and high-tech innovations, as well as in the context of the increasing vulnerabilities to political control over resource access [3-6].

The responsibility for administering the ocean floor and the subsoil thereof beyond the limits of national jurisdiction (the "Area") according to the 1982 United Nations Convention of the Law of the Sea (UNCLOS) and its 1994 Implementing Agreement relating to the deep seabed mining (DSM) belongs to the International Seabed Authority (ISA). Within this general legal framework, ISA issues rules, regulations and procedures for the exploration and exploitation of mineral resources in the Area (as totally called the "Mining Code") with a view to their sustainable management and use. Furthermore, the ISA is mandated through UNCLOS to "preserve and protect the marine environment" while administering the resources within the Area.

As of April 2021, the ISA has awarded 31 contracts for exploration for deep-sea minerals. Nineteen of these contracts are for exploration for polymetallic nodules in the Clarion-Clipperton Fracture Zone, CCZ (17), Central Indian Ocean Basin (1) and Western Pacific Ocean (1). There are seven contracts for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and five contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean [7]. So far, no contracts for actual mining have been issued by the ISA but the process of preparing regulations for DSM is on the final phase of its agreement and approval [8].

The Interoceanmetal Joint Organization (IOM), an intergovernmental consortium sponsored by six states (Bulgaria, Cuba, the Czech Republic, Poland, the Russian Federation, and Slovakia), was among the first entities, which in 2001 concluded with the ISA a contract for exploration for polymetallic nodules in 75,000-$km^2$ seafloor area, situated in the eastern part of the CCZ, NE Pacific (Fig. 1).

The increasing interest to deep-sea exploration and mining raises obviously serious concerns on environmental issues. To avoid any unintended consequences from DSM that may significantly destroyed biodiversity and ecosystem structure and function, the precautionary principles are applied in the development of the Environmental management plan (EMP) for the CCZ, approved by the Council of the ISA in 2012 [9].

Within the framework of the EMP, nine protected areas of particular environmental interest (APEI) were established, with a total area of 1.44 million $km^2$, what will ensure around 30% of the entire CCZ under protection. This ISA approach will secure the responsible environmental management what involves balancing resource use with maintaining and conservation of 30-50% of available habitat to prevent losses of biodiversity and ocean reserves [10-12].

Because the commercial DSM has not yet commenced, and together with the absence of disturbance studies on realistically large scales in space and time, the exact nature and broad-scale impacts on the benthic ecology remain yet unassessed [13]. Small-scale impact experiments undertaken to date (such as DISCOL in the South-East Pacific Ocean [14, 15], benthic impact experiments (BIEs) in the CCZ [16, 17,13], the Japan deep-sea impact experiment (JET) [18] in the CCZ, and the Indian deep-sea environment experiment (INDEX) in the central Indian Ocean [19] suggest that the environmental consequences of nodule mining will be severe and long-lasting.

Numerical ecology studies have described the high-resolution photogrammetric methods in deep-sea exploration as a cost-effective and rapid tool for acquiring time-series data on both geological and biological components of the marine environment [20-22]. Moreover, the identification and quantification of marine fauna has been designated as key requirements for the assessment of possible losses in biodiversity, as well as for detecting of any recolonization or post-mining recovery processes [11, 20, 23, 24].

This paper examines baseline data on the benthic megafauna (e.g. organisms large enough to be detected on bottom photograph, typically more than 1-2 cm length) and their habitats, currently identified and assessed from the photo/video survey along nine transects carried out during the 2014 IOM's expedition in the eastern CCZ. As a part of this study, the recolonization of the disturbed seafloor sediments and the recovery of megafauna were investigated within the IOM'BIE site, whereas 19-years ago the disturbance experiment was conducted. Epibenthic megafauna is considered as a significant biological component of the abyssal ecosystem, and time-series knowledge on their species diversity, population abundance and structure within the areas subject to nodule mining will be useful for reasonable protection and conservation of the marine environment.

## Materials and methods

The datasets are derived from the H22 exploration block (4151 $km^2$) located in the central-eastern part of the IOM license area, at a depth of 4300 - 4500 m (Fig. 1). The Benthic Impact Experiment (IOM'BIE) site, 2.5 x 2 km in size is situated almost in the central part of the exploration block H22, with the central coordinates $119^0$ 39.5'W;$11^0$ 04.2'N and at depths ranging within 4250 - 4400 m. Materials for this study were obtained during the IOM'2014 at-sea expedition on the board of RV Yuzhmorgeologiya.

A photo-video survey of the seafloor was carried out along nine profiles (transects) with a total length of 584.55 km, crossing the entire exploration block H22 in a northeasterly direction (Fig. 1). This include two transects across the IOM'BIE site having a total length of 6.27 km. Photo-video profiling of the seafloor was carried out with the NEPTUN C-M1 system, towed on a coaxial cable; the ship's speed during the survey ranged from 1.0 to 2.0 knots. Video images of the seafloor were recorded in the automatic mode using a QN-196 type camera, as the still photographs were taken with the EOS 60D digital camera. In the automatic mode, the shooting was carried out at a preset time interval (20 - 30 s), using the running readout from the sonic depth finder to keep the preset distance (4 m above sea bottom), which made it possible to take pictures of the bottom surface having an area of about 5 $m^2$. The spatial location of the towed vehicles and the shots were determined using an ultra-short-base underwater navigation system Posidonia 6000. Each frame was accompanied by information of the coordinates, number, date and time (hour, minute, second) of shooting.

To identify megabenthic individuals all the photographs were repeatedly viewed using IrfanView software. All frames with revealed animals were archived in Microsoft Excel format. Each individual was identified to the lowest possible taxonomic level – morphotype or morphospecies (msp.). The taxonomic classification of the distinguished megafaunal morphotypes/morphospecies was carried out in accordance with the ITIS (the Integrated Taxonomic Information System, https://www.itis.gov)

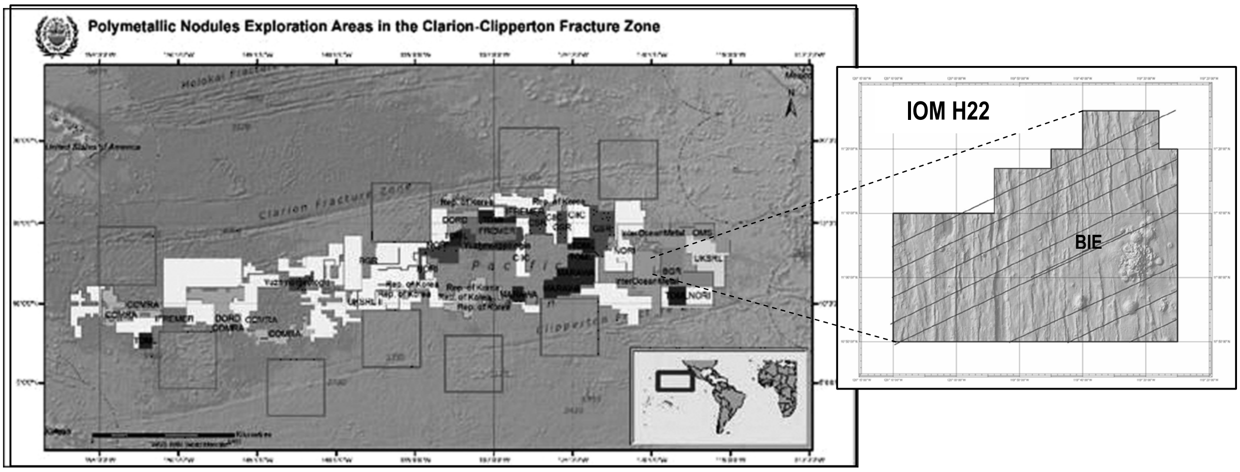


*Fig. 1: Map of exploration contract areas of polymetallic nodules in the Clarion-Clipperton Fractures Zone, NE Pacific Ocean (adapted from [www.isa.org.jm](http://www.isa.org.jm)); on the right, the bathymetric chart of the IOM H22 exploration block with the location of the IOM"BIE site and nine photo-video profiles observed during the IOM'2014 cruise*

## Results

### *Taxonomic composition of megafauna*

A total of 32139 images covering a seafloor area of 158737.8 $m^2$ were used for the baseline taxonomic and quantitative evaluation of megafauna in the exploration block H22, and so far 43722 individuals of megafauna were discovered during the processing. According to the results of this work, the megafauna was classified as consisting of 237 morphotypes, which are included in 31 taxonomic categories of higher rank (order, family).

The analyses revealed the presence of the following 10 phyla: Protozoa (Xenophyophorida), Echinodermata (Asteroidea, Crinoidea, Echinoidea, Holothuroidea, Ophiuroidea), Cnidaria (Actiniaria, Alcyonacea, Antipatharia, Pennatulacea, Scyphozoa, Ceriantaria, Corallimorpharia, Scleractina, and Hydrozoa), Porifera (Demospongiae and Hexactinellida), Arthropoda (Decapoda, Isopoda, Scalpdellia, and Pantopoda), Chordata (Actinopterygii and Ascidiacea), Annelida (Polychaeta), Mollusca (Bivalvia, Cephalopoda, Gastropoda, and Polyplacophora), Bryozoa, and Ctenophora.

As displayed in Fig. 2, the highest relative dominance (33%) of all the observed megafauna sorted by phyla, was recorded for protists xenophyophores. Of the metazoan phyla, the most abundant were echinoderms (Echinodermata) – 29%, followed by cnidarians (Cnidaria) – 22%, sponges (Porifera) – 12% and arthropods (Arthropoda) – 2%. The other megafaunal taxa: Chordata, Annelida, Mollusca, Bryozoa and Ctenophora, in decreasing order, represent overall about 4% of all the identified megafauna.

### *Abundance and morphotype richness of megafauna*

The abundance (individuals per hectare, ind./ha) of megafauna taxa counted on the basis of data obtained from individual photoprofiles, whereas the total abundance and taxonomic richness (the number of morphospecies) of megafauna throughout the entire exploration block H22 is presented in Table 1. The total abundance of megafauna in the survey area was estimated at 2754 ind./ha and varied from 1995 to 3156 ind./ha. The abundance of metazoans (excluding xenophyophores) reached 1840 ind./ha for the entire study area and varied from 1268 to 2239 ind./ha.

The analysis of megafaunal abundance demonstrated that the most dense group of megafauna are xenophyophores, their value reach to 914 ind./ha for the entire H22 block, ranging from 586 to 1747 ind./ha. Among metazoan megafauna, the most abundant groups in the study area were Echinodermata yielding an estimated abundance of 785 ind./ha, ranging from 440 to 1113 ind./ha, and Cnidaria with 601 ind./ha, varying from 288 to 730 ind./ha (Tab. 1). The third most abundant group was sponges (Porifera), their density varying from 288 to 423 ind./ha and yielding an abundance of 326 ind./ha for the entire study area. Far beyond these three group, the representatives of Arthropoda were found with an abundance of 64 ind./ha, varying from 52 to 72 ind./ha. The overall abundance of the remaining taxa – Chordata, Annelida, Mollusca, Bryozoa and Ctenophora reached around 64 ind./ha.

The taxa with the highest morphotype richness were Echinodermata and Cnidaria, for which a total of 67 and 63 morphotypes have been recognized, respectively. By contrast, the diversity of xenophyophores, which were the most dominant by abundance (914 ind./ha), was limited to only 8 morphotypes.

As the results of this study indicate, the sea cucumbers (Holothuroidea), glass sponges (Hexactinellida), sea anemones (Actiniaria), fish (Actinopterygii), starfish (Asteroidea) and coral polyps (Alcyonacea) accounted for about 56% of all the recognized morphotypes and around 41% of the total megafauna abundance in the study area. The group of the five most abundant megafaunal taxa, excluding xenophyophores included sea anemones (364 ind./ha), glass sponges (307 ind./ha), ophiuroids (297 ind./ha), sea urchins (233 ind./ha) and holothurians (209 ind./ha).

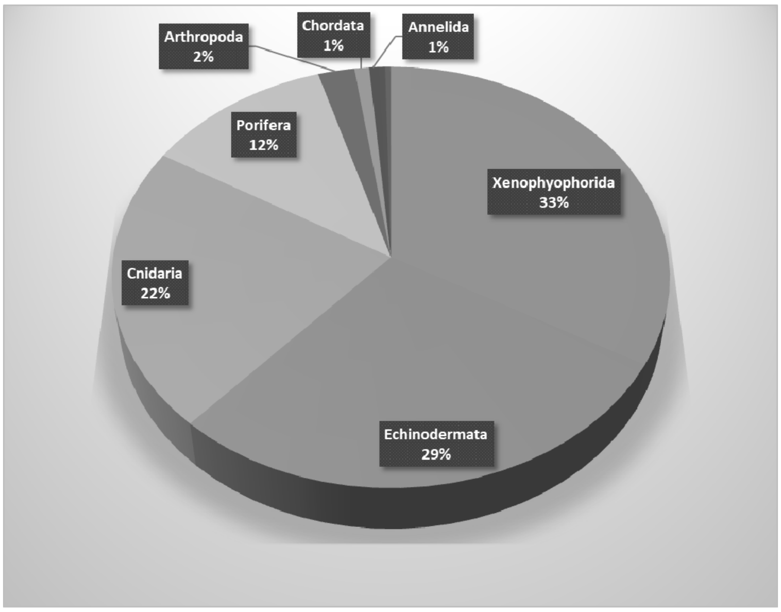


*Fig. 2: Relative dominance (%) of the main megafaunal phyla recognized in the study area*

Holothurians (Echinodermata, Holothuroidea) in terms of variety of identified morphotypes (apparently, a total of 42 morphospecies) far outnumbered all the other taxa found in the area. Representatives of seven families Mesothuriidae, Synallactidae, Deimatidae, Elpidiidae, Laetmogonidae, Psychropotidae and Pseudostichopodidae were identified, the largest diversity of forms belonging to Elpidiidae, Psychropotidae and Synallactidae. Selected examples of holothurians observed in the study area are displayed in Fig. 3.

All the megafauna found were also classified by their trophic type (Tab. 1) and by their behavioural strategy (mobility). Deposit feeders constituted 29% of the total megafauna, while 67.4% were seston feeders and 3.6% were carnivores. As far as taxonomic diversity is concerned, seston feeders constituted 53.6% of morphotype richness, while deposit feeders and carnivores accounted for 30.3% and 6.1%, respectively.

### *IOM'BIE seafloor structures*

Both the photographs and the video recordings showed that tow tracks on the seafloor were evident even 19 years after the original disturbance in the IOM'BIE site despite the presence of the substantial weathering changes. Tracks were noteworthy less sharp than the one documented immediately after the disturbance operations, the numerous light colored patches were visible on the surface (Fig. 4). The bottom sediments within the entire site featured presence of the abundant biogenetic traces (Lebensspuren) left by the various benthic organisms (Fig. 5).

*Table 1 Total abundance (ind./ha) and morphotype richness of megafaunal taxa observed in the exploration block H22*

| Phylum | Taxon | Feeding type | Abundance, ind./ha | Number of morphotypes |
|---|---|---|---|---|
| Protozoa | Xenophyophorida | Seston/Deposit feeder | 914 | 8 |
| Echinodermata | Ophiuroidea | Deposit feeder | 297 | 2 |
| | Echinoidea | Deposit feeder | 233 | 8 |
| | Holothuroidea | Deposit feeder | 209 | 42 |
| | Asteroidea | Deposit feeder | 44 | 11 |
| | Crinoidea | Seston feeder | 3 | 4 |
| Cnidaria | Actiniaria | Seston feeder | 364 | 24 |
| | Alcyonacea | Seston feeder | 169 | 11 |
| | Antipatharia | Seston feeder | 40 | 3 |
| | Pennatulacea | Seston feeder | 13 | 4 |
| | Scyphozoa | Carnivorous | 7 | 2 |
| | Ceriantharia | Seston feeder | 4 | 5 |
| | Corallimorpharia | Seston feeder | 2 | 4 |
| | Hydrozoa | Seston feeder | 3 | 7 |
| | Scleractinia | Seston feeder | 1 | 3 |
| Porifera | Hexactinellida | Seston feeder | 307 | 32 |
| | Demospongiae | Seston feeder /Carnivorous | 19 | 6 |
| Arthropoda | Decapoda | Carnivorous | 58 | 7 |
| | Isopoda | Carnivorous | 4 | 4 |
| | Scalpellidae | Seston feeder | 2 | 2 |
| | Pantopoda | Deposit feeder | 0 | 1 |
| Chordata | Actinopterygii | Carnivorous | 23 | 12 |
| | Ascidiacea | Carnivorous | 3 | 3 |
| Annelida | Polychaeta | Deposit feeder | 17 | 8 |
| Mollusca | Polyplacophora | Seston feeder | 7 | 1 |
| | Gastropoda | Carnivorous | 2 | 3 |
| | Bivalvia | Seston feeder | 1 | 2 |
| | Cephalopoda | Carnivorous | 1 | 7 |
| Bryozoa | Bryozoa | Seston feeder | 9 | 7 |
| Ctenophora | Ctenophora | Seston feeder | 1 | 4 |
| Total, ind./ha | | | 2754 | 237 |

***IOM'BIE megafauna***

A specialized analysis of 376 bottom photographs revealed 663 epibenthic animals entering into 17 megafauna taxa, which occurred at very different frequencies. The main part (around 90%) of this assemblage consisted of five most abundant taxa: Xenophyophorida, Actiniaria, Porifera, Holothuroidea and Ophiuroidea. The most dominant taxon on the seafloor were xenophyophores (giant protists) found to compound around 68% of the megafaunal individuals visible on the bottom photographs. Amongst the metazoan fauna, the most frequent taxa were sea anemones (Actiniaria) and sponges (Porifera), which comprised 6.8 and 6.2%, respectively. The rarest occurrences on the seafloor were those of Bivalvia, Ascidiacea, Hydrozoa, which were identified only in two frames, and jellyfish (Scyphozoa) found only in a single image.

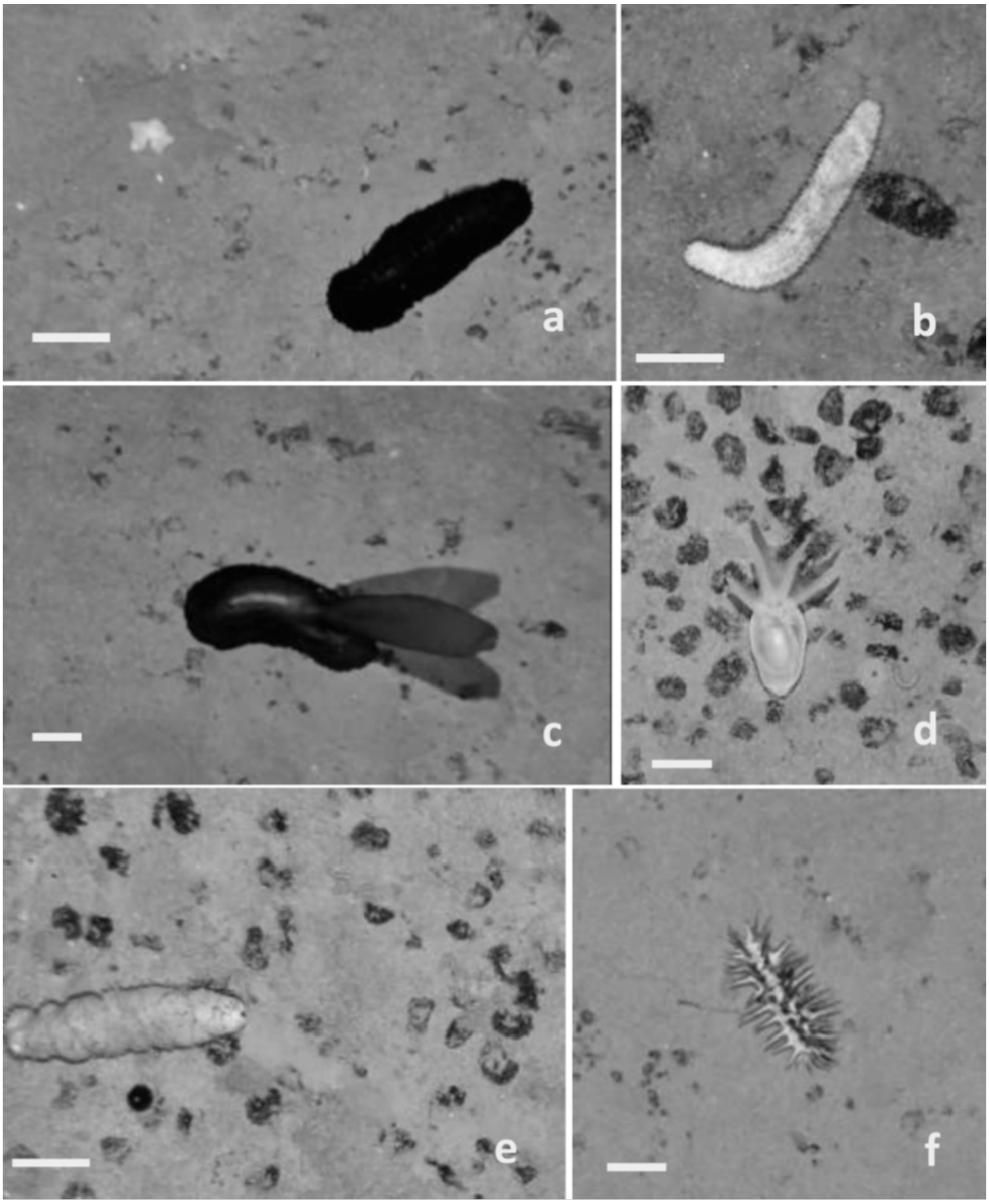


*Fig. 3: Examples of holothurians (Echinodermata, Holothuroidea) observed in the seafloor images during the IOM-2014 cruise in the exploration block H22. The scale bar represents 10 cm. (a) Benthodytes msp.2, (b) Paroriza msp., (c) Psychropotes msp.4, (d) Amperima msp. 1, (e) Molpadiodemas msp.1, and (f) Oneirophanta cf. mutabilis msp.2. A buried sea star Paxillosida msp. appears near the sea cucumber in (a).*

Abundance of the megafauna was assessed for both, the entire IOM'BIE site and each stratum: reference, disturbance and re-sedimentation zones. Total abundance of megafauna observed within the IOM'BIE site showed that an increasing trend detected in comparison with the reference zone, with value of

3130 ind./ha, through the disturbance zone (3493 ind./ha) and reached the maximum abundance in the re-sedementation zone, with an estimated value of 4563 ind./ha. The three strata were found to differ in taxonomic richness: the reference zone brought individuals representing a total of 14 taxa, 16 taxa were identified in disturber zone, and the re-sedimentation zone yielded a total of 13 taxa.

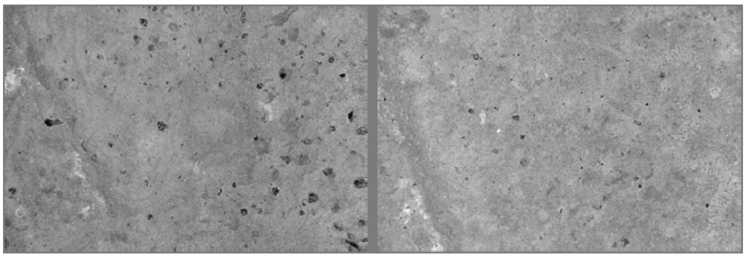

*Fig.4: Disturber tracks observed on the seafloor within the IOM'BIE site in 2014*

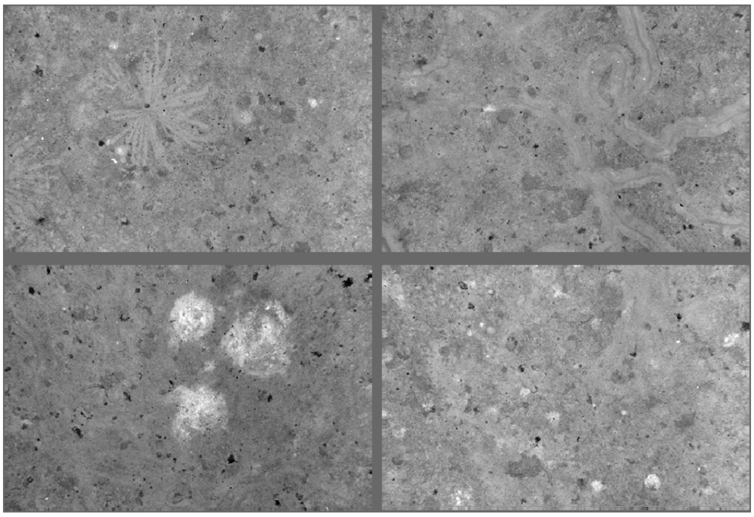

*Fig. 5: Bottom sediments within the tow zone featuring presence of abundant Lebensspuren left by various benthic organisms*

## Conclusions

Performed analyze of 32139 seafloor images, and processing of obtained results demonstrated that photo/video profiling is a reliable and effective method for baseline study of abundance, taxonomic structure and diversity of deep-sea megafaunal community.

The disturbance effects on the surficial sediment structures still remained present for over 19 years despite the signs of the tracks' smoothing and weathering and as well as occurrence of abundant traces of bioturbation processes. Respectively to the recovery of megafauna, the impact zone supplied the highest taxonomic richness followed by the reference and the re-sedimentation ones; in contrast, the most abundant is the re-sedimentation one, followed by the impact and reference zones.

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