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INTERNATIONAL SEABED AUTHORITY

Workshop on the development of a regional environmental management plan for the Area of the Indian Ocean, with a focus on the Mid-Ocean Ridges and Central Indian Ocean Basin

1-5 May 2023

Chennai, India

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Contents

Abbreviations

ABMT	area-based management tool
APEI	area of particular environmental interest
BGR	Federal Institute for Geosciences and Natural Resources, Germany
CCZ	Clarion-Clipperton Zone
CIR	Central Indian Ridge
COMRA	China Ocean Mineral Resources Research and Development Association
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
CTD	Conductivity, temperature and depth
EMP	environmental management plan
IOR	Indian Ocean Ridge
IRZ	impact reference zone
ISA	International Seabed Authority
KIOST	Korean Institute of Science and Technology
LTC	Legal and Technical Commission, ISA
MAR	Mid-Atlantic Ridge
MoES	Ministry of Earth Sciences, India
NCPOR	National Centre for Polar and Ocean Research, India
NIO	National Institute of Oceanography, India
NIOT	National Institute of Ocean Technology, India
OBIS	Ocean Biodiversity Information System
OEMMR	Office of Environmental Management and Mineral Resources, ISA
PMN	polymetallic nodule
PMS	polymetallic sulphides
PRZ	preservation reference zone
REMP	regional environmental management plan
SEIR	Southeast Indian Ridge
SWIR	Southwest Indian Ridge
UNCLOS	United Nations Convention on the Law of the Sea

Introduction

In accordance with the United Nations Convention on the Law of the Sea (UNCLOS) and 1994 Agreement relating to the implementation of Part XI of UNCLOS (1994 Agreement), the International Seabed Authority (ISA), on behalf of the States Parties to UNCLOS, is mandated to administer the mineral resources in the Area and to control and organize current exploration activities, as well as future mining activities, for the benefit of humankind as a whole. ISA is also mandated to take necessary measures with respect to activities in the Area to ensure effective protection of the marine environment from harmful effects and to adopt appropriate rules, regulations and procedures for, inter alia, the prevention, reduction and control of pollution and other hazards to the marine environment, the protection and conservation of the natural resources of the Area, and the prevention of damage to the flora and fauna of the marine environment (UNCLOS, Article 145).

In pursuance of this mandate, the ISA Council, during its seventeenth session in 2012, based on the recommendation of the Legal and Technical Commission (LTC), approved an Environmental Management Plan (EMP) for the Clarion-Clipperton Zone (CCZ) in the Pacific basin.[1] This included the designation of a network of nine areas of particular environmental interest (APEIs), which were designed to be protected and used for conservation management and to maintain sustainable populations and capture the full range of habitats and communities. In 2021, following a comprehensive review of the implementation of the EMP for the CCZ, the LTC recommended further actions to advance the implementation of the EMP. These included the establishment of four additional APEIs to enhance the effectiveness of the overall APEI network. The Council endorsed this recommendation in December 2021.[2] As a result, the network of APEIs in the CCZ now comprises 13 APEIs covering a total area of 1.97 million km^2 of seabed.

At its twenty-fourth session in March 2018, the Council took note of a strategy proposed by the Secretary-General for the development of regional environmental management plans (REMPs) for key provinces of the Area where there were contracts for exploration.[3] The Council agreed with the priority areas that had been identified on a preliminary basis as follows: the Mid-Atlantic Ridge (MAR), the Indian Ocean ridges near the triple junction and the nodule-bearing province, as well as the North-West Pacific and South Atlantic for seamounts. The Council also noted that the strategy laid out a coherent and coordinated approach to the process and identified as essential that REMPs be developed in a transparent manner under the auspices of ISA, in light of its jurisdiction under UNCLOS and the 1994 Agreement.[4] The strategy was later reflected in the ISA's strategic plan and its high-level action plan for the period 2019–2025.

At the twenty-fifth session, the Council took note of a report of the Secretary General on the implementation of the preliminary strategy, including a programme of work to develop REMPs through a series of workshops planned during 2019 and 2020 to undertake a scientific synthesis and prepare draft elements for

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[1] *See* ISA. 2011. Environmental Management Plan for the Clarion-Clipperton Zone (ISBA/17/LTC/7). ISA. 2011. Decision of the Council of the International Seabed Authority relating to an environmental management plan for the ClarionClipperton Zone (ISBA/17/C/19). ISA. 2012. Decision of the Council relating to an environmental management plan for the Clarion-Clipperton Zone (ISBA/18/C/22).

[2] ISA. 2021. Decision of the Council of the International Seabed Authority relating to the review of the environmental management plan for the Clarion-Clipperton Zone (ISBA/26/C/58).

[3] *See* ISA. 2018. Preliminary strategy for the development of regional environmental management plans for the Area (ISBA/24/C/3).

[4] ISA. 2018. Statement by the President of the Council on the work of the Council during the first part of the twenty-fourth session (ISBA/24/C/8), para 10.

inclusion in the REMPs.[5]

To support the organization of these workshops, the Secretariat prepared a guidance document to facilitate the development of REMPs. As requested by the Council, steps are being taken by the LTC to further develop this guidance document, with a view to recommending to the Council a standardized approach to the development, review and approval of REMPs.[6]

In line with the approach outlined in the strategy and the programme of work, since 2018, six expert workshops have been convened by ISA in collaboration with various partner organizations to support the development of REMPs in priority areas, including the CCZ, MAR and northwest Pacific.

Against this background, the Secretariat, in collaboration with the Ministry of Earth Sciences (MoES) and the National Institute of Ocean Technology (NIOT), Government of India, convened the workshop on the development of a REMP for the Area of the Indian Ocean, with a focus on the Mid-Ocean Ridges and Central Indian Ocean Basin.

The workshop aimed to:

- define an appropriate geographical area for the development of the REMP,
- review and analyse benthic and pelagic ecosystem data,
- synthesize environmental data across the region,
- describe current exploration activities within contract areas, and
- identify approaches and tools for area-based management and an assessment of cumulative impacts.

The results of this workshop will provide scientific inputs for additional workshops in this region. The results of these workshops will provide the core elements for the LTC to develop the REMP for the Area of the Indian Ocean.

The workshop was co-chaired by Dr. Malcolm Clark and Dr. Ramesh Sethuraman, members of the LTC. It was attended by 32 participants in their individual expert capacities. The full list of workshop participants is provided in Annex I to this report.

Item 1. Opening of the workshop

Mr. José Dallo, Director of the Office of Environmental Management and Mineral Resources (OEMMR), ISA, opened the workshop at 09:00 (India; GMT+5:30) on Monday, 1 May 2023. He welcomed the participants and thanked the MoES and NIOT for hosting and supporting the workshop.

Dr. G. A. Ramadass, Director, NIOT, MoES, delivered his opening statement. Dr. Ramadass remarked that sustainable utilization of ocean resources is one of the solutions for the fast-depleting resources on land and the increasing demand for strategic metals. The mineral resources in the Area are the common heritage of humankind and should be regulated and utilized without causing harm to the environment. Understanding the deep ocean environment is the first step towards protecting it. The development of the REMP for the Indian Ocean region is long overdue. NIOT, an autonomous institute of the MoES, is proud to host this first REMP workshop for the Area of the Indian Ocean, organized by ISA.

H.E. Mr. Michael W. Lodge, Secretary-General of ISA, delivered opening remarks through a pre-recorded video message. He expressed his appreciation to the MoES and NIOT for their excellent support in

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[5] ISA. 2019. Implementation of the Authority’s strategy for the development of regional environmental management plans for the Area Report of the Secretary-General (ISBA/25/C/13).

[6] ISA. 2020. Decision of the Council concerning a standardized approach for the development, approval and review of regional environmental management plans in the Area (ISBA/26/C/10).

organizing this important workshop. He also thanked Dr. Malcolm Clark, Dr. Ramesh Sethuraman and Dr. Se-Jong Ju, as LTC members, for their contributions to the workshop and for co-chairing the workshop discussions. He also thanked the National Institute of Oceanography (NIO) of India, Duke University of North Carolina, USA, and the Commonwealth Scientific and Industrial Research Organisation of Australia (CSIRO) for essential technical and scientific support to the workshop. He underscored the role of REMPs as the most effective tool for managing activities in the Area to achieve the objectives set out in UNCLOS and the Part XI Agreement. He reflected on the progress in the development, implementation and review of REMPs to date, including the convening of expert workshops for the CCZ, northern Mid-Atlantic Ridge and northwest Pacific Ocean and the development of a standardized approach for REMPs. Finally, Mr. Lodge also thanked the participants for supporting ISA in developing the REMP through a transparent and collective effort and building on the best available science and scientific information.

Dr. M. Ravichandran, Secretary, MoES, in his opening statement, mentioned that the MoES, being the pioneer investor for polymetallic nodule (PMN) exploration in the Central Indian Ocean Basin, is proud to host the first REMP workshop for the Indian Ocean organized by ISA. This initiative aims to develop a REMP for polymetallic nodule bearing provinces and the ridges near the triple junction of the Indian Ocean. The establishment of a REMP is an important precondition laid down in the draft exploitation regulations negotiated in the ISA Council. He underscored the importance of coordinated research and collaboration in developing a REMP to safeguard ocean ecosystem function, including biodiversity. Finally, Dr. M. Ravichandran affirmed India's active participation in all organs of ISA in developing robust, stringent and eco-friendly mining regulations ensuring the protection of the marine environment, preservation of biodiversity and utilization of the common heritage of humankind.

Dr. Vijay Kumar, Scientist G and Adviser at the MoES presented an overview of recent progress relating to India's programmes for PMN and polymetallic sulphides (PMS) programmes. The presentation initially provided an overview of the structure of the MoES, including the roles of (i) the NIO in mine site exploration and environmental impact assessment, (ii) the NIOT in the development of mining technologies and (iii) the Institute of Minerals and Materials Technology in metallurgy for the recovery of metals including Cu, Ni and Co. The revised first-generation mine site was discussed, including relinquished areas and the proposed impact reference zone within the PMN contract area. Dr. Kumar provided an update on ocean technology developments, which included descriptions of in situ soil testers, coring systems, remotely operated and autonomous underwater vehicles, underwater collector and mining machines, and a planned manned submersible with a capability reaching up to 6,000 metres. A summary of an integrated flowsheet was provided for the PMN programme. Dr. Kumar also presented recent milestones for the PMS programme and a brief overview of environmental baseline studies, with further details to be provided in subsequent presentations.

Item 2. Workshop background, scope and expected outputs

Under this item, the following presentations were delivered:

- Malcolm Clark, Scientific approaches to the development of REMPs in the Area
- Pedro Madureira, Development of the draft REMP for the northern MAR
- Se-Jong Ju, Report of the workshop on the development of a REMP for the Area of the Northwest Pacific (2020)
- José Dallo, Workshop objectives and expected outcomes

Annex II contains the abstracts of the presentations.

Item 3. Review, analysis and synthesis of relevant scientific data/information/maps relating to biodiversity and ecosystem patterns in the Indian Ocean

Under this agenda item, participants had before them:

- Draft Data Report compiling environmental and biological information, biogeographic classification and other geospatial information in GIS layers, prepared by Duke University in support of the workshop objectives, and
- Compilation of information towards a regional environmental assessment, prepared by CSIR-NIO, MoES, Government of India.

Jesse Cleary (Duke University, United States) provided a presentation on the draft Data Report, Samir Damare (CSIR-NIO, India) provided a presentation on a compilation of information towards a regional environmental assessment, which was followed by a presentation by Luciana Genio (ISA Secretariat) on ISA's DeepData.

The following presentations were delivered on environmental baseline studies conducted by ISA contractors in the Indian Ocean:

- Thomas Kuhn (Federal Institute for Geosciences & Natural Resources (BGR), Germany): Environmental and geological studies conducted by BGR in its contract area in the Indian Ocean-INDEX
- Chunhui Tao and Yadong Zhou (Second Institute of Oceanography, China): Report on background information of the hydrothermal vents & habitat classification in the Indian Ocean
- Baban Ingole (MoES, India): Environmental baseline studies for preparing the REMP in the Indian Ridge System
- Junguk Kim (Korean Institute of Science and Technology, KIOST)): Korean exploration activities for PMS in the Indian Central Ridge: environmental studies
- Samir Damare (CSIR-NIO, India): Environmental studies conducted by ISA contractors in the Indian Ocean: Government of India – PMN

Building on the presentations above, participants exchanged their views, insights and suggestions regarding the work carried out to date. It was noted that, overall, the presentations include both published and unpublished studies and data. Contractors and researchers were encouraged to submit and share data through DeepData and, as appropriate, other platforms (e.g. GenBank for DNA sequence).

After plenary discussions, participants split into the following break-out groups to engage in focused discussions:

- Group 1: State of knowledge related to geological aspects of the marine environment in the Indian Mid-Ocean Ridges and Central Indian Ocean Basin. This group discussion was moderated by Mr. Pedro Madureira (University of Évora and Task Group for the Extension of the Continental Shelf. Portugal, former member of ISA LTC).
- Group 2: State of knowledge related to oceanographic and biological aspects of the marine environment in the Indian Mid-Ocean Ridges and Central Indian Ocean Basin. This group discussion was moderated by Mr. Malcolm Clark and Mr. Se-Jong Ju (LTC).

A summary of the discussions in response to the above presentations is provided under Annex III.

Item 4. Scientific approaches and tools in support of area-based management and assessment of cumulative impacts

Building on the presentations and the results of discussions under the previous agenda items, participants discussed scientific approaches and tools in support of area-based management and assessment of cumulative impacts. In this regard, Mr. Jesse Cleary and Ms. Sarah DeLand (Duke University, United States), Mr. Jeffery Dambacher and Mr. Piers Dunstan (CSIRO) were invited as facilitators to moderate the respective discussions, together with the workshop co-chairs. The facilitators briefed participants on suggested approaches to producing outputs under this agenda item.

The results of the discussions under this agenda item are summarized in Annex IV of this report for cumulative impact assessment and Annex V for area-based management tools (ABMTs).

Item 5. Summary and conclusion

ISA Secretariat informed that the draft workshop report would be completed after the workshop and shared with the participants for their inputs and comments. The background documents (draft Data Report and Regional Environmental Assessment) will also be updated after the workshop based on the comments and inputs received from the participants, and the final versions of them will be submitted to the next REMP workshop for the Indian Ocean region. The Secretariat also briefed the participants that follow-up work may be organized to further develop cumulative impact modelling before the next workshop, in discussion with CSIRO.

Item 6. Closure of the workshop

The workshop was closed at 17:00 (India; GMT+5:30) on Friday, 5 May 2023.

Annex I

List of participants

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Annex II

Summary of theme presentations delivered under Item 2

Scientific approaches to the development of REMPs in the international seabed area

Malcolm Clark

Mr. Malcolm Clark, a member of the LTC, provided an overview of scientific approaches to the development of REMPs under the auspices of ISA, discussing the role of the ISA in ensuring the protection of the marine environment with specific reference to UNCLOS Article 145, ISA Strategic Goals (Strategic Direction 3.2) and the draft regulations for exploitation of mineral resources in the Area and associated standards and guidelines. The presenter provided an overview of recent ISA REMP workshops (2018-2020) covering the CCZ, MAR and Northwest Pacific Ocean. The presenter highlighted the engagement of the LTC with over 300 experts and other stakeholders in six expert workshops since 2018, as well as the ISA's progress towards a standardized approach to REMP development. The presenter described the iterative development of the CCZ EMP to illustrate the evolution of the process (first approved by the ISA Council in 2012), the requirements for review of the plan every five years and a recent scientific synthesis workshop in 2019. The latter led to the development of habitat classification models to assess the representativity of the network of APEIs and the designation of four new APEIs to address issues of connectivity and protection of environmental gradients (i.e. topography, particulate organic carbon flux and nodule abundance). The presenter emphasized the importance of the goals and objectives of the CCZ EMP (ISBA/17/LTC/7), and the role of science in supporting the development of appropriate management options with comprehensive baseline data and identification of key design elements. Finally, drawing on the experiences of developing REMPs in various regions, Mr. Clark concluded by highlighting the process- and the science-related challenges in further developing REMPs, including the setting of overarching and generic regional goals, considerations of the spatial scale of REMPs to preserve ecosystem structure and function, the effectiveness of non-spatial management measures, approaches to addressing knowledge gaps and the need for regional monitoring. It was stressed that one size does not fit all and that different regions with different resources and different environmental characteristics may need different REMP structures.

Development of the draft REMP for the northern MAR

Pedro Madureira

Mr. Pedro Madureira, a former member of the LTC, provided an overview of the REMP workshop for the MAR in Évora, Portugal, held in 2019 and the subsequent virtual workshop from 2020. The presenter reminded that the current contract areas for exploration for PMS in the MAR include the Government of the Russian Federation, the Government of the Republic of Poland and Institut français de recherche pour l'exploitation de la mer (sponsored by France). It was noted that vent sites are unevenly distributed, and many sites are yet to be discovered in the MAR. Next, the presenter discussed spatial scales of contract areas, including an example of the relinquishment process and the requirement for higher resolution mapping to account for strong environmental gradients and high heterogeneity within contract areas. Mr. Madureira noted that a combination of different approaches was applied in the draft REMP for the MAR, including both area-based and non-spatial management, and adaptive management.

Report of the workshop on the development of a REMP for the Area of the Northwest Pacific (2020)

Se-Jong Ju

Dr. Se-Jong Ju, a member of the LTC, presented the outcomes of the virtual workshop on the development of the REMP for the Northwest Pacific held in 2020. The presenter emphasized the approach to two types of seabed mineral resources (cobalt-rich ferromanganese crusts and PMNs), noting that the Indian Ocean REMP will also need to be flexible to account for two different types of resources, PMS and PMNs, which occur at different spatial scales. The presenter also introduced the qualitative modelling approach for both benthic seamount ecosystems and pelagic and abyssal plain ecosystems to showcase the cumulative impact assessment process. The presenter discussed the approach to area-based management, which included network criteria to identify coarse-scale areas in need of protection. The results will provide input to the next workshop to be held in Japan in 2024.

Workshop objectives and expected outcomes

José Dallo

Mr. José Dallo, the Director of the OEMMR at the ISA Secretariat, presented an overview of the objectives and expected outcomes of the Indian Ocean REMP workshop: (i) identify an appropriate area for the development of the REMP, (ii) review and synthesize ecosystem data, (iii) describe current exploration activities within contract areas and (iv) discuss approaches and tools for area-based management and assessment of cumulative impacts. Workshop preparations included the development of the terms of reference by the LTC, the nomination of workshop participants and the preparation of supporting information and background documents. The workshop outcomes will be summarized in the workshop report. The draft data report and regional environmental assessment report will be finalized after the workshop. The expected outputs presented in the workshop report will include (i) a synthesis of the current state of knowledge on the marine environment for the Indian Ocean and (ii) scientifically sound approaches for area-based management and assessment of cumulative impacts. Ultimately, this work will contribute towards a shared understanding of the current knowledge base to identify knowledge gaps and scientific approaches that will inform the development of REMP for this region.

Introduction to the draft Data Report

Jesse Cleary

Mr. Jesse Cleary, researcher at Duke University, reviewed the compilation of scientific data and information prepared for the workshop and presented a document entitled “Data report: a background document for the Workshop on the REMP for the Area of the Indian Ocean.” The presenter explained that the baseline data layers developed for this workshop stem from open-access data sources to provide consistency between regional efforts, along with many data specific to the Indian Ocean region. About 90 data layers were collated and prepared for this workshop. In addition to data layers, the report identifies a number of published scientific papers that list additional data resources. The presentation covered five general types of data: (1) environmental data, (2) biological data, (3) biogeographic classification, (4) human uses and (5) areas defined for management and/or conservation objectives. The biogeographic data focused on major biogeographic classification systems. The biological data portion of the draft report covered a variety of data sources, including data and statistical indices compiled by the Ocean Biodiversity Information System (OBIS), habitat suitability models and area used by sea turtles and important bird and marine mammal species. Biological data records from the ISA DeepData Portal for this region were also included. The environmental data layers included bathymetric and physical substrate data, oceanographic features and remotely sensed data. The report also identified a number of published scientific papers that listed additional data resources. Mr. Cleary explained that the draft data report will be finalized after the workshop to include additional data sets suggested by participants and will be kept as a living document.

Compilation of information towards a regional environmental assessment for the Indian Ocean

Samir Damare

Mr. Samir Damare, presented a compilation of information towards a regional environmental assessment for the Indian Ocean. The Indian Ocean, the third largest ocean of the world accounts for the one fifth of the world oceans in size. Unlike the other two major oceans, the Pacific and the Atlantic, the Indian Ocean is unique with respect to its physical features, having landlocked northern parts, as well as monsoonal formations and typical biogeochemical cycles. In terms of living resources, the Indian Ocean has a varied diversity from mammals to microbes. The non-living resources include the PMNs along the abyssal plains as well as PMS on the mid-oceanic ridges, which have been attracting the attention of researchers. Found in water depths ranging from 2,500 to 6,000 metres, PMNs are either layered concretions of iron and manganese oxides around a nucleus containing metals precipitated from the water column or the associated substrates. The hydrothermal sulphides are rich in sulphide minerals deposited from hydrothermal activity on the sea floor. The document presented is a compilation of background information to inform discussions at the ISA workshop on the development of a REMP for the Area of the Indian Ocean. It provides an overview and synthesis of existing scientific information relating to the mineral resource-bearing areas of the Indian Ocean, including geology and oceanography. The information presented in the document was collated from multiple sources. It included both published and unpublished information, including results from ongoing surveys and environmental baseline studies conducted by CSIR-NIO in this region. The MoES, Government of India, is the major stakeholder and only contractor for the exploration of PMN resources in the Indian Ocean. The PMS deposits are located along the mid-ocean ridges in the Indian Ocean. Four contractors hold contracts with ISA for undertaking PMS exploration activities in the Indian Ocean: the Government of India, COMRA, the Government of the Republic of Korea and BGR. The respective areas of PMS exploration in the Indian Ocean of all the contractors are located along the ridge axis.

Introduction to the ISA DeepData

Luciana Genio

Ms. Luciana Genio, OEMMR, ISA Secretariat, presented data compiled from the ISA DeepData database to support the development of the Indian Ocean REMP.[8] The presenter began with a brief introduction to DeepData, highlighting its current main role as the global repository of data and information collected by ISA contractors during mineral exploration activities. Launched in 2019, DeepData is a georeferenced web platform that contains information on mineral resource assessment and environmental data, including physical and chemical oceanographic and geological and biological data collected from the ocean surface to the seabed. Both structured data submitted through digital templates and unstructured data, including images, maps and raw data files, are available for downloading on the web platform. The presenter summarized biological and physical oceanographic data (currents, conductivity, temperature and pH) available for the Indian Ocean region since the first contract for PMN exploration was signed in 2002. These biological and physical oceanographic data were reviewed and synthesized by the Secretariat and made available to participants to support workshop deliberations. The presenter outlined several ongoing efforts and next steps for improving data quantity and quality in DeepData as part of the ISA data management strategy, including future workshops to improve data standardization and training

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[8] ISA. DeepData Database. Available at: https://www.isa.org.jm/deepdata-database.

opportunities for contractors and other ISA stakeholders. Ms. Genio closed by presenting other initiatives launched by the ISA: the Sustainable Seabed Knowledge Initiative[9] and Area 2030.[10] These initiatives aim to enhance access to data collected in the Area by establishing interoperable links with external databases and strengthening collaboration among ISA contractors and the scientific community.

Environmental and geological studies conducted by BGR in its contract area in the Indian Ocean-INDEX, Thomas Kuhn

Mr. Kuhn reminded that the BGR, as the Federal Geological Survey of Germany, has signed a contract with the ISA for the exploration of massive sulphides in the Indian Ocean on 6 May 2015. The contract area stretches 500 km to the north of the Rodriguez Triple Junction along the Central Indian Ridge (CIR) and 500 km to the southeast along the Southeast Indian Ridge. BGR has conducted eight exploration cruises since 2015, another almost three months cruise is planned for 2023 and more cruises for the upcoming years. Currently, 14 hydrothermal fields are known in the German contract area, of which 12 fields have been newly detected by the exploration work, six fields along the southern CIR and eight fields along the northern end of the Southeast Indian Ridge (SEIR). Three fields are hosted in ultramafic and plutonic rocks the other fields are basalt hosted. Four hydrothermal fields are inactive, and the other fields contain both active and inactive sites. About 50 per cent of BGR's budget and ship time has been spent on environmental and biodiversity studies in the contract area. These investigations include oceanographic and biogeochemical studies of the particulate matter flux, water masses and nutrient cycle using moorings with sediment traps, current metres, passive samplers, as well as CTD/rosette casts. So far, 30 moorings have been deployed within a total of 42 sediment traps at seven locations distributed over the entire contract area. Overall, 545 recovered particulate matter samples could be recovered and analysed up-to-date. Studies of trace element concentration in the water column, hydrothermal fluid, the surrounding sediment and the microbial community are also part of the environmental investigations conducted by BGR and its partners. Biodiversity studies include species composition, distribution and abundance of both the benthos and plankton. The investigation of benthic species at active, inactive and non-vent species are realized for the mega-, macro- and meiofauna and planktonic studies comprise phyto- and zooplankton. Ecological and connectivity investigations are mainly based on molecular and genetic methods such as (meta-)barcoding, RADs and eDNA. This way, for instance, connectivity studies on the megafauna species *Rimicaris kairei*, the macrofauna genus *Sutilizona sp.* and the meiofauna species *Stygiopontius sp. 1* have been carried out. Habitat mapping based on photo annotation and sampling have aimed to understand the faunal assemblages, zonation patterns and structuring factors of active, inactive and non-vent sites and to distinguish biogeographic provinces along the southern CIR and the northern SEIR.

Report on background information of the hydrothermal vents and habitat classification in the Indian Ocean

Yadong Zhou

Mr. Zhou reminded that given that biological data in both the Indian Ocean Ridge (IOR) and the Central Indian Ocean Basin (CIBO) are scarce, methods applying concepts of environmental proxies of species distributions are urgently needed to inform spatial management within these areas. Habitat classification has been proved to be a powerful tool guiding marine seabed spatial planning for data-poor regions. The presenter showed the results from habitat classification on the IOR and in the CIBO, using a non-hierarchical k-medoids technique. Environmental factors used in analyses include topographic variables, particulate organic carbon flux and physical/chemical characters of bottom water. Preliminary outputs

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[9] ISA. Sustainable Seabed Knowledge Initiative. Available at: https://www.isa.org.jm/sski.

[10] ISA. AREA2030: Facilitating the high-resolution mapping of the international seabed area by 2030. Available at: https://www.isa.org.jm/area-2030.

are checked and further modified based on either similarity among habitats, proximity to one another, areas or combined. As a result, we identify a total of 14 habitat types along the IOR and in the CIBO, with three types on the Carlsberg Ridge, five on the CIR, 10 on the Southwest Indian Ridge (SWIR), seven on the SEIR and five in the CIBO (Figure 1). Areas showing frequent habitat transitions are marked, especially those featured by dense fracture zones, such as those on the SWIR and northern CIR, exhibiting the highest spatial heterogeneity. This indicates that these areas may have the highest priority for future surveys.

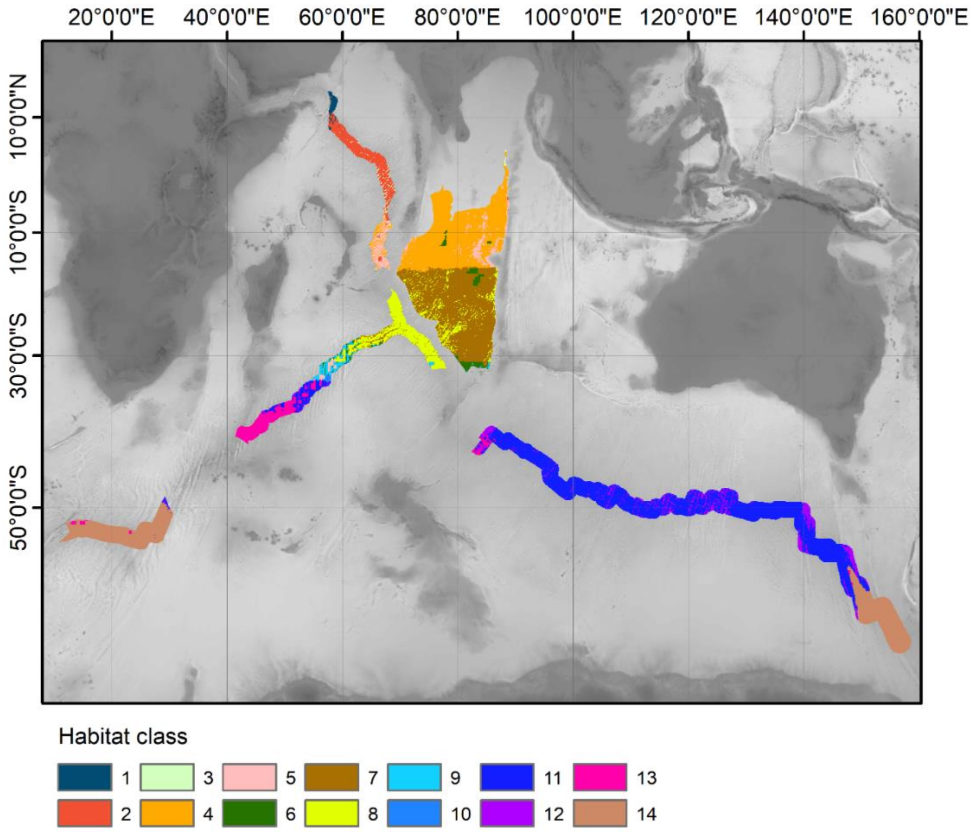

Figure 1. Habitat types along the IOR, the CIBO, the Carlsberg Ridge, the CIR, the SWIR, the SEIR and the CIBO

Environmental baseline studies for preparing the REMP in the Indian Ridge System

Baban Ingole

Mr. Ingole reminded that ISA has issued four contracts for the exploration for PMS deposits in the Indian Ocean, which led to the discovery of 15 hydrothermally active sites with a high abundance of vent-associated biota. Most of the vent fauna have symbiotic relations with a vent-specific bacterial community and, therefore, are restricted in their distribution. Moreover, some benthic species have a marked endemicity to a particular vent site. Consequently, understanding the diversity, abundance, biomass and community structure of the vent-associated biota and their role in ecosystem functioning becomes critical to assessing the impact of proposed sulphide mining on these understudied yet ecologically significant communities. The National Centre for Polar and Ocean Research (NCPOR), under the aegis of the MoES, Government of India, is the nodal agency for deep-sea mineral explorations. Under India's 15-year contract with ISA for the exploration for PMS in the Indian Ocean region, NCPOR has undertaken four exploration cruises since 2016 to carry out exploration activities and generation of baseline environmental data in the Indian contract area. The physical characteristics of the water column (temperature, salinity and turbidity) did not change on a temporal scale. The dissolved oxygen concentration showed minimum values at around 1,200 to 1,300 m water depth. The enrichment of dissolved nutrients was in the mid-depths (1,200-1,300 m). The total prokaryotic count (bacterial) increased vertically in the water column. Proteobacteria was the most abundant bacterial phylum, constituting 25-90 per cent of bacterial abundance. The diversity of phytoplankton and zooplankton was higher in the top 100 m. The study on benthic macro- and megafauna identified over 80 faunal species, including nine new species (four sponges, three corals and two lobsters). The diversity of sessile fauna was relatively higher in the seamount regions. Environmental data generated from this study can be useful in the conservation and management of the biodiversity of the deep Indian Ocean.

Korean exploration activities for PMS in the CIR: environmental studies

Junguk Kim

KIOST has carried out an exploration programme for PMS in the CIR since 2009. Investigation of hydrothermal activity in the middle CIR between 8°S and 17°S, in the Korean contract area, revealed that hydrothermal plumes indicated through an anomaly of turbidity and/or dissolved methane were most commonly associated with the asymmetrical ridge sections where ultramafic massifs formed along one ridge flank near ridge-transform intersections or non-transform offsets. However, the long-term magmatic budget of the middle CIR is still the primary control on the spatial frequency of hydrothermal venting at this slow-spreading ridge. We identified 11 active and inactive PMS deposits at the locations of hydrothermal activity within the exploration area. During the exploration, we collected physical, chemical, geological and biological oceanographic data for environmental baseline studies. Some of our recent studies on vent fauna, including food web analysis, population genetics and phylogenetics, have increased our understanding of the biogeography of hydrothermal vent organisms in the CIR area. However, further effort to collaboration among the contractors and other research groups interested in the Indian Ocean is needed to understand the impact of future mining activity and to establish appropriate EMPs.

Environmental Studies Conducted by ISA contractors in the Indian Ocean: Government of India – PMN, Samir Damare

The Environmental impact assessment for PMN mining (PMN-EIA) is a programme funded by the MoES, Government of India, implemented at CSIR-NIO, Goa, India since 1996. The work is undertaken in different phases: determination of baseline oceanographic conditions in the nodule area and identification of test of reference areas, deployment of a benthic disturber to create the disturbance and simulate ocean mining, collection of environmental data for monitoring the effects of disturbance and environmental variability in the potential mining area, collection of baseline environmental data in the impact reference zone (IRZ) and preservation reference zone (PRZ) areas as per the revised ISA guidelines. In the pre-contract period (1996-2002), three expeditions were undertaken. In the second phase, two cruises were undertaken on-board the Russian vessel R.V. Yuzhmorgeologiya in 1997. The first cruise was to conduct pre-disturbance studies. During the second cruise, the benthic disturbance was created. The benthic disturbance was created with 26 tows of 47.5 hours along 88 km within a 3x0.2 km strip on a relatively flat seabed, displacing about 3,594 tons of sediment. The first (2002-2007) and the second (2007-2012) contract periods were dedicated to collecting the environmental variability data in the Pioneer area. The third contract period (2012-2017) was used to collect baseline environmental data in the identified IRZ and PRZ. The data collected is a result of 14 expeditions in the area from 1996 to 2017. In the current period, additional baseline data is collected as per the revised LTC guidelines. In the same period, deep-sea moorings have been deployed in the area to collect data over one year, along with sediment traps, to understand the sediment fluxes in the area. Most importantly, a huge number of samples have been collected for understanding the genetic connectivity at both micro and macro levels for benthic as well planktonic life forms.

Approaches for spatial planning

Patrick N. Halpin

Mr. Halpin presented an overview of spatial planning approaches and described the relationship between spatial and complementary non-spatial approaches. The presenter began emphasizing the results of the previous REMP workshops. He described the potential interaction between broader-scale cumulative impacts analysis, area-based management and finer-scale adaptive management approaches. He also described criteria-based approaches, noting that the selection of areas for protection in spatial planning is often based on criteria that must be interpreted through quantitative regional analysis and/or qualitative scientific expert judgment. These criteria may be applied to attributes or properties of individual species, ecological communities, habitats or broader ecosystems. The application of the criteria may also focus on the inherent attributes of species or habitats or their vulnerability to disruption or damage. In this regard, the differences between site-level and network-level criteria were presented. Next, the presenter described two approaches to applying ABMTs: a coarse-filter approach, which targets the representation of broad ecosystem features and gradients and a fine-filter approach, which targets unique sites that may be of particularly high values or at particularly high risk. He suggested that the current interpretation of APEIs is an example of a coarse-filter approach and that this type of ABMTs could be augmented with the inclusion of fine-scale sites in need of protection (SINPs). He also suggested that a purposefully configured mixed portfolio, combining large areas to protect and buffer intact gradients of habitats augmented with specific SINPs, may provide the most flexibility to satisfy both mining interests and protection needs. Lastly, he noted that a portfolio of ABMT areas could include areas of increased precaution or other categories of use in addition to closure areas. These areas could require more intensive pre-use exploration, mapping and monitoring. Finally, Mr. Halpin highlighted that defining the appropriate biogeographic spatial extent of a REMP is a fundamental step in the planning process. Defining tractable evaluation criteria for assessing different ABMT network configurations (size, spacing, placement) will also be key to REMP planning. Increased spatial precision will require increased data coverage and detail, which have implications for adaptive management. An adaptive management approach will likely be required to anticipate changes in data and knowledge, new technologies and contract area relinquishment.

Developing cumulative impact assessments

Piers Dunstan

Mr. Dunstan began his presentation by introducing the basis for adaptive management, which has three key components: (1) a clear understanding of objectives and desired outcomes, (2) an assessment process that includes all potential positive and negative effects of development and (3) a monitoring programme that can test this assessment and ensure that the desired outcomes are achieved. The presenter described the process used to assess cumulative impacts and the data needed to support this. He also emphasized that understanding the effects of cumulative impacts in a region is a multi-tiered process, which requires the description of the distribution of key ecosystems, key effects on the ecosystems, and then understanding how these components interact. He noted that qualitative models represent a working hypothesis about how an ecosystem works. They should: a) identify the important components and processes in the system, b) document assumptions about how these components and processes are related, c) identify the linkages between these components/processes and anthropogenic pressures and d) identify knowledge gaps or other sources of uncertainty. The presenter explained how the participants would construct conceptual models during the workshop. This process includes first identifying the bounds of the system of interest, key model ecosystem components and subsystems, and natural and anthropogenic pressures, then describing relationships of stressors, ecological factors and responses. The presenter provided an example of previous work on developing qualitative models to assess the potential risks from future mining operations in the region of the northern MAR. Mr. Dunstan concluded his presentation by highlighting that the outputs of the models can be used to develop monitoring questions (e.g. what will be impacted, by what pressures and over what timescale) and identify the best indicator species/groups.

Annex III

Summary of discussion on review, analysis and synthesis of relevant scientific data/information/maps relating to the marine environment, biodiversity and ecosystem patterns in the Indian Ocean

A. Summary of break-out discussion relating to the geological aspects of the marine environment in the Indian Mid-Ocean Ridges and Central Indian Ocean Basin

Participants discussed the scientific information that could be used to identify the geographical scope of the REMP. It was noted that existing contract areas for the exploration of seabed mineral resources in the Area of the Indian Ocean are distributed in both the Indian Ocean Basin and along the three Indian Mid-Ocean Ridges. The ridges and the basin present markedly different geomorphological characteristics. The basin presents a flat abyssal-plain-type morphology, soft sediment habitat broken intermittently by volcanic seamounts and PMNs related to steady hydrogenetic and diagenetic mineral growth processes. In contrast, the ridges present slow to intermediate spreading rates with rougher topography, strong morphological gradients, volcanic and exhumed deeper crust exposures and recent sulphide mineral formation and accumulation. In view of the differences in both geomorphological settings, participants initially considered the ridges and basin separately when discussing the parameters for the identification of the potential geographical scope of the REMP, but also noted that an integrated approach may be applied to both the ridges and abyssal plain in a single REMP.

In defining the potential geographical scope of the REMP for the Central Indian Ocean Basin, there was a consensus to use the base of the Ninety East Ridge as the boundary to the east, the SEIR as the boundary to the south, the outer limits of continental shelves of coastal countries as the boundary to the north and the CIR as the boundary to the west.

In defining the potential geographical scope of the REMP for the Indian Mid-Ocean Ridges, discussions built on the approach developed for the draft REMP for the northern MAR. The geographical scope for the draft REMP for the northern MAR extends 100 km on each side of the ridge axis to cover the ridge flanks and the possible range of potential environmental impacts from future exploitation activities. In addition to the 100 km distance from the ridge axis, it was proposed that the age of the crust should be an important parameter for defining the boundary of the ridge systems. This is because hydrothermal activity mostly occurs in the first 10 million years, according to crustal heat and magmatic activity along spreading centres. The crustal age is determined by the respective magnetic anomaly in the oceanic crust.

Participants also discussed the types of geological data that can be used to inform the identification of ABMTs. For the Central Indian Ocean Basin, it was noted that data are available for bathymetry, age and structure of the oceanic crust, general geology of the area, as well as nodule abundance and size distribution. Available scientific information related to oceanography in the region has been compiled in the draft Data Report. In line with ISA guidance, contractors have been collecting data, such as those related to bathymetry, nodule abundance, primary productivity, sedimentation rate, particulate composition, nutrients and sediment properties.[11] A large number of CTD data have also been collected by contractors and submitted to DeepData. Outside the contract areas, numerous data are available and have already been compiled in the draft regional environmental assessment, covering 73-81°E, which extends beyond the contract areas.

Some data types were identified as a potential gap for parts of the Central Indian Ocean Basin, including data on sediment physical properties, sedimentation rate and backscatter data. Sedimentation rate is considered a proxy for biological productivity in the benthic environment. Not much information is

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[11] See ISA. 2023. Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area: Issued by the Legal and Technical Commission (ISBA/25/LTC/6/Rev.3).

available at the basin scale, but some data is available for the contract areas. Some information on sedimentation will be retrieved from the moorings currently deployed in the contract areas, and additional information can be retrieved from box core samples. Data on sediment physical properties, such as pore water, are available but possibly need to be extended and integrated. Backscatter data are available only locally and are important for defining habitat distribution given the incomplete sediment coverage, leaving a patchy distribution of hard rock exposures. It was noted that the collection of new backscatter data at the scale of a thousand kilometres requires an enormous effort.

Participants also discussed the availability of data for the three Indian Mid-Ocean Ridges. Participants agreed to adopt a common approach for spatial planning for all ridges. The coverage of high-resolution mapping is high in the four PMS contract areas and reasonably good outside them. For the data on magnetics and spreading rate, the coverage is high. For data on sediments, some are available but the existence of significant gaps was also recognized by participants. There is a need to collect sediment samples inside and outside the contract areas where possible and at some distance from the spreading ridge to estimate the local productivity. The patchy sediment in the ridge crest region can be described by backscatter data.

The seismicity data on ridge systems are available from existing databases and need to be integrated in the Data Report. In particular, it would be important to retrieve the more precise data set from the Hydroacoustic Observatory of the Seismicity and Biodiversity in the Indian Ocean, a long-term hydroacoustic programme for monitoring the seismic activity and the vocal activity of large marine mammals in the southern Indian Ocean.[12] Some contractors have mapped the bottom substrate (talus, hard rock, sediment) based on multibeam data with some ground-truthing through sample collection. Lithological characteristics and geochemical data can be derived from the PetDB database. Some contractors also mapped the structural (tectonics) patterns (density, direction) in their contract areas. Public databases and scientific publications deliver structural analyses for the ridge areas. Satellite and ship-borne gravity data have been completed for some contract areas and can be added to the regional environmental assessment report.

For physical and chemical data on some of the known vents, it was noted that data on fluid temperature and composition can be retrieved from the public INTERRIDGE database. It is suggested to upload any new data to the INTERRIDGE database.

An important discussion ensued on how to define the parts of a hydrothermal system and its limits. Participants reached consensus on the following:

- The term “hydrothermal system” indicates the whole system, including the geological deep structure, the heat source (dike or magma chamber), the faulting and tectonic system, along the recharge and discharge zone of the hydrothermal cell (~15 km).
- The attribute “field” should be used for the surface expression only. Hence, vent fields occur on a scale of 10-1,000s metres, vent sites occur on a scale of 10-100s metres and chimneys or diffuse venting occurs on a scale of 1-10s metres. Vent fields, vent sites and chimneys, therefore, occur in decreasing size.
- A vent field may comprise several vent sites. A vent site comprises mounds and chimneys or a cluster of chimneys and/or diffuse venting. Geometrically separated vent sites cluster to form a vent field.
- A hydrothermal system can host different vent fields. For example, a single recharge zone can supply two distinct vent fields along with two different fault systems.

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[12] Jean-Yves Royer. 2009. OHA-SIS-BIO: Hydroacoustic Observatory of the Seismicity and Biodiversity in the Indian Ocean, https://doi.org/10.18142/229.

An observation was made on the fast growth rates of chimneys, measured at a scale of several centimetres per day, resulting in constant changes to the site's morphology and local habitats.

Concerning the definition of hydrothermal activity versus inactivity and related scale, a consensus was reached to use parameters introduced in Jamieson & Gartman 2020 to define active and inactive sites.[13] Participants considered that given the dynamic nature of the hydrothermal system, mining an inactive site close to an active site will introduce the need for monitoring the activity of the active sites. It was considered technologically challenging to mine sulfides from hydrothermally active sites.

There was a suggestion to define "extinct" vent sites (or fields) as the sites that, based on the best available knowledge, cannot be reactivated as interpreted from geological considerations. The background heat flow in the area containing the field is an important parameter that possibly needs to be measured. A suggestion was made to use micro-seismicity to define the boundaries of a hydrothermal system and a hydrothermal field. Ocean Bottom Seismometer surveys were suggested.

Discussions also ensued on the interpretation and application of the precautionary approach, considering the dynamic nature of natural hydrothermal activity and the difficulty in defining active and inactive sites. One suggestion was to consider any vent site or field as active if at least one chimney or diffuse venting occurrence is found to be active. Long-time vent monitoring was suggested to help define the local hydrothermal activity.

Participants also noted that the detection of a natural hydrothermal plume over a contract area might not necessarily mean that the source of the natural plume is located within the contract area.

B. Summary of break-out discussion relating to the biological and oceanographical aspects of the marine environment in the Indian Mid-Ocean Ridges and Central Indian Ocean Basin

Participants focused on the availability, sources and spatial and temporal coverage of biological and oceanographical data. Since the draft regional environmental assessment was incomplete, the group concentrated on determining what key data sources were available to inform future consideration of REMP-scale patterns and where there were major gaps.

An overview of sampling efforts and data availability is presented in Table 1. It was noted that the availability of data varied among different categories of environmental variables, locations in the region and biological taxa. Pelagic taxa are poorly studied compared to benthic communities. Most biological studies are focused on the contract areas, with gaps in sampling, especially along parts of the ridge systems and outer regions of the Central Indian Basin. Progress in taxonomic identification varies with taxonomic level.

In general, more data is available on the spatial patterns of environmental variables and biological communities than on the temporal (annual or seasonal) patterns. More efforts will be needed to improve understanding of the scale of temporal variability.

For the use of image data, the role of curated libraries such as BIIGLE was highlighted, as well as the need for further standardization of such data and consistency in the image IDs between contractors and international science efforts.

There was an important discussion around genetic connectivity for vent fauna, the extent to which such connectivity exists across different Indian Mid-Ocean Ridges and how this differs between species. Information on the genetic connectivity of non-vent taxa is sparse and only became available recently

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[13] Jamieson, J.W., and A. Gartman. 2020. "Defining Active, Inactive, and Extinct Seafloor Massive Sulfide Deposits." *Marine Policy* 117 (July). Elsevier BV: 103926. doi:10.1016/j.marpol.2020.103926.

through several publications and the development of global-scale modelling. It is not known if connectivity is present beyond contract areas.

Given the limited availability of biological data, the use of environmental proxies and habitat modelling was considered a useful and necessary starting point for assessing the spatial distribution of representative habitats. Various biogeographic classifications were discussed and considered useful at the regional scale (see Table 1).

Environmental factors to be considered in defining the geographical scope of the REMP were identified, including the age of the crust (an indicator of hydrothermal activity), the spatial distribution of habitats (based on biogeographical classification and ongoing studies on habitat suitability/species distribution modelling) and the spatial extent of potential environmental impacts from future activities.

Knowledge gaps for environmental proxies with implications for the REMP development were considered, such as sedimentation rates and POC flux (indicators of biological productivity), sediment thickness (indicator of nodule density and distribution of nodule-associated species), backscatter data (indicator of substrate type), depth distribution (indicator of habitat variability) and current flows near the sea floor.

There was also a discussion on potential collaboration among ISA contractors, including on the standardization of image data and future connectivity studies, which would contribute to addressing some of the knowledge gaps identified.

Table 1. Overview of sampling effort and data availability for selected environmental variables in the Indian Ocean

Parameters	**Wider Indian Ocean**	**Central Indian Basin**	**Carlsberg Ridge**	**Central Indian Ridge**	**South West Indian Ridge**	**South East Indian Ridge**	**Comments**
Primary productivity/ phytoplankton	Chlorophyll concentration (annual mean, 2012-2021), Mercator Ocean; IIOE data available for Phyto- and Zooplankton	Good spatial-temporal variability issues; some sampling outside ISA contract area and results indicate limited spatial variability in the patterns of productivity	Limited field measurements; data available from remote sensing	Remote sensing data available for contract area	Remote sensing data available for contract area	Remote sensing data available for contract area	DeepData hosts data submitted by contractors; primary productivity composition variable; Global patterns of primary productivity can be inferred from remote sensing data globally
POC flux	Lutz model (Lutz et al. 2007)	3 moorings have been deployed (2 inside the contract area, one outside the contract area (NIO))	Time series data have been collected and are under review (SIO)	BGR: 2 sets of moorings (2014-present), results indicate low nutrients		BGR: 2 sets of moorings (2014-present), results indicate low nutrients	
Zooplankton (and consider depth stratification)	IIOE NIO Goa; Weekly data available (mean for 1 year) of surface zooplankton (5° resolution)	1996 onwards, reasonable spatial coverage (NIO). 2 stations, vertical sampling of zooplankton by KIOST	1-2 multi-net <3000m-limited stations (research team from India)	NCPOR-India <100m; ROK max 1000m; BGR: multi nets deployed in 2019 covering full depth; CTD Niskin bottle (since 2013)	South Africa data (copepods); NCPOR-India <100m; COMRA: multi net <1000m	BGR: multi nets deployed in 2019 covering full depth; CTD Niskin bottle (since 2013)	Data available but limited spatial and temporal coverage; sampling focus on vent-associated zooplankton rather than more generic; SIOFA and IOTC may have important data; need to differentiate between pelagic and benthic fauna.
Micro-organisms	OBIS records	NIO – sediment samples; from 2015 water column – inside and outside contract area – counts + bacteria; from 2019 eDNA	Limited	Water column (Indian institute); KIOST- water column + sediment; BGR sediment+ symbiotic and water column	A number of papers are available, including from NIO; Studies conducted by COMRA and the research team from India	BGR: sediment + symbiotic and water column	More spatial coverage than temporal; IIOE (NIO, the resolution needs to be checked).

Parameters	Wider Indian Ocean	Central Indian Basin	Carlsberg Ridge	Central Indian Ridge	South West Indian Ridge	South East Indian Ridge	Comments
Meiofauna	OBIS records	NIO -BC+MC 50cm; mostly morphological ID + genetics starting (NIO, available in ISA DeepData)	Limited coring (research team from India)	BGR: MC+push core+ slurp across contract area with limited temporal series; same for KIOST;	COMRA: few MC; Multiple scales, tasks and much of the data submitted to DeepData and published	BGR: MC+push core+ slurp across contract area with limited temporal series; same for KIOST;	Sample processing and analysis vary with taxonomic level; variable species ID for "extinction risk" assessment; more data available for abyssal plain areas but limited for the ridges.
Macrofauna	OBIS records	BC+MC 50cm; mostly morphological ID + genetics starting (NIO, available in ISA DeepData)	Same as above for meiofauna	Same as above for meiofauna	Same as above for meiofauna	Same as above for meiofauna	Information variable between faunal groups and with area-as per meiofauna.
Megafauna (benthic)	OBIS records	NIO imagery (see draft REA report) - spatially limited	A research team from India – image limited (non-vent); COMRA – some available	KIOST: image and genetics; BGR: active and inactive sites images and samples	SIOFA report (non-vent) ; COMRA : vent samples published ; vent fauna composition	BGR: active and inactive sites images and samples; non-vent samples and images, less coverage	BIIGLE – should use as standard; curated library; consistency in image ID variable; temporal gaps in some areas; consider Alex Rogers + SCOR programmes in WIO. Temporal gaps in some areas (in particular non-vent),
Megafauna (pelagic + Nekton)	OBIS records (often occurrences of certain species; migratory routes, feeding/breeding areas etc. availability depends on taxon); OBIS Seamap; ocean tracking network; whale.org; SIOFA Report and IOTC						Dughal Lindsay – Jellyfish database; Shark and Ray areas (publication in preparation =>next year).

Parameters	Wider Indian Ocean	Central Indian Basin	Carlsberg Ridge	Central Indian Ridge	South West Indian Ridge	South East Indian Ridge	Comments
Trophic relationships				KIOST: - isotope ratios for one vent; Kairei field (Cindy van Dover); BGR: vent fauna in Kairei vent field	Data collected by various authors (John Copley; Alex Rogers) COMRA: Longqi vent field; John Copley: study on Cephalopods		Look at Alex Rogers's programme on seamounts; available through publications, although typically site-limited; some seabirds + pelagic information.
Connectivity		Bacteria + eukaryotic genetic samples > 300, sediment top 50 cm + surface to bottom; not much larger fauna	Zhou et al. 2022 ; CR, CIR, SWIR	ICA : eDNA zooplankton +megafauna NV ; Zhou et al 2022 ; BGR-meio/macro/mega-CIR-SEIR, more data for vent fauna than non-vent fauna	Copley et al 2016; Zhou et al 2022	BGR-meio/macro/mega-CIR-SEIR, more data for vent fauna than non-vent fauna;	Encourage collaboration among contractors; refs in COMRA report; western Indian Ocean – larval dispersal for a wide range of fauna (pel+bent); 100km connectivity "benchmark" from analysis by Amy Baco; not known if connectivity is present beyond contractor areas, which is considered a knowledge gap; For vent taxa, whether connectivity exists across ridges or not depends on the species.
Ecosystem structure and function				KIOST: carbon source to define ecosystems;			Habitat-forming species information is available (modelled); A number of key functional aspects unknown (e.g.

Parameters	Wider Indian Ocean	Central Indian Basin	Carlsberg Ridge	Central Indian Ridge	South West Indian Ridge	South East Indian Ridge	Comments
							respiration? Metabolic profiles? Enzymes? Nutrient cycles; bacterial functions) Particle transport and flux, some parameters already measured; Qualitative modelling of cumulative impacts being done in this workshop; What scale and what functions should be prioritized for modelling? => 100km or 10 km or 1 km?; Bacterial metabolic functions can be progressed through indirect modular studies.
Biogeography	SIOFA report; biographic provinces (CSIRO report); OBIS/GBIF	SIOFA report;	Zhou et al. 2022 ; CR, CIR, SWIR	Zhou et al. 2022 ; CR, CIR, SWIR	Zhou et al. 2022 ; CR, CIR, SWIR		Biogeography limited by taxonomy; CSIRO for Indian Ocean wide scales for certain taxa => coral modelling, etc.
Environmental drivers/proxies	POC, sediment types/sediment geochemistry, topography, nodule/resource density, bottom temperature and dissolved oxygen, nutrients, but maybe not at the large-scale	POC (small-scale measurements, well-established relationship between POC and benthic fauna abundance);	Substrate structure; multibeam backscatter data; topography and vent distribution; geological properties and hydrothermal fluid chemical composition	Substrate structure; multibeam backscatter data; topography and vent distribution; geological properties and hydrothermal fluid chemical composition;	Substrate structure; multibeam backscatter data; topography and vent distribution; geological properties and hydrothermal fluid chemical composition.	Substrate structure; multibeam backscatter data; topography and vent distribution; geological properties and hydrothermal fluid chemical composition	Regional data available from the remote sensing data (indicators of nutrients); foraminifera as an indicator of biodiversity in nodule areas. For non-vent fauna, in general, topography

Parameters	Wider Indian Ocean	Central Indian Basin	Carlsberg Ridge	Central Indian Ridge	South West Indian Ridge	South East Indian Ridge	Comments
				BGR and KIOST: possible correlation between community composition and fluid chemistry	COMRA study on fluid geochemistry		and substrate are important. For vent fauna, we need more backscatter data.
Currents (at different depths)	OSCAR data (surface 0.25degree, monthly scale); Mercator – modelled data depth layers; Argo 2005 onwards	Limited data on bottom currents (single point, from 2021 more sampling using ICA); ADCP (1 or 2 cruises, limited temporal and spatial scale)		BGR: CTD and moorings ADCP, sediment traps		BGR: CTD and moorings ADCP, sediment traps	Turbidity a common driver; WOCE data available 1990-1995
Water masses	SIOFA report has environmental data; OISST						Geotraces
Fisheries, water masses, IMO, cable lanes etc	IOTC, SOIFA, Global Fishing Watch (total fishing hours plus individual gear type), SWIOFC						
Biogeography	GOODs (abyssal and bathyal) Sutton et al. (mesopelagic); Longhurst epipelagic, Spalding et al. 2012; CSIRO report and SIOFA VME data (benthic)						Some reasonable large-scale (provinces) classifications by depth.

Abbreviations: ADCP: Acoustic Doppler Current Profiler. BC: box corer. IIOE: International Indian Ocean Expedition. IOTC: Indian Ocean Tuna Commission. OSCAR: Observing Systems Capability Analysis and Review tool, World Meteorological Organization. NCPOR: National Centre for Polar and Ocean Research, MoES, Government of India. MC: Multi-corer. SIO: Second Institute of Oceanography, Ministry of Natural Resources, China. SIOFA: Southern Indian Ocean Fisheries Agreement. SWIOFC: Southwest Indian Ocean Fisheries Commission.

Annex IV

Results of break-out group discussion on qualitative modelling for cumulative impacts assessment

A. Introduction and general description of qualitative mathematical modelling approaches for assessing cumulative impacts

Workshop **discussions** on this subject were guided by a strategy of model building that recognizes a practical trade-off between realism, generality and precision when building models of complex systems (Levins 1966, 1998). To obtain a manageable model, one typically sacrifices one attribute for the other two (Figure 2). Qualitative process models emphasize generality and realism but lack precision, while quantitative process models can be both precise and realistic but are not generalizable (i.e. application of the model to changed circumstances requires reparameterization). A third approach is through statistical models, which emphasize precision and generality. In the latter, there are precise insights into the general pattern of correlations among variables, but at the cost of causal understanding of the processes involved. In practice, a robust strategy considers all three modelling approaches, such that models are mutually informative and build upon the strengths and insights provided by each approach.

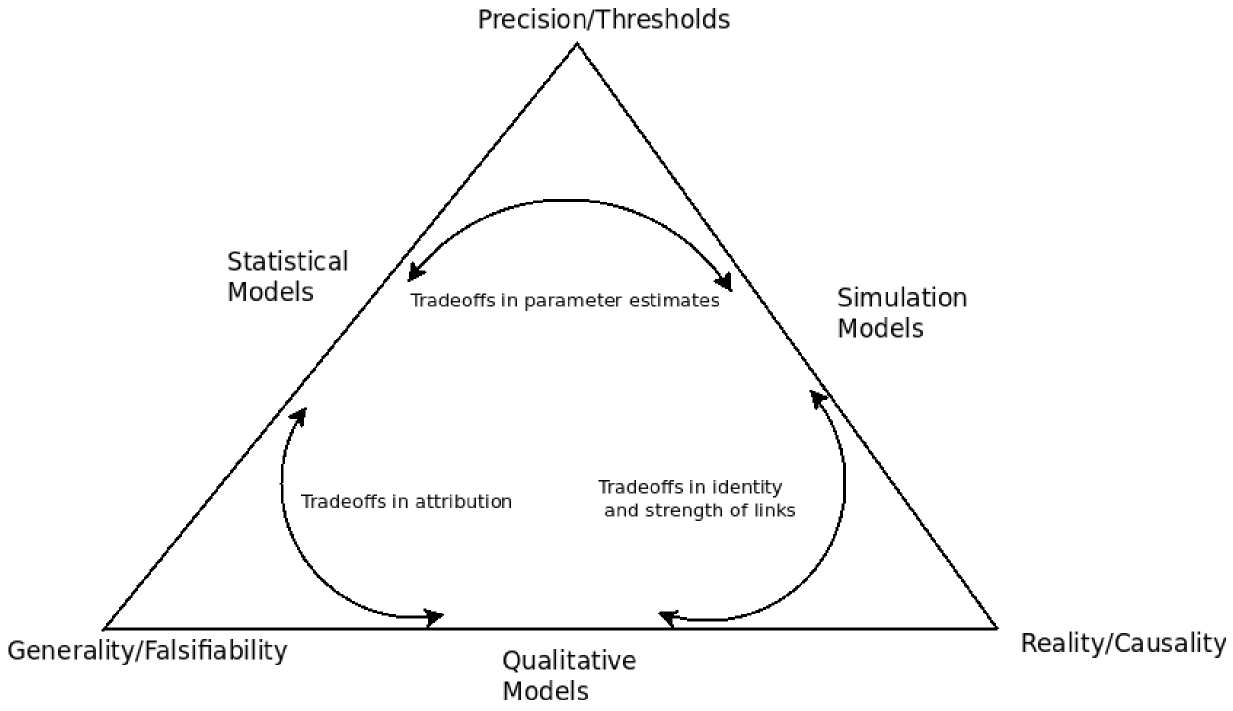


Figure 2. Trade-offs comparison among different types of mathematical modelling approaches

Qualitative mathematical models represent a working hypothesis about how an ecosystem works. They should identify important components and processes in the system, document assumptions about how these components and processes are related, identify the linkages between these components, processes and anthropogenic pressures and identify knowledge gaps or other sources of uncertainty. These models are useful in identifying the potential cumulative impacts of pressures on ecosystem components and the best indicators for those impacts. They can be applied to a very broad range of ecosystems, from coastal marine systems to deep-sea systems (Dunstan et al. 2020).

Steps or tasks in constructing qualitative mathematical models include identifying the bounds of the system of interest, determining key model components, subsystems and interactions, identifying natural and anthropogenic stressors (pressures), describing relationships of stressors, ecological factors and responses and identifying clear knowledge gaps in the system.

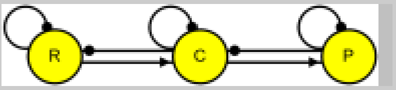
Qualitative mathematical models need to portray the ecological system at a level of resolution that is useful for risk assessment, striking a balance between simplicity and complexity. They should not seek to represent the entire system with myriad components and processes. Rather, they should focus on the dominant processes and feedback that sustain and regulate the main components of interest, along with potential anthropogenic pressures and natural stressors relevant to the ecosystem (Gross 2003; Dambacher et al. 2009).

A qualitative mathematical model is implemented through a partial specification of the system. In a partially specified system, only the qualitative nature of the relationships between variables is specified. Under this approach, the effect of one variable on another can be specified only through the sign of its effect, e.g. positive (+), negative (-) or no (0) effect. Qualitative modelling is based on representing the qualitative nature of the relationships shared between system components and variables (Puccia & Levins 1991). This approach sacrifices precision in model details and predictions but gains a causal understanding of a system that is pertinent to a broad range of contexts and applications (Justus 2005, 2006).

The method of qualitative mathematical modelling is based on the analysis of system structure using signed graphs (Puccia & Levins 1985). A signed digraph is a graphical representation of variables and their interactions, where the nodes or vertices of the graph represent the system variables and the graph edges or links represent both the sign and the direction of the direct effect of one variable on another, i.e. a positive (+), a negative (-) or a null (0) effect. Signed digraph models of ecosystems commonly include trophic interactions. In a predator-prey interaction, the positive benefit to a predator of consuming a prey represents a rate of birth, and the negative effect to the prey represents a rate of mortality (Box 1).

Box 1. Qualitative mathematical models and their analysis

This digraph is a straight-chain system with a basal resource (R), consumer (C) and predator (P). There are two predator-prey relationships, where the predator receives a positive direct effect (nutrition, shown as a link ending in an arrow (□)), and the prey receives a negative direct effect (mortality, shown as a link ending in a filled circle (●—included also are self-effects, such as density-dependent growth.



Prediction of perturbation response

One can predict the direction of change in each variable (increase, decrease, no change) due to a sustained input or pressure to the system. Consider the pressure on the system in the way of food supplementation to the predator that increases its reproductive capacity. The predicted response of C is determined by the sign of the link leading from P to C, which is negative (denoted P —● C). The predicted response of R will be positive because there are two negative links in the path from P to R (P —● C —● R), and their sign product is positive (- x - = +). In this system, there is complete sign determinacy for all response predictions, as there are no multiple pathways between variables with opposite signs.

Based on the qualitative structure of a system detailed in a signed digraph, one can assess the scope or potential for a system to be stable and, if it is stable, how it will respond to a perturbation that shifts the system to a new equilibrium. Under a sudden and small pulse perturbation, a stable system will return to its former equilibrium. Still, if the system is unstable, then it will either be attracted to a new equilibrium in which abundances or values of the variables are shifted to different levels or the system may even collapse, leading to the extinction of one or more components.

A sustained change in a system parameter or a press perturbation will displace the system to a new equilibrium point. This system displacement occurs through a change in the growth rate of one or more input variables, which then creates a series of direct and indirect effects that are transmitted to other variables through the system's network of interactions. Based on the structure of these interactions, one can predict changes in the equilibrium abundances and rate of turnover in model variables. Obtaining a clear description of the interaction structure based on the direct effects of the system enables disentangling complex relationships between variables that can be key when evaluating system response to perturbations. Once the structure of a signed digraph model is defined, it can be analysed to determine predictions for perturbation response (Puccia & Levins 1985; Dambacher et al. 2002, 2003). These qualitative predictions can be assessed to determine their relative potential for sign determinacy. A model variable that receives only positive direct and indirect effects from a perturbation can only have a positive response. If a variable only receives negative effects, it can only have a negative response. Where a variable receives both positive and negative effects, then its response is qualitatively ambiguous. Still, here a probability for the response sign can be determined based on the relative balance of positive and negative effects involved. Dambacher et al. (2002) and Hosack et al. (2008) developed a method to assign probabilities of sign determinacy based on the results of numerical simulations of signed digraph models. For instance, a variable that receives three positive and one negative effect from a pressure will, in computer simulations, have a positive response greater than 90 per cent of the time. Here we use this approach to distinguish completely determined response predictions (sign determinacy equal to 100 per cent) from those that are ambiguous and further identify those with a relatively high probability of sign determinacy set at ≥80 per cent and those with a low probability of sign determinacy (<80 per cent).

Qualitative mathematical models can be created almost entirely from the description of processes and narratives. The scope and bounds of the studied system or problem are first defined, followed by an identification of the components of interest. Variables are chosen with respect to the research or management problem that motivated the formulation of the model. Guiding questions to establishing the relationships between variables include: what is the direct influence of one variable on another, and what else in the system determines the creation or destruction of a variable. In addition to biological variables, model components can also include physical and environmental factors as well as social and economic processes.

Workshops with domain experts and literature reviews are a primary source of system description. Additionally, symbolic analysis of process-based equations can help elucidate interactions that are not clearly defined through a verbal description, as frequently is the case for the self-damping of a variable or modified interactions (Dambacher & Ramos-Jiliberto 2007).

The discussion also benefited from a presentation by Mr. Piers Dunstan (CSIRO), who presented the broader management context for qualitative modelling and the techniques and tools CSIRO has been developing to implement ecosystem-based management (Figure 3), including (i) the ecosystem-based management cycle, (ii) key elements of the assessment process, (iii) qualitative mathematical modelling, (iv) exploitation pressures and cumulative impacts, (v) zones of influence, (vi) linking qualitative models to ecosystem complexes and (vii) linking qualitative models to quantitative estimates of impact to key ecosystem indicator variables.

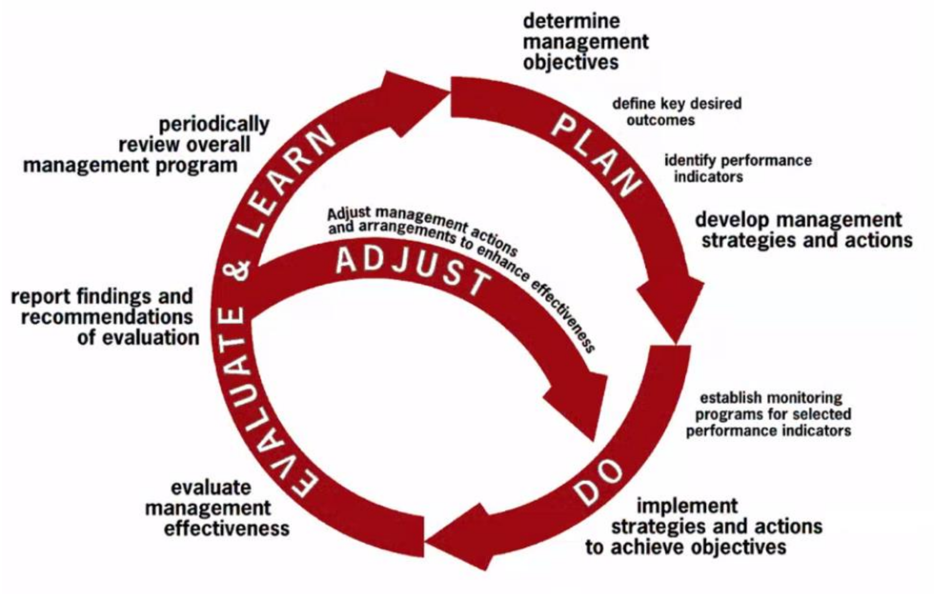


Figure 3. Ecosystem-based management cycle

B. Results of group discussions

Two levels of cumulative impacts were considered for the modelling exercise:

- where a single pressure can have a cumulative impact across multiple ecosystem components in the model, the impact from an initial direct pressure on one ecosystem component is propagated to other ecosystem components through the web of interactions established in the model, showing the expected changes to parts of the ecosystem that are not directly impacted
- where multiple individual pressures are combined into perturbation scenarios, the direct effect of these combined pressures on individual ecosystem components is again propagated to other components through the model, allowing calculation of cumulative impacts to the ecosystem.

This modelling approach enables the identification of pressures that are most likely to cause the largest change, either individually or when combined.

A qualitative model for a hydrothermally active ecosystem, developed during the workshop for the development of a REMP for the MAR, was used as a preliminary model to initiate workshop deliberations. Due to time constraints and considering the recent experience with the development of qualitative models for similar systems, it was considered an effective approach to provide an initial working model that the experts could modify based on their knowledge.

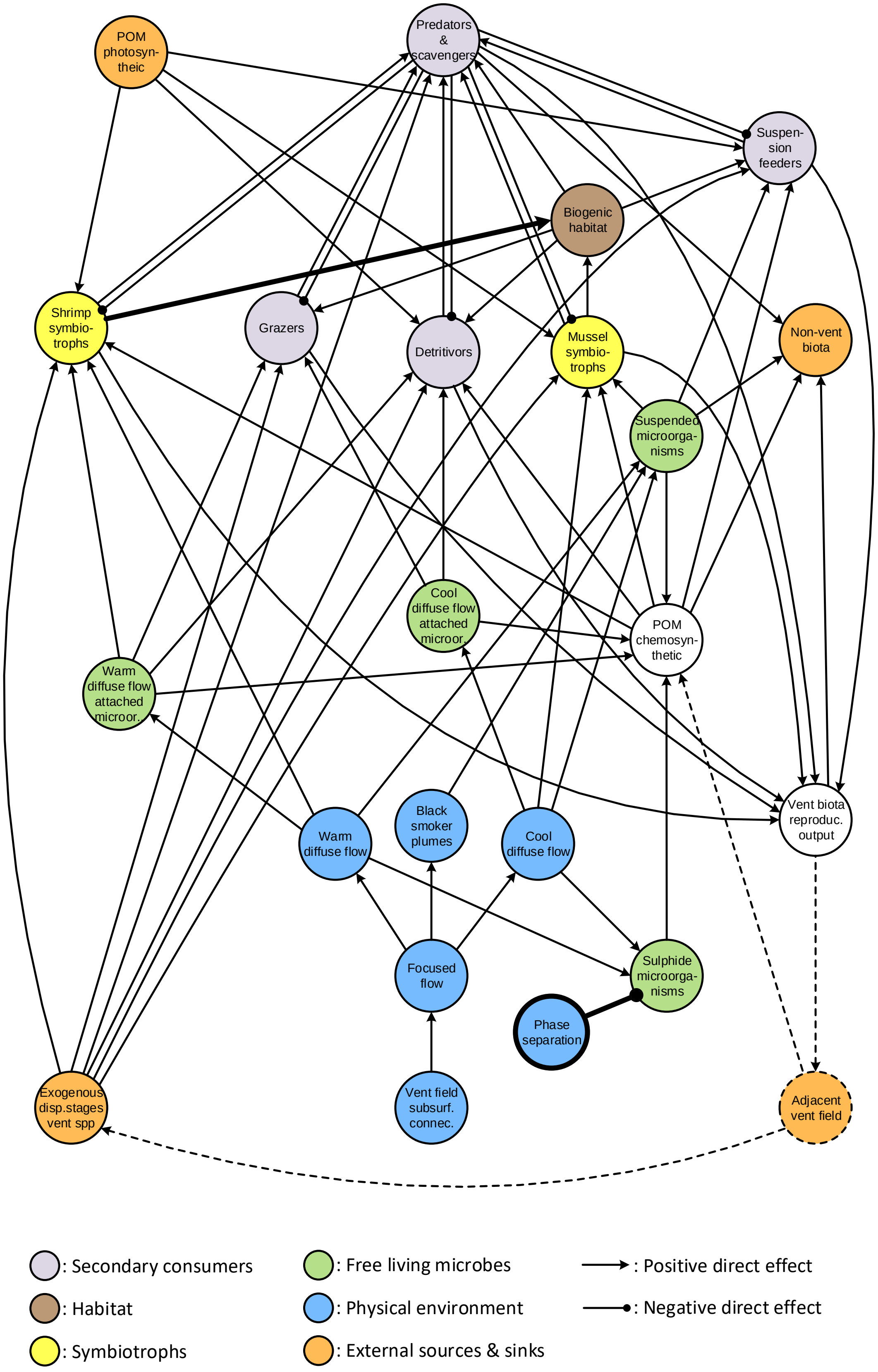

POM photosyn-theic
Predators & scavengers
Suspen-sion feeders
Biogenic habitat
Shrimp symbio-trophs
Grazers
Detritivors
Mussel symbio-trophs
Non-vent biota
Suspended microorga-nisms
Cool diffuse flow attached microor.
POM chemosyn-thetic
Warm diffuse flow attached microor.
Vent biota reproduc. output
Warm diffuse flow
Black smoker plumes
Cool diffuse flow
Focused flow
Sulphide microorga-nisms
Phase separation
Exogenous disp.stages vent spp
Vent field subsurf. connec.
Adjacent vent field
: Secondary consumers
: Habitat
: Symbiotrophs
: Free living microbes
: Physical environment
: External sources & sinks
: Positive direct effect
: Negative direct effect

Figure 4. A qualitative mathematical model for a hydrothermally active vent ecosystem for the Indian Ocean

Note: This model was adapted from that of vents in the MAR. The thick black lines show the additional variables and links as suggested by the workshop participants for the Indian Ocean.

First, an overview of the working model was provided, including a description and classification of model variables, including (i) secondary consumers, (ii) habitat, (iii) symbiotrophs, (iv) free-living microbes, (v) physical environment and (vi) external sources and sinks, followed by a brief overview of the positive and negative direct effects linking the model variables. The physical environmental variables were a significant point of discussion, which included variables of warm diffuse flow, black smoker plumes and cool diffuse flow. There was general agreement with the approach and the model developed for the MAR. Several potential modifications were proposed to adapt this model to the Indian Ocean:

- Phase-separated fluid emanating from a chimney affects the intensity of negative interactions between cold diffuse flow and sulphide microorganisms. This resulted in the addition of a new physical environment variable and link to sulphide microorganisms.
- Habitat structure formed by warm fluid holobionts (e.g. shrimps), which added a link from shrimp symbiotrophs to biogenic habitat (renamed from mussel bed habitat).

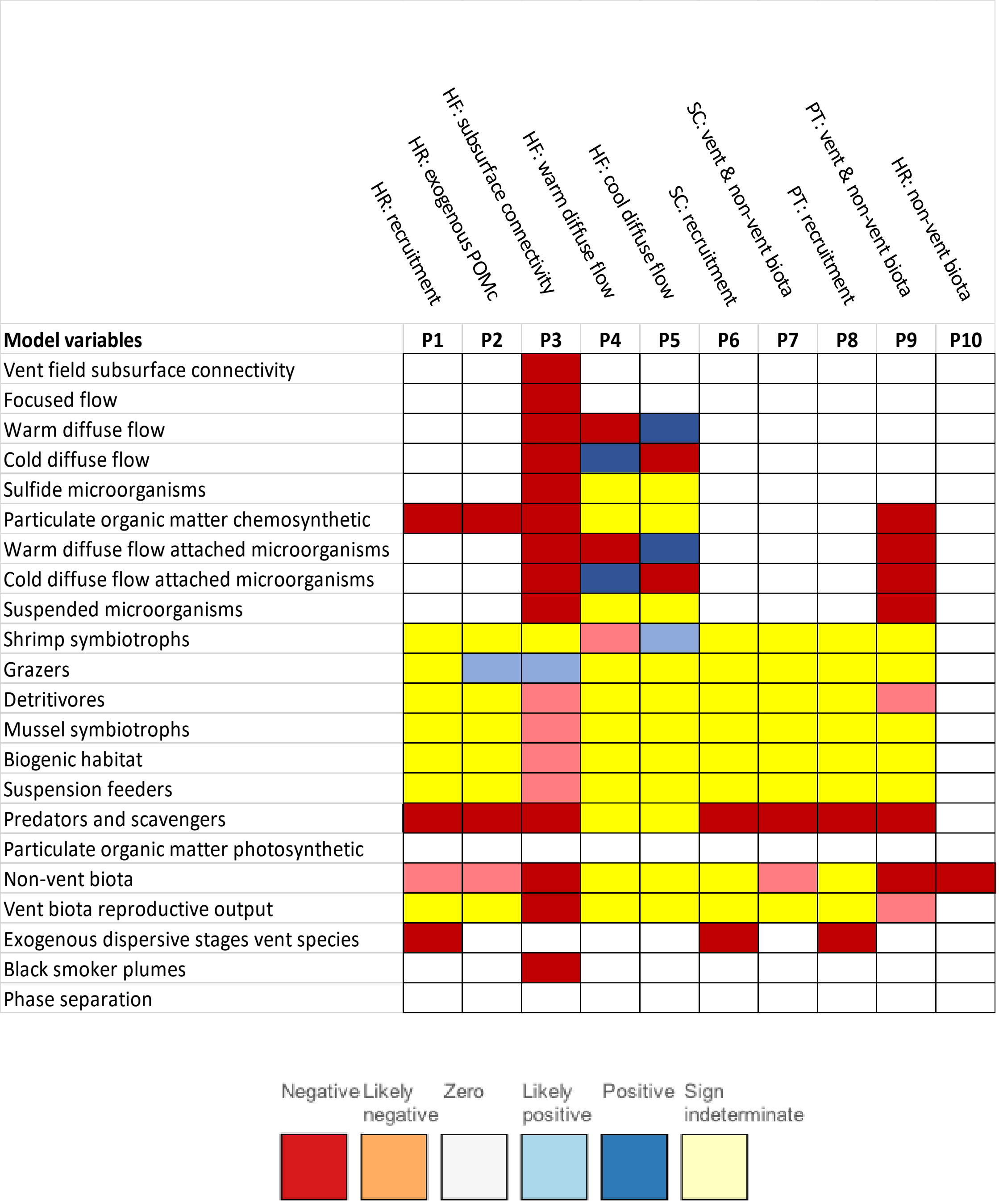
Discussions then moved to the context of mining activities and how they could be represented through a set of possible perturbation scenarios. There was general agreement around the assumption that a vent site that was directly mined would be completely removed and that perturbation scenarios would consider impacts to active or inactive vents in the same field or outside the impacted vent field. Several pressure scenarios were discussed, starting with pressures identified during the REMP workshop for the MAR, including:

- Scenario 1: A single hydrothermally active PMS deposit is exploited. Hydrothermal habitats at unmined locations in the same vent field may experience direct and indirect effects.
- Scenario 2: A single hydrothermally active PMS deposit is exploited. Hydrothermal habitats at unmined locations in a different vent field may experience direct and indirect effects.
- Scenario 3: A single hydrothermally inactive PMS deposit is exploited. There is the potential for the exploited hydrothermally inactive PMS deposit to reactivate and become hydrothermally active. Hydrothermal habitats at unmined locations in the same vent field may experience direct and indirect effects.
- Scenario 4 (new): A single hydrothermally inactive PMS deposit is exploited. Hydrothermal habitats at unmined locations in a different vent field may experience direct and indirect effects.

There was also discussion about the possibility of mining activities increasing vent fluid flows (focused or diffuse) and possibly altering the vent site from inactive to active. This was added as a new fourth scenario.

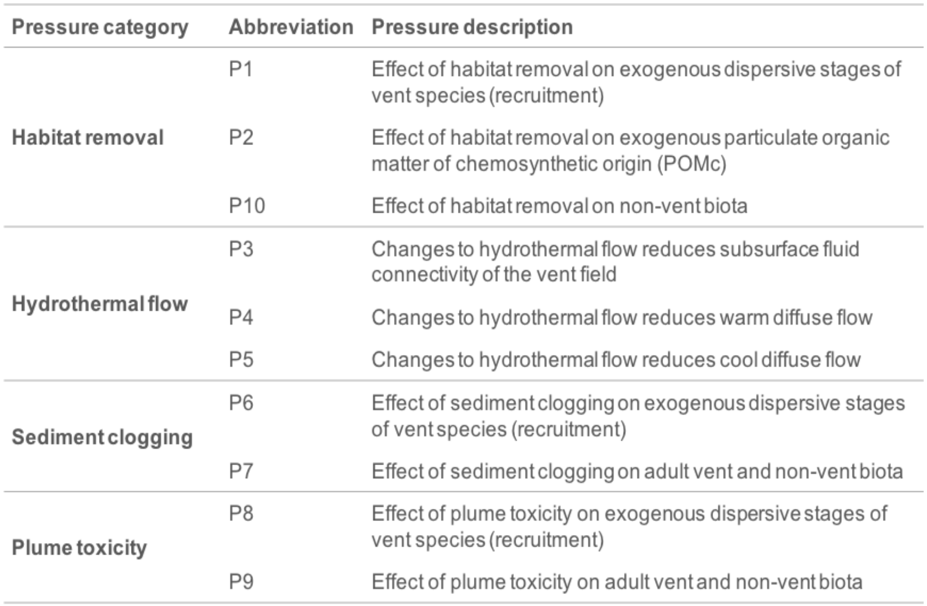
The definition of cumulative impacts was also discussed, with the potential to include pressures that are not associated with mining, such as fishing, climate change and marine litter. There was also a suggestion to consider interactions between different pressures. There were also discussions on several mitigation measures and the need for exploring the spatial footprint of the pressures.

Figures 5 and 6 show the results of qualitative analysis of the 10 pressures and the first three pressure scenarios using the revised hydrothermally active vent model. The fourth pressure scenario has yet to be sufficiently detailed to progress the analysis. The analysis presented in these figures was added after the workshop based on the discussion. Further discussion on the pressure scenarios and interpretation of the model results will be needed in future workshops.



	HR: recruitment	HR: exogenous POMc	HF: subsurface connectivity	HF: warm diffuse flow	HF: cool diffuse flow	SC: recruitment	SC: vent & non-vent biota	PT: recruitment	PT: vent & non-vent biota	HR: non-vent biota
Model variables	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Vent field subsurface connectivity	⬜	⬜	🟥	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Focused flow	⬜	⬜	🟥	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Warm diffuse flow	⬜	⬜	🟥	🟥	🟦	⬜	⬜	⬜	⬜	⬜
Cold diffuse flow	⬜	⬜	🟥	🟦	🟥	⬜	⬜	⬜	⬜	⬜
Sulfide microorganisms	⬜	⬜	🟥	🟨	🟨	⬜	⬜	⬜	⬜	⬜
Particulate organic matter chemosynthetic	🟥	🟥	🟥	🟨	🟨	⬜	⬜	⬜	🟥	⬜
Warm diffuse flow attached microorganisms	⬜	⬜	🟥	🟥	🟦	⬜	⬜	⬜	🟥	⬜
Cold diffuse flow attached microorganisms	⬜	⬜	🟥	🟦	🟥	⬜	⬜	⬜	🟥	⬜
Suspended microorganisms	⬜	⬜	🟥	🟨	🟨	⬜	⬜	⬜	🟥	⬜
Shrimp symbiotrophs	🟨	🟨	🟨	🟧	🩵	🟨	🟨	🟨	🟨	⬜
Grazers	🟨	🩵	🩵	🟨	🟨	🟨	🟨	🟨	🟨	⬜
Detritivores	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟨	🟧	⬜
Mussel symbiotrophs	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟨	🟨	⬜
Biogenic habitat	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟨	🟨	⬜
Suspension feeders	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟨	🟨	⬜
Predators and scavengers	🟥	🟥	🟥	🟨	🟨	🟥	🟥	🟥	🟥	⬜
Particulate organic matter photosynthetic	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Non-vent biota	🟧	🟧	🟥	🟨	🟨	🟨	🟧	🟨	🟥	🟥
Vent biota reproductive output	🟨	🟨	🟥	🟨	🟨	🟨	🟨	🟨	🟧	⬜
Exogenous dispersive stages vent species	🟥	⬜	⬜	⬜	⬜	🟥	⬜	🟥	⬜	⬜
Black smoker plumes	⬜	⬜	🟥	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Phase separation	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

Negative	Likely negative	Zero	Likely positive	Positive	Sign indeterminate
🟥	🟧	⬜	🩵	🟦	🟨

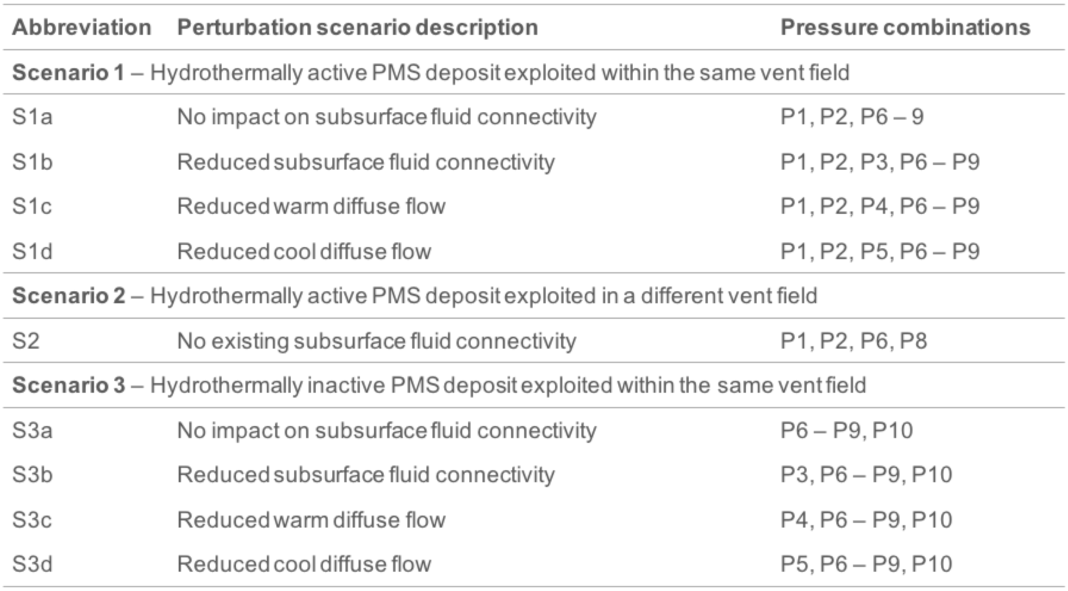


Pressure category	Abbreviation	Pressure description
Habitat removal	P1	Effect of habitat removal on exogenous dispersive stages of vent species (recruitment)
	P2	Effect of habitat removal on exogenous particulate organic matter of chemosynthetic origin (POMc)
	P10	Effect of habitat removal on non-vent biota
Hydrothermal flow	P3	Changes to hydrothermal flow reduces subsurface fluid connectivity of the vent field
	P4	Changes to hydrothermal flow reduces warm diffuse flow
	P5	Changes to hydrothermal flow reduces cool diffuse flow
Sediment clogging	P6	Effect of sediment clogging on exogenous dispersive stages of vent species (recruitment)
	P7	Effect of sediment clogging on adult vent and non-vent biota
Plume toxicity	P8	Effect of plume toxicity on exogenous dispersive stages of vent species (recruitment)
	P9	Effect of plume toxicity on adult vent and non-vent biota

Figure 5. Qualitative response predictions for individual pressures to the model of active hydrothermally vent ecosystem in the Indian Ocean.

	no impact to subsurface connectivity	reduced subsurface connectivity	reduced warm diffuse flow	reduced cool diffuse flow	no subsurface connectivity	no impact to subsurface connectivity	reduced subsurface connectivity	reduced warm diffuse flow	reduced cool diffuse flow
Model variables	**S1a**	**S1b**	**S1c**	**S1d**	**S2**	**S3a**	**S3b**	**S3c**	**S3d**
Vent field subsurface connectivity	⬜	🟥	⬜	⬜	⬜	⬜	🟥	⬜	⬜
Focused flow	⬜	🟥	⬜	⬜	⬜	⬜	🟥	⬜	⬜
Warm diffuse flow	⬜	🟥	🟥	🟦	⬜	⬜	🟥	🟥	🟦
Cold diffuse flow	⬜	🟥	🟦	🟥	⬜	⬜	🟥	🟦	🟥
Sulfide microorganisms	⬜	🟥	🟨	🟨	⬜	⬜	🟥	🟨	🟨
Particulate organic matter chemosynthetic	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟧	🟧
Warm diffuse flow attached microorganisms	🟥	🟥	🟥	🟨	⬜	🟥	🟥	🟥	🟨
Cold diffuse flow attached microorganisms	🟥	🟥	🟨	🟥	⬜	🟥	🟥	🟨	🟥
Suspended microorganisms	🟥	🟥	🟧	🟧	⬜	🟥	🟥	🟧	🟧
Shrimp symbiotrophs	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟨	🟨
Grazers	🔷	🔷	🔷	🟨	🟨	🟨	🔷	🟨	🟨
Detritivores	🟧	🟧	🟨	🟧	🟨	🟨	🟧	🟨	🟧
Mussel symbiotrophs	🟨	🟧	🟨	🟨	🟨	🟨	🟧	🟨	🟨
Biogenic habitat	🟨	🟧	🟨	🟨	🟨	🟨	🟧	🟨	🟨
Suspension feeders	🟧	🟧	🟧	🟨	🟨	🟨	🟧	🟧	🟨
Predators and scavengers	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Particulate organic matter photosynthetic	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Non-vent biota	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Vent biota reproductive output	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟧
Exogenous dispersive stages vent species	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Black smoker plumes	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Phase separation	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

Negative	Likely negative	Zero	Likely positive	Positive	Sign indeterminate
🟥	🟧	⬜	🔷	🟦	🟨



Abbreviation	Perturbation scenario description	Pressure combinations
Scenario 1 – Hydrothermally active PMS deposit exploited within the same vent field		
S1a	No impact on subsurface fluid connectivity	P1, P2, P6 – 9
S1b	Reduced subsurface fluid connectivity	P1, P2, P3, P6 – P9
S1c	Reduced warm diffuse flow	P1, P2, P4, P6 – P9
S1d	Reduced cool diffuse flow	P1, P2, P5, P6 – P9
Scenario 2 – Hydrothermally active PMS deposit exploited in a different vent field		
S2	No existing subsurface fluid connectivity	P1, P2, P6, P8
Scenario 3 – Hydrothermally inactive PMS deposit exploited within the same vent field		
S3a	No impact on subsurface fluid connectivity	P6 – P9, P10
S3b	Reduced subsurface fluid connectivity	P3, P6 – P9, P10
S3c	Reduced warm diffuse flow	P4, P6 – P9, P10
S3d	Reduced cool diffuse flow	P5, P6 – P9, P10

Figure 6. Qualitative response predictions for three pressure scenarios to the Indian Ocean hydrothermally active vent model

Annex V

Main results of discussion on spatial planning and ABMTs

A. Background

This Annex provides a summary of discussions related to the following workshop objectives:

- define an appropriate geographical area for the development of the REMP, drawing upon information on the geology, biogeography and oceanography of the region and
- provide scientific descriptions of potential areas that could be protected from exploitation in order to achieve effective protection of the marine environment.

It should be noted that workshop discussions focused on the scientific rationale and data that will inform the delineation of geographical boundary/ies for the development of the REMP and the identification of ABMTs as part of the future REMP.[14] This workshop did not reach conclusions on the geographical scope of the REMP or any potential areas that would be protected from future exploitation.

This discussion built on the state of knowledge related to the geological, oceanographical and biological aspects of the marine environment in the Indian Ocean (Annex III) and was informed by the approaches, criteria and methods used for the identification of ABMTs in the CCZ, the northern MAR and Northwest Pacific Ocean.[15]

Mr. Patrick Halpin (Duke University) introduced approaches to spatial planning. It was noted that defining the appropriate biogeographic spatial extent of a REMP is a fundamental step in the planning process. Regarding ABMTs, there are, in general, two scales of application: a coarse-filter approach targeting the representation of broad ecosystem features and gradients and a fine-filter approach targeting unique sites that may be of particularly high values or at a particularly high risk. The current interpretation of APEIs in the CCZ is an example of a coarse-filter approach, while the proposed SINPs in the draft REMP for the northern MAR are an example of a fine-filter approach. A purposefully configured mixed portfolio combining large areas to protect and buffer intact gradients of habitats augmented with specific SINPs may best provide the flexibility needed to satisfy both mining and conservation interests.

In the discussion about the overall approach, participants agreed that, in general, area-based planning requires two types of criteria and scales of analysis: (1) individual site criteria that guide the priority, size, shape and orientation of individual sites and (2) network or regional criteria that guide the representativity, adequacy, spatial configuration, connectivity and other broader criteria guiding the development of the entire collection of sites. In spatial planning, increased spatial precision will require increased data coverage and a high level of detail, which have implications for adaptive management. An adaptive management approach will likely be required to accommodate changes in data and knowledge, new technologies and relinquishment of contract areas.

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[14] ABMTs are spatial instruments for conservation and management of different forms of ocean use. A multitude of these tools exist in marine areas within and beyond national jurisdiction, ranging from tools for the regulation of specific human activities (e.g. fisheries, shipping or mining) to cross-sectoral tools, such as marine-protected areas and marine spatial planning.

[15] See ISA. 2011. Environmental Management Plan for the Clarion-Clipperton Zone (ISBA/17/LTC/7). ISA. 2021. Review of the implementation of the Environmental Management Plan for the Clarion-Clipperton Zone Report and recommendations of the Legal and Technical Commission (ISBA/26/C/43). ISA. 2022. Regional environmental management plan for the Area of the northern Mid-Atlantic Ridge with a focus on polymetallic sulphide deposits Issued by the Legal and Technical Commission (ISBA/27/C/38). ISA. 2022. The report of the workshop on the development of the REMP for the Northwest Pacific Ocean. Workshop on the Regional Environmental Management Plan for the Area of the Northwest Pacific - International Seabed Authority (isa.org.jm)

As part of the discussion, as a context for the workshop discussions about what a REMP needs to achieve, Mr. Malcolm Clark provided a presentation on environmental goals and objectives. He described the hierarchy of goals, objectives, management actions, indicators and thresholds. He suggested that an overarching environmental goal could be the conservation of biodiversity and ecosystem integrity, further supported by a suite of more detailed environmental objectives specific to defining ecosystem structure and function. Participants noted that the future REMP, including the development of ABMTs, will contribute to the fulfilment of ISA's environmental goals and objectives.

B. Summary of discussion

Workshop participants agreed that the geographical scope of the future REMP should consider the Central Indian Ocean Basin and the ridge system, with different approaches to area-based management in order to accommodate the environmental and topographical differences.

Building on the discussions from the break-out groups, there was a consensus that abyssal plains in the Central Indian Ocean Basin were constrained by the limits of the extended continental shelf and exclusive economic zones to the north, the CIR to the west, the SEIR to the south and the Ninety East Ridge to the east (Figure 7).

For the ridge systems, participants proposed options based on the combination of several parameters for defining the potential geographic scope of the REMP (Figure 8):

- the limits of the extended continental shelf and exclusive economic zone to the north and the south
- the age of the crust, with crust less than 10 million years considered as a potential boundary indicator for the active ridge system
- extent of potential environmental impacts from future activities in the Area, with 100 km from the ridge axis considered an appropriate "buffer zone" following the draft REMP for the MAR and
- bathymetry, with an ecosystem approach aiming to cover the ridge "system" as a whole which should include the flanks and base. Hence, a 200 km distance from the ridge axis to include soft sediment and the 4,000 m depth contour to cover the lowest point of the ridge system were considered.

The discussions were also informed by the work on biogeographical classification (Table 1, Annex III) and habitat modelling in this region, including information shared by participants and which has not yet been published (e.g. see abstract of the presentation by Yadong Zhou in Annex II), as well as a study conducted on a hydrothermal field in the SWIR.[16]

It should be noted that no final consensus was reached on the geographical boundary of the future REMP. While there was broad agreement with the extent of the Central Indian Ocean Basin and abyssal plain boundaries, the ridge system was more complicated. For the ridges, the width of a ridge axis was complicated by different ridge systems having variable relationships between the criteria suggested above. There was a level of agreement that a 200 km distance would generally include the 10 Ma age criterion and also, in most cases, encompass the full ridge bathymetry out onto the abyssal plains. Importantly, there were various views on how far along the three main ridges the REMP boundary should extend. It was recognized that having a larger area for the development of the REMP beyond the existing distribution of exploration licence areas could increase the chances of protecting species and habitats similar to those present in contract areas and better fulfil the goal of maintaining ecosystem structure and function in the region. However, it was also noted that having a larger management area could increase the challenges for

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[16] Lecoeuvre, Aurélien, Bénédicte Ménez, Mathilde Cannat, Valérie Chavagnac, and Emmanuelle Gérard. 2020. "Microbial Ecology of the Newly Discovered Serpentinite-Hosted Old City Hydrothermal Field (Southwest Indian Ridge)." *The ISME Journal* 15 (3). Oxford University Press (OUP): 818–832. doi:10.1038/s41396-020-00816-7.

implementation and monitoring when the REMP is in place. The adjacent extended continental shelf and exclusive economic zone claims will need to be considered when defining the REMP boundaries. Participants agreed that further discussion in this respect would be needed during the next workshop.

Participants also engaged in an interactive mapping exercise to illustrate how the available data and expert evaluation could be used in determining the placement of potential ABMTs. For the abyssal plain areas in the Central Indian Ocean Region, participants considered a similar approach as APEIs in the CCZ by using environmental variables such as sediment thickness and sedimentation rate as proxies for identifying representative habitats. For the ridge system, participants noted the influence of large fracture zones and adjacent ridges in the distribution of biological communities. Participants also exchanged views on the distance of potential ABMTs to the nearby contract areas and the potential use of buffer zones. Participants also noted that the approach proposed for SINPs in the draft REMP for the northern MAR could be applied in certain locations of the ridge system to promote connectivity among such sensitive habitats.[17]

Based on this preliminary exercise, a combination of ABMTs of different sizes, shapes and scales positioned at various distances from each other is likely. Further discussion will be needed on the application of conservation criteria in the identification of potential ABMTs, such as representativity, connectivity and the area for self-sustaining biological populations.

Participants also discussed the need for more work to help address some data gaps before the next REMP workshop in this region. Among other parameters, data on bathymetry, bottom currents, sediment and POC fluxes were suggested for better defining the geographical scope of the REMP and for evaluating potential ABMTs.

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[17] ISA. 2022. Regional environmental management plan for the Area of the northern Mid-Atlantic Ridge with a focus on polymetallic sulphide deposits Issued by the Legal and Technical Commission (ISBA/27/C/38).

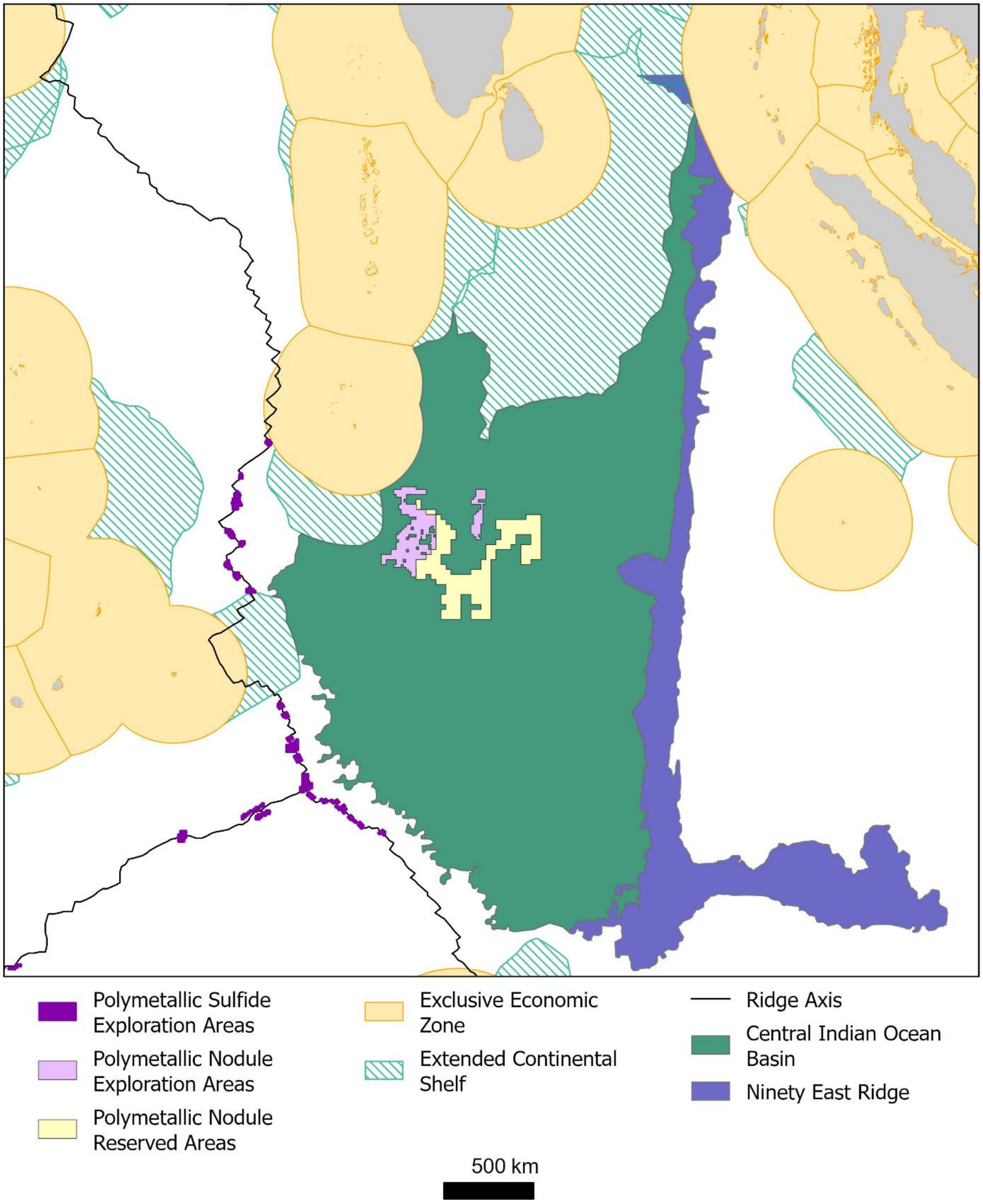

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Figure 7. Potential geographical scope for abyssal plain areas in the Central Indian Ocean Basin based on workshop discussion.[18]

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[18] Sources of data used for producing the maps as presented in Figures 7 and 8:

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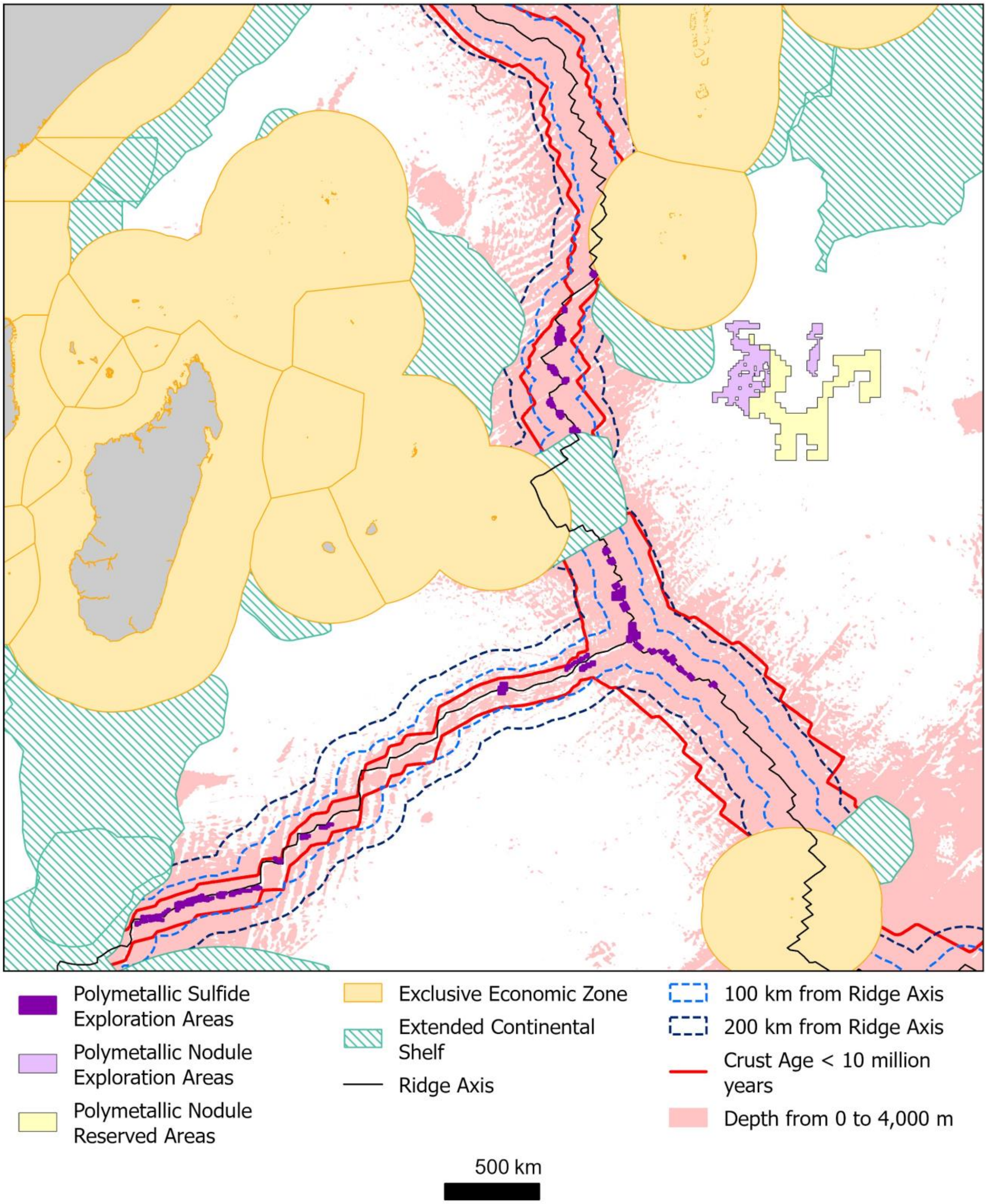

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Figure 8. Potential geographical scope for the Indian Mid-Ocean Ridges based on workshop discussion.

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