EcoDeep-SIP Workshop

# THE CRAFTING OF SEABED MINING ECOSYSTEM-BASED MANAGEMENT

*Assessing deep sea ecosystems in the Pacific Ocean*

**FINAL REPORT**

***Fact findings and recommendations***
***from the Tokyo international workshop on***
***June 29-July 1st, 2015, Embassy of France in Japan, Tokyo***

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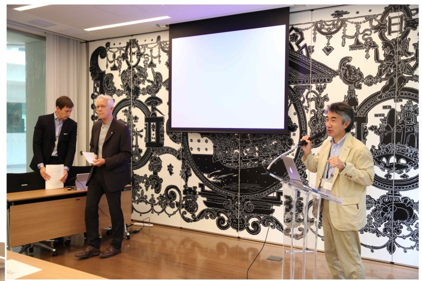

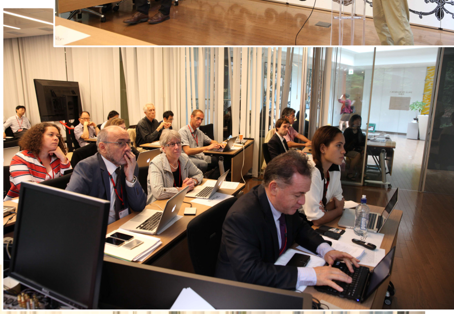

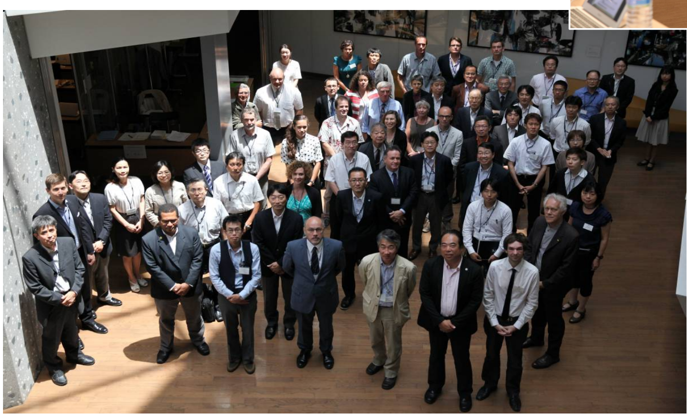

## *Overview*

Deep-sea environments are faced with cumulative effects of many human activities, e.g. waste deposition, oil exploitation, fishing, maritime transport, and potential seabed mining. Recently, growing interest in deep-sea mining, within States' Exclusive Economic Zones or in areas beyond the limits of national jurisdiction, has increased exploration and the development of early environmental impact assessments and scientific research. The issues on seabed mining raised recently, such as the potential environmental impacts, has given rise to many workshops, meetings, and conferences, since the initial discovery of polymetallic nodules at 5000-6000 metre depth on the seafloor of Pacific Ocean was raised in the latter decades of the 1900's. In the Pacific region, the first site likely to be commercially exploited is located in Papua New Guinea, where seafloor massive sulphide (SMS) deposits at 1600 metres water depth occur in the Bismarck Sea, and this has received the appropriate approvals. The mining company, Nautilus Minerals Ltd., expects first production in 2018.

The protocols for effective protection of marine environment from harmful effects and making a clear, effective and transparent code for sustainable deep-sea mining are being discussed and progressed through many national and regional programmes, as well as international workshops and experts networks, e.g. Inter-Ridge, INDEEP, DOSI, MIDAS, SIP, Vent Base, etc. In 2015, the leader's declaration from the G7 summit in Germany identified the conducting of Environmental Impact Assessment (EIA) and scientific research as a priority issue for sustainable deep-sea mining. EIA for deep-sea mining is recognized as an upcoming issue in our oceans and a key component for ensuring effective protection of deep-sea ecosystems.

With this emerging interest, an international workshop was held in the framework of the EcoDeep project between IFREMER and JAMSTEC and was attended by about 50 participants including scientists and experts (science and industry) from Japan, South Korea, France, UK, USA, and South Pacific countries (New Zealand, Australia, Cook Islands) and territories (New Caledonia), including the Secretariat of the Pacific Community (SPC) and the International Seabed Authority (ISA).

This report aims to synthesize discussions from this workshop and the state of knowledge of seabed mining in the context of assessment and management of deep-sea environments, especially hydrothermal vent fields associated with SMS.

# 1 – FACT FINDINGS

## *1.1 Case of regional studies*

***The seabed is a very complex place on a range of scales about which we just start to have some knowledge. High quality Regional Environmental Assessment, Environmental Impact Assessments and Ecological Risk Assessment are all important steps in the regulatory process that require a strong partnership between research and industry.***

***Case of Papua New Guinea***

A very good example was given by Cindy Lee Van Dover (Duke University, USA) based on a joint study with Nautilus Minerals on sulfides and other hard substrates in the Back-Arc Basins (South Pacific). Baseline studies in active and peripheral areas of the vents were focused on oceanographic and meteorological data (CTD, DO, turbidity, currents, waves…), community structure and species richness, their trophic relationships, and their connectivity (larval dispersal) at the basin scale.
All the data involved in baseline studies of community and trophic structures, oceanographic characteristics, and genetic diversity lead to metrics and indicators that might be useful for monitoring and assessing change (post-mining recovery / pre-mining conditions) in species richness, abundance, their trophic relationships, the effective population size and its genetic structure. The understanding of natural variability and population maintenance is still missing.

More specifically, it is observed that:

- Species richness is higher in peripheral areas (where mining might occur) than in active areas. The observed taxa (in peripheral areas) rely in part on chemo-autotrophic primary production for nutrition;
- Community structure is distinctive among different faunal assemblages, but not between the same faunal assemblage at different sites within a same basin;
- Connectivity has a very large extent leading to large-scale baseline studies of community and trophic structures and exchange of genes within a single basin (e.g. Manus Basin) and between adjacent basins (at least a single gene evidence of migration from the Lau Basin to the Manus Basin and vice-versa);
- Nevertheless, genetic diversity seem specific to each basin (e.g. between Manus, Lau and Fiji Basins), meaning that basin populations may be in genetic equilibrium;
- This could be confirmed by oceanographic data (Argo floats) suggesting that circulation in basins could be retentive and important in maintenance of local populations.

Those closest to industrial extraction in the next 4 or 5 years are the sulfide deposits of the Solwara 1 site within the EEZ of Papua New Guinea (Sea of Bismark) under a partnership between Nautilus Minerals Co. and the government of Papua New Guinea. The sulfides deposit at stake is for the moment limited to 5 mineralized zones totaling approximately 11ha.

The seafloor production equipment (already constructed) is composed of a production support vessel, a riser and lifting system, and the seafloor production tools (auxiliary cutter, bulk cutter, collecting machine).

Under international guidelines and the country's deep-sea minerals code, there are two permits to obtain: the Environment Permit (obtained December 2009) and the Mining Lease (obtained January 2011). The Environment Permit includes, among others, 12 adaptive management sub-plans (air quality and dust, stockpile and acid drainage, offshore sediment, noise and vibration, water quality, waste, lighting, marine mammal and turtle, introduced species, benthic ecology, emergency response, rehabilitation and closure) and an Environmental Monitoring Programme. These plans are submitted to the country authorities and have to be reviewed every 6 months. Since the completion of the Environmental Impact Study, additional studies have been performed on the generated noise, sub-sediment fauna, plankton larval abundance, water quality and its variations, fish tissue, all this to feed the needed baseline for future comparative studies.

Potential impacts have been assessed from the sea surface and the water column (lighting, noise, routine discharges, shipping operations) to the seabed (material and habitat removal, plumes, light, noise/vibration).

This pioneering joint research/industry/government pre-mining process, led by international and national regulations but also as a 'learning by doing' process, is bringing and will bring in the future important lessons for the industry as well as for scientists. Among these, were highlighted:

- The importance of the regional survey (large scale) including the mine and control sites but also the possible extent of the plumes impact in regard to the basin characteristics and intra-connectivity between living communities;
- The importance of real-time long-term variability monitoring (sediment rates, water quality, community structure);
- In regard to the Environment Permit sub-plans, the necessity to develop operational staff ownership for their full implementation;
- All environmental studies and monitoring data should be fully transparent to stakeholders and the public;
- In a not 'business as usual' situation, the industry engagement towards governments, scientific groups, and local populations should be highly valued as an integral part of the mining activity, more particularly regarding the means to reduce the predictable

impacts either by mitigating them (ship and machines conception) or by confining them (no runoff back to the sea, noise/vibration reduction).

***Case of New Zealand***

Another interesting case is given by the situation in New Zealand and what recently happened in regard to two different mining permit applications.
The New Zealand EEZ is rich in conventional and non-conventional hydrocarbon (oil & gas, gas hydrates) and minerals (ironsands, massive sulfides, cobalt-rich crusts, phosphate nodules, manganese nodules).
As everywhere, the problem is that little is known about these resources and their relationship with the broader environment where they are located. Science is fundamental to providing to the government and industry the necessary knowledge for establishment of baselines (oceanography, biological aspects, community vulnerability and recovery rates, response to resource use resources), monitoring programmes (what to measure, sampling design, repeatable surveys to separate natural from human-induced changes), and conservation plans (observation+modeling of species and habitat distributions, appropriate spatial units, criteria for conservation areas, methods for effective mitigation and restoration).
Regarding baselines, a systematic survey of several of seamounts along a chain containing massive sulfides in the North East of New Zealand has been carried out between private industry (Neptune Resources) and a public research institution (NIWA). Biodiversity surveys have revealed community patterns that indicate clear differences between seamounts whilst connectivity mechanisms are also taking place between them. Similarly, numerous studies have been completed in phosphorite nodules and ironsands environments. These studies have helped inform the ongoing development of science guidelines including EIA (template and guidelines) and baseline scientific requirements. These will contribute to setting environmental standards and the basis for future marine spatial planning.

But two denials of permit applications in 2014 for mining iron sands and phosphorite nodules, gave useful insights into how much science is required. Though any political decision is actually a complex one of environmental, social, economic and cultural considerations, several key scientific issues raised in the two cases (permit submission) were touched upon:

- Inadequate description and treatment of scientific uncertainty;
- Inadequate “whole system” understanding (some faunal components ignored, limited characterization of ecosystem structure and function);
- Inadequate assessment of impacts (e.g., toxicity of re-deposited sediment to local fauna, sensitivity of fauna to suspended sediment loading, impact of sedimentation)

and recovery dynamics;
- Insufficient protection of endemic species;
- Limitations in monitoring plans and adaptive management regime.

The strong research/industry partnership that so far has characterized the exploration work needs to further develop sufficient baseline scientific information building on lessons learnt:
- Though complex spatial scale patterns (community structure, connectivity) occur, there is no "one size fits all", each resource has its own faunal characteristics requiring detailed studies;
- Multidisciplinarity is required to address the complex array of direct and indirect impacts;
- An ecosystem approach is required allowing the integration of benthic and midwater components across physical, chemical and biological elements;
- Precautionary development requires the use of adaptive management and spatial management.

***Case of Wallis and Futuna***

Under a French innovation programme (World Innovation Challenges), Technip is coordinating the structuring and management of the French deep-sea mining industry.
Among the main French working areas for exploration of deep-sea minerals, it is in the EEZ of Wallis and Futuna that research/industry collaboration is the most advanced (Technip/Eramet/IFREMER).
Wallis and Futuna, officially the Territory of Wallis and Futuna Islands, is a French Polynesian territory located close to Samoa and Tonga. Its EEZ covers 266,000 km² and is a key promising area for deep-sea minerals.
Three exploration surveys led to the identification of several types of deposits: polymetallic ferromanganese crusts, and seafloor massive sulfides (SMS) with high concentrations of Copper, Zinc, Gold, Silver and Lead. After completion of the surveys, observations included:
- The potential of the EEZ South part to hold SMS deposits was confirmed;
- The existence of a massive active volcano with a 5km diameter caldera in its center;
- The prospect of a large perimeter of active and inactive hydrothermal deposits.

However, a number of targets still require further exploratory diving, bathymetric study, and drillings, while there are no data yet available under the seafloor (2D data only), and negotiations are still going on to get an exploration permit from the Wallis and Futuna authorities.

## *1.2 Technical issues for management of deep-sea mining*

***Technology development is needed for exploration equipment, production equipment (including noise reduction) and monitoring equipment***

In terms of risk assessment, what are today the major unknown impacts we should focus on? Practically those that were raised as key scientific issues in the New Zealand situation:

1) faunal community response to habitat removal;
2) the effect of particle plumes, that could be toxic and particle laden, and have an impact both horizontally and vertically, affecting plankton, pelagic and benthic organisms. Regarding possible toxicity, very little is known at such high pressures/ low temperatures where metabolic rates are lower;
3) Noise/vibrations generated by the mining activity

Given the multiplicity of parameters to measure and their spatial distribution, it will be necessary to conceive and develop a multiplatform (fixed and mobile) system with all kind of sensors or imaging devices: adaptive monitoring for adaptive management.

Fixed-point long-term observatories are already under development and trials for several years with the EU-funded project MOMAR (Lucky Strike site on the Atlantic mid-ridge). Transects using AUVs are now possible using different kind of sensors. Either fixed-point or mobile observatories will require versatile sensors with analytical (in situ) and sampling capacity for a number of elements: IFREMER and its industrial partners are currently developing and testing a number of them.

Interestingly, this IFREMER presentation was completed by geological considerations (JAMSTEC) regarding hydrothermal vents and ferro-manganese crusts. Naturally produced plumes (from the 'smokers' of hydrothermal vents) were tentatively mapped using geological sensors (acoustic, turbidity, Red-ox, electrometer) whilst ferro-manganese crust environments were investigated with bathymetric data, information on tidal direction and velocities, videos, deposit samples (chemical composition and microbe analysis), and surrounding seawater samples. It goes without saying that future work will need to become much more integrated across a range of disciplines.

Another example was given by the French company DCNS: amongst the various potential impacts of deep-sea mining, noise production (from surface to bottom) and low size grading particle suspending (plume on the bottom) are considered as the most serious.

One may think that within the spectrum noise level, the level of deep-sea mining noise will be at least equal and probably higher than the known emissions from drill rigs and dredging with a low frequency and a level of around 200 Decibel (Db). A level of 120 Db of noise may have an impact on an area of up to 70 km away from the mining site.

As regards the production of suspended particles, depending on the soil morphology, sediment types and currents, their area of spreading may be quite large, up to thousand $km^2$ though the different kind of impacts (physical, chemical, biological) remain poorly known with somewhat contradictory results.
To face these impact issues, the best response is to minimize them as much as possible when operating. To perform the appropriate technology development, DCNS is using its know-how in military submarine construction as regards the low noise emission design and acoustic barrier and the multi-sensors platform concept.
In partnership with IFREMER, sea trials on AUV dynamic docking has been performed towards the future deployment of a real time, highly automated and self-learning system for the prediction and the monitoring of seabed activity impacts on the environment, thus feeding the EIA process. Current research at DCNS is focused on the conception of fixed and energy-free observatories, and a ‘multi-shield’ system to mitigate noise and stop the plume diffusion for a 3000m deep- sea mining operation.

*Various monitoring devices and procedures are being/have been developed but there is no agreed strategy for monitoring as yet. This will require regulation/standards to be set (e.g. by the ISA) and may be different for different types of mining and/or locations*

The European project, MIDAS (Managing Impacts of Deep Sea Resource Exploitation), to which IFREMER is associated, aims to investigate the environmental impacts of deep-sea mining and develop a science/industry interface to deliver new technologies in monitoring impact, and promote best practices.
They first note that crusts, SMS deposits and nodules each have different characteristics, distributions and environmental concerns:
On top of these different characteristics, the areas to be impacted by mining are huge for nodules and crusts but smaller in the case of SMS deposits. When comparing the footprints of land mines with mining in the deep sea, the values would be rather similar for massive sulfides (SMS) whilst those of nodules and crusts would be much higher.
Given these conditions, there are areas where engineering design could reduce impacts by, for example:

- reducing the spread of plumes (mid water and benthic) since they risk to considerably extend the areas impacted, and,
- reducing the sediment compaction in nodule areas to allow potential recolonization.

The best way to test the appropriate technology would be to consider test mining sites where engineering and environmental issues could be tackled together and monitoring strategies could be developed.

| Polymetallic nodules | Seafloor massive sulfides | Cobalt crusts |
|---|---|---|
| High species diversity<br>Low biomass<br>Long-lived individuals<br>(slow growth)<br>Very stable conditions<br>Recovery: extremely slow | ***Active vents***<br>Many endemic species<br>High biomass, low biodiversity<br>Linear distribution<br>Recovery: high<br>(with slow or fast spreading)<br>***Inactive vents***<br>High biodiversity, lower biomass<br>Recovery: unknown | Hotspots of biodiversity<br>High species diversity<br>Complex ecosystems<br>(some with limited distribution)<br>Long-lived individuals<br>(slow growth)<br>Linear distribution<br>Recovery: unknown |

The Japan project for development of new generation research protocol for submarine resources conducted by JAMSTEC/SIP, consisting of research and industry project teams (e.g. National Institute of Environmental Studies, marine consultants, ocean industries), focuses on observation/monitoring technology, assessment and evaluation of ecosystem components, data availability with open access, and prediction for connectivity/recoverability in case of seabed mining. The induction of a new technology package, which combined with the advanced instruments and techniques, will improve deep-sea EIAs, although the reduction of cost as much as possible is recognized as another concern.

Regarding observation and monitoring, the focus is on one hand on cabled-ecosystem monitoring system for in situ, long-term, and real-time sensing to detect symptoms of change in local environment and ecosystem near the sea floor. On the other hand, JAMSTEC and partners are also working on the so-called 'Edokko' system, a 'free-fall and stand-alone platform' (up to 8000m depth) equipped with video cameras, cheap and very easily handled, e.g. from a fishing boat.
New protocols are similarly developed for biological survey and monitoring (downward and forward-looking camera), autonomous determination (visual plankton recorder, flow cam and flow cytometer), and metagenomics (community structure) of meiofauna and microbes.
All these tools have been developed for scientific purpose and the challenge is now to adapt them for commercial application of standard protocols usable in an environmental assessment study.

Data availability under standard protocols will also need appropriate data on ecosystems at regional and local scale as shown in the New Zealand cases. Since its launching under the Census of Marine Life project, JAMSTEC is using the OBIS open-access data bank from which it further developed the 'BISMaL' (Biological Information System for Marine Life) data system (http://www.godac.jp/bismal).

Regarding the assessment and value of ecosystems, JAMSTEC has been involved in the

CBD EBSAs process at regional (Asia-Western Pacific Ocean Region) and national levels. Considering the EBSA criteria, only a very limited amount of data is currently available. Nevertheless, EBSA as the other recognized types of area of particular environmental importance (e.g. the ISA Area of Particular Environmental Interest) are deemed essential for future strategic environmental assessment and conservation planning. VMEs (Vulnerable Marine Ecosystems) are another category of ecosystem meriting protection defined by regional fisheries management organizations for bottom fisheries and emphasizes fragility or vulnerability to damage.

Seafloor-cabled observatories (JAMSTEC operates 3 of them: Muroto, Hatsushima, Kushiro) are used to measure physico-chemical parameters and observe (camera) visible events on deep seafloor.
Finally, some work has been done on the prediction of connectivity and recoverability, more particularly for the deep-sea chemosynthetic macro-megabenthos within the Japan EEZ. On the longer term, prediction protocols of distribution and migration pattern of species and populations should feed the preparation and implementation of environmental plans for biodiversity conservation including related impact and recovery processes.

## *1.3 Network of experts and information sharing*

***Deep ocean stewardship as a transdisciplinary, multi-sectoral and multi-stakeholder endeavor within and beyond national jurisdictions***

The ocean is highly interconnected but our governance and management regimes are very fragmented! Our jurisdictions and boundaries are not recognized by marine populations, natural changes and anthropogenic impacts. The two latter accumulate and impact the same ecosystem.
From diamonds, oil and gas, phosphates, and the varied mineral deposits (including rare earth), the ocean seabed holds resources of interest at all depths. But following Lisa Levin (Scripps Institution of Oceanography, USA), the special features of the deep sea (beyond 200m) require new thinking about impact assessment. Why?

- We are addressing huge areas where it will be impossible to catalogue all biodiversity
- These areas are remote and far from shore inferring high exploration and exploitation costs
- We are still technology limited meaning a lack of capacity for a host of measurements
- The consequence is our lack of scientific knowledge in assessing what is there and

the significant (cumulative) impacts

- We are addressing living communities with high heterogeneity (habitats and time/space scales; variable response to disturbance)
- Many deep ecosystems have slow processes where recovery of long-lived species may be impossible and there will be a great time lag between biodiversity response and actual services to humans
- Since the resources of interest are in areas ruled up by two different governance regimes (international waters/EEZ) with a lack of public awareness in both cases, there is a great challenge in coherent adaptive policy making for development and protection.

Given these peculiarities of the deep sea, 'significant impacts' will be a function of the inherent properties of the ecosystem and how the resource will be exploited (intensity and duration). Huge unknowns exist about ecosystem functioning, including sources and sinks, and numerical thresholds for significant impact given the species rarity and its ecological and social importance. Moreover, we must look at the cumulative impacts within a single sector, across sectors with similar or different impacts, and in the context of increasing climate-stressors (warming, acidification, de-oxygenation).

All in all, there is a strong need for deep-ocean stewardship to balance the use of resources with the need to maintain the integrity of deep-ocean ecosystems for present and future generations. The Deep-Ocean Stewardship Initiative (DOSI) (www.dosi-project.org) seeks to integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdictions. This practically means advanced scientific research on several well-defined topics, strategies based on a precautionary approach (avoid and minimize harm), the protection of the unknown through spatial planning, and as much as we can, the definition and quantification of ecosystem services at stake, the rectification of governance gaps and stakeholders' engagement whilst encouraging/building multidisciplinary expertise and international capacity (http://www.indeep-project.org/deep-ocean-stewardship-initiative).

## *1.4 Governance for deep-sea mining*

In international waters (the Area), there are now a total of 26 exploration contracts signed with ISA (International Seabed Authority): 16 contracts signed in the Clarion-Clipperton zone (Polymetallic manganese nodules) including by 4 Pacific small island developing states ; 6 contracts in the case of Polymetallic massive sulfides, and 4 contracts in the case of cobalt crust.

The only existing environmental management plan (with defined obligations and responsibilities) is the one in the Clarion-Clipperton zone, which used the precautionary approach in absence of adequate scientific information. This plan is meant to:

- Establish requirements for a periodically updated environmental baseline data for the region;
- Consider the environmental risks to the Clarion-Clipperton zone posed by technological developments in mining operations;
- Undertake cumulative impact assessments as necessary based on exploitation proposals;
- Design Impact Reference Zones (IRZ) and Preservation Reference Zone (PRZ) areas within the wider exploration areas.

But the harsh reality is that the current status of environmental data after 15 years of exploration activities is still poor (quality and quantity) as observed by ISA. There is then the issue of standardized format in reporting for which some efforts have already started for the deep-sea macrofauna of the Clarion-Clipperton zone (ISA Technical Study No13).

***Case of Deep seabed mineral activities in the Pacific islands region***

A regional and overall presentation was first made by the Secretariat of the Pacific Community, which is coordinating an EU-funded project on deep sea minerals (http://gsd.spc.int/dsm/).

The national jurisdictions of the Pacific island countries and territories represent a total area of 27.8 million km$^2$ of ocean, i.e. more than 50 times the total land area to which 2 million km$^2$ may be added when considering the extended continental shelf claims.

In these huge areas, the 3 main types of deposits (seafloor massive sulfides, polymetallic nodules, cobalt crust) may be found. There is a high exploration interest in the respective EEZs and in “the Area” (Tonga, Nauru, Kiribati and Cook Islands are sponsoring States in the Clarion-Clipperton zone for Polymetallic nodules).

The main driver and expected benefits are the opportunity to participate in a new economic sector for local development (poverty alleviation and wellbeing), generating revenue (including mining revenue saving scheme), employment, and subsequent stimulation of other economic sectors.

Key issues which the SPC-EU Deep Sea Minerals (DSM) Project is assisting Pacific States to address are:

- The legal (national policy and law government/company DSM contract negotiations) and financial aspects (fiscal regime and revenue management);

- The technical and research aspects (exploration, environmental management and monitoring, social aspects, data management);
- Capacity building and stakeholder engagement (training, institutional strengthening, ongoing stakeholder consultation and awareness).

Currently, Fiji, Tonga, Tuvalu, and Cook Islands have enacted a seabed minerals legislation. A number of other countries are currently drafting their policy and legislation documents.

Beyond numerous capacity strengthening events, the Project developed with UNEP and GRID-Arendal, an impressive set of 5 booklets covering all aspects regarding the current understanding and perspectives of deep-sea mining in the Pacific region.

Besides cost-benefit analysis case studies in Cook islands, Marshall islands, and Papua New Guinea, a partnership was established with the Pacific Financial and Technical Assistance center to assist island countries in developing their own Regional fiscal and revenue management framework for deep sea mineral activities.

Regarding research, guidance on requirements for regional scientific research during exploration were developed with NIWA on marine research activities “to develop robust environment baselines”.

A Regional Agreement aiming to foster cooperation and harmonization of legal instruments in the frame of international law, is currently under preparation.

Therefore, the SPC-EU DSM project represents a strong framework and network for knowledge-sharing in the region. It could be further reinforced by the Japan-South Pacific IO-NET network initiative currently under discussion between OPRI (Ocean Policy Research Institute, SSPF, Japan) and a number of partners in the South Pacific including the DSM-SPC project.

***<u>Cook Islands case</u>***

*<u>From Seabed Minerals Authority</u>*

In the heart of the Polynesian culture, and with an EEZ of 2.4 million km², the Cook Islands polymetallic nodules resource is estimated at 10 million tons, close to the Clarion-Clipperton zone (CCZ) figures.

The resource depth is between 3500 and 5000m. While the target metal is cobalt (with a grade of 0.41%), the other potential elements are Nickel, Copper, Manganese, Titanium, Vanadium and, not the least, rare earth elements which would be double the concentrations found in the CCZ nodules.

Following rather comprehensive exploration studies, though limited to nodule resource assessment (a visually effective 3D video of the entire zone was played), the Cook Islands government prepared for licensing to commence in August 2015.

As already introduced through the SPC-EU DSM project, the Cook Islands has a

Seabed Minerals (SBM) specific national policy and enacted the world's first legislation dedicated to SBM activities to invite and contract with foreign investors.

The centerpiece of the regulatory framework is a comprehensive law (SBM Act, 2009) with provisions to govern all rights, obligations and interests in seabed mining activities in the Cook Islands.

As described on the dedicated website (www.seabedmineralsauthority.gov.ck), the invitation for bids concern 130 gridded blocks of 100km² each, where one single bid cannot exceed 50 unit areas. From the earlier surveys there are maps showing the areas of highest value likely to be the best prospective areas of interest.

As in the Clarion-Clipperton zone (CCZ), limited information (German R/V Sonne biological survey of Manihiki Plateau troughs, 2007) suggests the faunal biomass in these areas is rather low but unlike the CCZ, biodiversity would be instead rather low as well (though that could be a sampling artifact).

Amongst the key environmental objectives while mining operations take place, is conservation through the Biodiversity Preservation Area (BPA), each 100km wide as in the case of the CCZ Areas of Particular Environmental Interest (APEI).

The whole EEZ of Cook Islands is thus intended as a multi-use marine managed area with objectives to have high conservation values whilst preserving the future development of maritime activities like fisheries, tourism, and deep sea mining. Regarding conservation, the NGO 'Te Ipukaera Society' representative declared that we still "have time to do it right", ensuring that the 1.1 million km² marine park ('Marae Moana'; a 'Marae' on land is the sacred place of ancestors) plays its role of protection. It is why they are actively partnering with DSM with the objectives of: i) developing awareness about the role of the ocean, ii) ensuring the gathering and transferring of information; iii) ensuring that minimizing future mining impacts will be the rule.

In parallel and through its ISA contractor, Cook Islands Investment Corporation, settled in partnership with the Belgian company GSR, the country is involved in the CCZ where exploration work is to commence in 2015/16.

Interestingly, the deal with the Belgian partner gives to the latter a 'privileged customer' status with access to the richest Cook Islands 'EEZ Reserve Area'.

The CCZ exploration activities will thus allow productive synergies in applying the same environmental objectives (ISA Regulations; 'build with nature' best environmental practice; minimizing impacts; baselines, data collection and monitoring; environmental management plan) in the CCZ and the Cook Islands EEZ.

The environmental assessment process will be of the same standard, if not higher, as in the CCZ or in the case of Papua New Guinea (Nautilus Minerals Co.), based on the concept of Common Heritage of mankind including the principles of information gathering and delivery, consultation of stakeholders, precautionary approach, proportional application of measures, Impact and Preservation Reference Zones, test mining and initial scoping for possible exploitation. Cook Islands could then be a learning case in regard to the shared decision making process in light of environmental assessment.

***New Caledonia case***

*From Geological Survey division, Department of Industry, Mining and Energy*

The archipelago of New Caledonia is part of the Melanesia sub-region. It is a French territory with a large political autonomy (with a New Caledonian citizenship) where among others the New Caledonia government has the full mandate for environmental management and exploration and exploitation of resources all over its EEZ of 1.8 million $km^2$.

Within the Department of Industry, Mining and Energy, the recently created (2006) Geological Survey of New Caledonia (SGNC) main objectives are about the knowledge of tectonic evolution and regional geodynamics in the SW Pacific context, and the inventory of marine energy/mineral resources, mainly hydrocarbon. The produced geographic information is available on a single website (www.Georep.nc).

Very recently (2014), the Coral Sea (Mer de Corail) marine park was created, covering the entire New Caledonian EEZ with the same underpinning principle as for the Cook Islands, i.e. the setting up of a multiuse marine managed area based on a regional diagnostic and a strategic analyses of the NC maritime domain.

As regards the deep ecosystems, the amount of data is still relatively poor and coming from surveys operating multi-beam bathymetry, seismic lines, and some biological and chemical geological sampling. The type and nature of seafloor substrate could indicate the presence of oil and gas though it remains unknown.

Little is known as well regarding the deep-sea minerals (nodules, crusts, sulfides) since no exploration license has yet been granted like in the Cook Islands. Although a detailed survey is needed, there is a high probability of massive sulfides deposits in the Matthew & Hunter zone along the New Hebrides subduction line in the South-East of New Caledonia.

On land, New Caledonia has a long history of mining and metallurgy with 25% of the world lateritic Nickel. Thanks to its 3 world-class metallurgy plants, New Caledonia is a modern industrial small country with a comprehensive legislation for land mining.

In this context, what could be the yet to be set up strategy for deep sea minerals in New Caledonia?:

- A specific scientific survey (Zoneco) in the Matthew & Hunter zone in co-partnership with IFREMER and JAMSTEC;
- Legislation for oil and gas exploration that could be extended to deep sea minerals;
- An overall integrated maritime policy reflected in the governance (marine park management committee) and management plan of the NC multi-use marine park.

## 2 – RECOMMENDATIONS

In the workshop, making a scientific review on the major knowledge gaps, and description of the nature, intensity and scales of potential impacts in case of deep-sea mining, were primary objectives. In the review process, participants discussed and identified the physicochemical and biological variables, indicators or proxies relevant to assessment and monitoring of potential impacts. Technologies and protocols for assessment and monitoring of the potential impacts were suggested throughout the workshop discussions. Another objective was development of links with the industry and other stakeholders. The information and knowledge provided from the workshop participants have been used as the background feeding the separate Task working groups.

Its main recommendations represent the outcomes of three days of presentations and discussion in plenary and through specific working group sessions which were assigned with the following tasks:

**Task 1 – Review of deep-sea mining impact** - Assessing the nature, intensity and scales of potential deep-sea mining impact, including a review of knowledge and gaps regarding natural and anthropogenic disturbances on deep-sea ecosystems: How relevant they are to deep-sea mining? How are they assessed and monitor?

**Task 2 – Best targets in assessing/monitoring impacts – Feasibility of deep-sea ecosystems modeling -** Considering potential impacts, what are the physico-chemical, biological and ecosystem function variables, indicators or proxies relevant to assess and monitor the environmental consequences of deep-sea mining activities, and assess the feasibility of deep-sea modeling (e.g. deep-sea food-web, connectivity of ecosystem components, variation in natural or human-induced conditions, resilience).

**Task 3 – Needed technologies for assessment/monitoring/mitigation** – What are the existing technologies and what is the need for technological development to assess and monitor the environmental consequences of deep-sea mining activities.

**Task 4 – Integration into the Environmental Assessment process including EIA** – Integrating the Tasks 1 to 3 outcomes to feed the Environmental Assessment process including EIA, more particularly: i. Relevant ecosystems components, interactions and vulnerability; ii. Intensity pressures/vulnerable ecosystem components; iii. Temporal and spatial aspects (cumulative impacts); iv. Technology: building with nature principles

**We need deep-ocean stewardship as a transdisciplinary, multi-sectoral and multi-stakeholder endeavor within and beyond national jurisdictions**

The ocean is highly interconnected but our governance and management regimes are very fragmented. National jurisdictions and boundaries are not recognized by marine populations, or natural changes and the additional stressors of anthropogenic impacts can cause cumulate effects onto the same ecosystem. The very special features of the deep sea (beyond 200m) require new thinking about impact assessment, because:

- We are addressing huge areas where it will be impossible to catalogue all biodiversity
- These areas are remote and far from shore inferring high exploration (and future exploitation) costs
- We are technology limited, lacking capacity for many measurements
- Our lack of scientific knowledge of what is there and how it will be effected by significant (and cumulative) impacts
- Living communities have high heterogeneity (habitats and time/space scales; variable response to disturbance)
- Recovery of long-lived species may be impossible and there will be a great time lag between biodiversity response and ecosystem services recovery
- There are two different governance regimes (international waters/EEZ) and a challenge to align policy and legislation which is coherent, adaptive and protective
- There is a lack of public awareness regarding the role and richness/vulnerability of the deep ocean.

All in all, there is a strong need for deep-ocean stewardship to balance the use of resources with the need to maintain the integrity of deep-ocean ecosystems for present and future generations. This practically means advanced scientific research on several well-defined topics is needed: strategies based on a precautionary approach (avoid and minimize harm); the protection of the unknown through spatial planning; the definition and quantification of ecosystem services; the rectification of governance gaps and stakeholders' engagement; and encouraging/building multidisciplinary expertise and international capacity (http://www.indeep-project.org/deep-ocean-stewardship-initiative).

**We already know that the deep seabed may be a very complex place, interconnected on a vast range of scales**

From observations in situ at SMS sites:

- In the case of SMS, species richness is higher in peripheral areas (where mining might occur) than in active areas. The observed taxa (in peripheral areas) rely in part on chemo-autotrophic primary production for nutrition;
- Community structure can be distinguished among different faunal assemblages, but not between the same faunal assemblage at different sites within the same basin;
- Depending on taxon, connectivity can occur over very large areas leading to large-scale baseline studies being needed of community and trophic structures and exchange of genes within a single basin (e.g. Manus Basin) and between adjacent basins (at least a single gene evidence of migration from the Lau Basin to the Manus Basin and vice-versa), though genetic connectivity can also be restricted between seamounts within a chain like in the case of the Kermadec Arc;
- Nevertheless, genetic diversity seem specific to each basin (e.g. between Manus, Lau and Fiji Basins), meaning that basin populations may be in genetic equilibrium;
- This could be confirmed by oceanographic data (Argo floats) suggesting that circulation in basins could be retentive and important in maintenance of local populations.

In regard to possible loss of connectivity (larvae transfer) during and after mining activities, there are four key issues to be considered:

- ***Will there be a supply of the same species as being supplied before mining?***
  *Measurement and tools to be considered: DNA barcoding and population fingerprinting in comparing the benthic recruits to the input of larvae;*
  *Sampling methods? Imaging, sediment traps, settlement plates (artificial substrate), plankton pump (in situ and pumped to surface ship)*
  *To be developed: samplers on AUV, imaged DNA chip, whilst considering the taxonomy bottleneck (lack of qualified taxonomists)*
- ***Will larvae receive the environment cues they need to recruit?***
  *Rearing and behavior experiments are needed (deep aquarium-type system)*
- ***Will larvae survive after recruitment long enough to reproduce?***
  *Tagging-imaging surveys are needed to measure growth rates and extrapolate reproductive age/size*
- ***Is everything else secondary and will it take care of itself?***

*Look at possible proxies…*

**What are the most significant impacts expected from deep-sea mining and how do we minimize or mitigate them ?**

Although a number of points are also valid for other type of deposits, the discussion was mainly focused on future SMS mining:

***Baseline***

- Ensure chemical fingerprinting of sediment but also of benthic fauna before initiating any activity
- Learn about plume dispersion from geo-mapping of naturally-produced plumes on active SMS sites (see JAMSTEC geosciences research activities).
- Assess the ambient noise levels (fluid flow, eruptions, organisms…)
- Ensure that environmental baselines are periodically updated

***Main Environment Impact Sources***

Most significant impacts are identified as follows (from bottom to surface)

*Mineral extraction (physical removal of substrate)*
*Cutting plume (particles and toxicity)*
*Return plume (particles and toxicity)*
*Extraction machines and riser noise*

Relatively less significant impacts may be: Introduction of light; Removal of seawater at depth; ship-related activities (noise, discharges, etc.)

***Plumes (return and cutting) characterization***

- The scale and type of plume generated will depend largely on the technology used
- Ground truth observations should focus on dispersion pattern, spreading range, duration, turbidity, sedimentation rate
- The particle properties are of the utmost importance (size, density, surface area)
- Besides the plume produced by mining operations, the impact of 'return' plume on mesopelagic and other pelagic plankton should be looked at
- Toxicity is a complex issue which needs a framework strategy to be properly assessed including:
  - ➢ identification of key metals and compounds, their bioavailability and bioaccumulation through experimental approaches (with uncertainties

regarding the validity of LD50 or sublethal effects in extreme conditions, high pressure / low temperature), but shallow-water or coastal toxicity standards may not be appropriate for deep-sea application,

- ➢ the microbial detoxification or mobilization capacity
- ➢ physiological and behavioral responses
- ➢ In the choice of benthic fauna and use of analogs, taxonomic expertise is crucial
- ➢ Differential toxic effect on larvae and other organisms (pelagic vs benthic organisms; fouling and burial effects; in regard to pressure / temperature thresholds)
- ➢ For simplification of EIA protocol, appropriate indicators should be selected for monitoring the spatial and temporal impact of mining. Existing metrics for toxicity include the average burial level and LD50. Acceptability criteria need to be determined, for example, is it acceptable to kill 50% of the organisms and how far from the mined areas?
- ➢ Looking at any positive impacts?; microbial primary (secondary) productivity through in situ and experimental measures
- ➢ Current and relevant case studies: IZENA Okinawa trough (JOGMEC); oil and gas for dispersion and toxicity (e.g. Horizon); tailings disposal (PNG, MIDAS in Norway observing non toxicity but decreasing of burial populations); El Hierro submarine volcanic eruption (MIDAS); IODP drilling in North Okinawa (JAMSTEC/SIP); any turbid current impacts in regard to burial and subsequent recovery…

***<u>Noise emission characterization</u>***

- The offshore industry should be a good source for noise assessment (data and kind of technology) from the surface ship and the trans-shipment of ore
- On the other hand, the noise qualification/quantification regarding the seabed equipment and the lifter system to be used in DSM is unknown
- Impacts should be first of all assessed on cetaceans and other pelagic organisms (behaviors, physiological responses) and to a certain extent on benthic organisms (larval attractors/repellers; behavioral impacts)

***<u>Mitigation priorities are:</u>***

- *Protection of areas from damage or impacts, e.g. representative MPAs (including APEI, Preservation Reference Zone, and other zoning options)*
- *Limit spread of return plume*
- *Limit generation of plume by mining tools*

- *Limit noise intensity and frequency*
- *Slow start to mining*
- *Spacing and timing of mining*

… with one overall rule:
*mitigation approaches assume appropriate monitoring and adaptive management (use of technologies and knowledge as become available) based on systematically minimizing mining impact.*

***About cumulative impacts***

Cumulative impacts might be looked at with respect to multiple mines in the same zone (e.g. CCZ), multiple industry activities in the same area (e.g. mining and fisheries), and in the context of increasing climate-stressors (warming, acidification, de-oxygenation) and eutrophication events.
Potential approaches for assessment include:

- Undertake cumulative impact assessments as part of Strategic Environmental Assessment, linking existing baseline datasets and determining regional patterns; *and* based on exploitation proposals;
- Build on experiences in regional seas (e.g. HELCOM: cumulative impacts in the Baltic);
- Measurement and modelling of non-mining impacts (e.g. climate modelling) to identify areas of potential change in specific areas at high resolution;
- Habitat suitability modelling;
- Experimental work on cumulative impacts (e.g. heavy metal contaminants; sedimentation/habitat removal; thermal stress…) – (more research focused, not for contractors);
- Develop appropriate metric and tools:

    - At local level:
        - from different stressors within a single mining site
        - from different industrial sectors in the same area,

    - At regional level:
        - from similar stressors associated with multiple regional mining events,
        - from mining interacting with climate change variables (warming, acidification, deoxygenation) and other external stressors (eutrophication)

**What are the main ecosystem functions and services at stake?**

Many of the functions and services of the deep sea result from a combination of its vast size and the long duration of time that it is separated from the Earth's atmosphere. The water masses that bathe the deep-sea environment are formed largely in the North Atlantic and the Southern Ocean, with additional input from the Sea of Okhotsk and the Mediterranean and Red Seas. As soon as these cold dense water masses sink below the photic zone, they are cut off from the atmosphere for approximately 1000 years ('global conveyor belt'), allowing a huge buffering capacity for nutrient and carbon cycles hence rendering it a regulating service to the benefit of other ecosystem services such as primary production and biological habitat formation. In other words:

- Vast area and long residence times typify deep sea environments, meaning that even fast processes on small spatial scales (e.g. hydrothermal vents) create massive services, although in many cases the processes are far removed from their resultant services;
- Many of the functions of the deep sea result in interrelated regulating and provisioning services. (Thurber et al., 2014)[1].

However, the rapid sinking of water at high latitudes is bringing CO2 from the atmosphere into contact with deep-sea organisms at intermediate depths relatively rapidly in the N. Atlantic, with potential consequences for deep water corals and other organisms

It is therefore of the utmost importance to relate the identified impacts with the functioning and the services rendered by deep-sea ecosystems, mainly (but not exclusively):

**Provisioning services -** Primary production, Deep-sea fishes, Energy extraction, Deep sea mineral resources (removal), Genetic resources

**Regulating services –** Carbon sequestration, Nutrient recycling, Buffering capacity

**Supporting services -** Biological habitat formation, Connectivity, Food Web support

**Cultural services -** Scientific knowledge, Communication/Connectivity (society / people / animals)

These services need to be linked to the functions of the ecosystem through:

- Integrating standard/traditional measures and novel tools to address changes in ecosystem functions (baselines, and living communities response such as changes in respiration/burial, successional stage, etc., -in short, their resilience changes-)
- Develop habitat suitability modeling to describe regional faunal distributions and

[1] A.R. Thurber, A.K. Sweetman, B.E. Narayanaswamy, D.O.B. Jones, J. Ingels, R.L. Hansman, 2014. *Ecosystem function and services provided by the deep sea.* Biogeosciences, 11, 3941-3963, 2014.

integrating distribution of suspended particles, contaminants, noise and other stressors;

- Develop in situ sensors that detect multiple environmental and biological parameters (multiplatform monitoring system)

## Some examples:

| *How to monitor Food Web Support ?* | | |
|---|---|---|
| **Components** | **Elements** | **Monitoring tools** |
| *Food web structure* | *Isotope composition*<br>*Trophic modeling* | *Amino-acid and lipids isotope measurement*<br>*NGS of stomach contents* |
| *Fisheries* | *Production*<br>*Stock assessment* | *Stock assessment studies*<br>*Key biological metrics (age composition, fecundity)*<br>*Recruitment (juvenile fishes)*<br>*MSY, natural geochemical and artificial tags (otoliths)* |
| *Spatial distribution of fish* | | *Biologging, chatter tags, active acoustics…Time series of surveys* |
| *Ecotoxicology* | *Contaminants, consumability, acceptability* | *Heavy metals in top predator tissues* |
| *Community structure* | *Composition, diversity, spatial pattern* | *Imaging, meta-genomics, selected sample sorting* |

| *How to monitor Nutrient cycling ?* | | |
|---|---|---|
| **Components** | **Elements** | **Monitoring tools** |
| *Nutrient balance* | *Nitrogen, Phosphorus, Silica, hydrogen, sulfur* | *Elementals quantification* |
| *Metabolism* | *Metabolic pathways* | |
| *Respiration* | *Sediment and hard substrate communities* | *Respiration chambers and experiments / O2 profile / Eddy correlation, red-ox* |
| *Nutrient stocks* | *Fluxes* | *Discrete water sample, N, C, Amino-acid, colorimetrics* |
| *Chemical/ Organic matter stock* | *Fluxes* | *Discrete water sample, nets and sediment traps* |

| ***How to monitor Biological habitat formation ?*** | | |
|---|---|---|
| **Components** | **Elements** | **Monitoring tools** |
| *Habitat heterogeneity* | *Pattern in space and time* | *Sediment profiles, 3-D imaging Fine-scale multibeam/sidescan* |
| *Habitat forming species* | *Distribution, Density, Size, Community structure* | *Imaging, Fine-scaled multibeam, Side scan sonor, laser line* |
| *Spatial distribution and extent* | *Distribution patterns* | *Continuous imaging* |
| *Health status of key structural organisms (including habitat forming organisms)* | *Areal cover, growth, gene expression (HIF, heat shock etc.) Environmental parameters* | *Continuous imaging of varied colonies, in situ tagging, sampling for gene expression of stress, sediment loads, etc.* |

| ***How to monitor Primary production ?*** | | |
|---|---|---|
| **Components** | **Elements** | **Monitoring tools** |
| *Surface primary productivity* | *Chlorophyll* | *Satellite imagery* |
| *POC flux* | *Source markers* | *Traps, models* |
| *Phytoplankton communities* | *Biochemical, ecological* | *NGS sortings, flowcam imagery, flowcytometry, continuous plankton recorder* |
| *Biomass* | *Chlorophyll* | *Satellite, C-13* |
| *Chemosynthesis* | *Tracer uptake studies (13C-labeled bicarbonate or methane) Enzymes, gene expression* | *transcriptomics* |
| *Indicator species* | *Biomass, Cover* | *Sorted samples, NGS* |

**How to reflect priorities in the environmental assessment process?**

*Minimize Mining Impacts*
*Make Measurement/Sampling Activities As Minimally Intrusive As Possible*

1. ***High quality Regional Environmental Assessment, Environmental Impact Assessments and Ecological Risk Assessment are all important steps in the regulatory process that require a strong partnership between research and industry***

- Because deep-sea ecosystems exhibit complex spatial patterns (community structure, connectivity), there is no "one size fits all" . Instead each resource has its own faunal characteristics requiring detailed studies;
- Multidisciplinary research is required to address the complex array of impacts, direct and indirect;
- An ecosystem approach is required allowing the integration of benthic and midwater components across physical, chemical and biological elements;
- Development must proceed with caution, and in most cases will require the use of adaptive management (responding to a monitoring programme) and spatial management to safe-guard against unforeseen impacts.

The few examples in pioneer joint research/industry/government pre-mining process, led by international and national regulations but also as a 'learning by doing' process, is bringing and will bring in the future important lessons for the industry as well as for scientists. Among these, are highlighted:

- The importance of regional surveys (large scale) including the mine and control sites but also the possible extent of the plume impact in regard to the basin characteristics and intra-connectivity among living communities;
- The importance of long-term variability monitoring (sediment rates, water quality, community structure);
- In regard to the Environment Permit sub-plans, the necessity to develop operational staff ownership for their full implementation;
- All environmental studies and monitoring data should be fully transparent to stakeholders and the public;
- The industry engagement towards governments, scientific groups, and local populations should be highly valued as an integral part of the mining activity and not as a mere additional activity, more particularly regarding the means to reduce the predictable impacts either by mitigating them (ship and machines conception) or by confining them (no runoff back to the sea, noise/vibration reduction).

Such an environmental impact assessment process is facing key scientific issues such as:

- Inadequate description and treatment of scientific uncertainty (whole faunal components have in some cases been ignored, there is often limited characterization of ecosystem structure and function);
- Inadequate assessment of impacts (toxicity of re-deposited sediment to local fauna, sensitivity of fauna to suspended sediment loading, impact of sedimentation);
- Insufficient knowledge of and protection of endemic species (recovery dynamics);
- Limitation in monitoring plans and adaptive management regime. It is unlikely that enough information to know all the answers will be available before mining begins. Hence it must proceed with caution, and in a way to carefully monitor changes, and adapt the operation as required.

***2. Technology development is needed for exploration equipment, production equipment (including noise reduction) and monitoring equipment***

The different deep sea resources of cobalt crusts, SMS and polymetallic nodules each have different characteristics, distributions and environmental concerns:

| **Polymetallic nodules** | **Seafloor massive sulfides** | **Cobalt crusts** |
|---|---|---|
| High species diversity<br>Low biomass<br>Long-lived individuals<br>(slow growth)<br>Very stable conditions<br>Recovery: extremely slow | ***Active vents***<br>Many endemic species<br>High biomass, low biodiversity<br>Linear distribution<br>Recovery: high<br>(with slow or fast spreading)<br>***Inactive vents***<br>High biodiversity, lower biomass<br>Recovery: unknown | Hotspots of biodiversity<br>High species diversity<br>Complex ecosystems<br>(some with limited distribution)<br>Long-lived individuals<br>(slow growth)<br>Linear distribution<br>Recovery: unknown |

On top of these different characteristics, the areas to be impacted by mining are huge for nodules, large for crusts, but smaller in the case of SMS deposits. When comparing the footprints of land mines with mining in the deep sea, the values would be rather similar for massive sulfides (SMS) whilst those of nodules and crusts would be much higher.
Given these conditions, there are areas where engineering design could reduce impacts by:

- reducing the spread of plumes (mid water and benthic) since plumes dispersal may considerably extends the areas impacted, and,
- reducing the sediment compaction in nodule areas to allow potential recolonization.

The best way to test the appropriate technology would be to consider test mining sites where engineering and environmental issues could be tackled together and monitoring strategies could be developed.

***3. Various monitoring devices and procedures are being/have been developed but there is no agreed strategy for monitoring as yet. This will require regulation/ standards to be set e.g. by the ISA and may be different for different types of mining and/or locations***

- Fixed-point, long-term observatories (autonomous units or cabled-ecosystem monitoring system to measure physico-chemical parameters and observe (camera) visible events on deep seafloor) are already under development and trials over the past several years in a number of sites
- Transects using AUVs are now possible using different kind of sensors.
- Either fixed-point or mobile observatories will require versatile sensors with analytical (in situ) and sampling capacity for a number of elements.
- Given the multiplicity of parameters to measure and their spatial distribution, it will be necessary to conceive and develop a multiplatform (fixed and mobile) system with multiple sensors or imaging devices (adaptive monitoring for adaptive management).
- New protocols are similarly developed for biological survey and monitoring (downward and forward-looking camera), autonomous determination (visual plankton recorder, flow cam and flow cytometer), and metagenomics (community structure) of meiofauna and microbes.
- All these tools have been developed for scientific purpose and the challenge is now to adapt them to the need of standard protocols usable on a commercial basis.
- To do this, standard protocols are crucially needed as shown in the case of the Clarion-Clipperton Zone: after 15 years of exploration activities, the status of environmental data is still poor, raising the issue of standardized procedure in monitoring/sampling and standardized format in reporting. Attention is needed to data base development, for optimal use of shared data in environmental management.

Summary of some of the required regulations

- *Holistic strategic environmental assessments are required prior to individual actions on mining claims. These assessments should incorporate an ecosystem approach including all relevant system components.*
- *Decision making based on the precautionary principle*
- *Strategic networks of marine protected areas taking into account connectivity*
- *Limit spreading of plumes from return water by <xx mm sedimentation per yy within xx m of mine site and using LD50 (or other possible metrics like bioaccumulation of metals by larvae when methods become available) of key indicator taxa or faunal groups (e.g., macrofauna) to within xx m of mine site*
- *Limit generation of plumes by mining tools: <xx mm sedimentation per yy within xx m of mine site and using LD50 (or other metrics, e.g. bioaccumulation of metals by larvae when methods become available) of key indicator taxa or faunal groups (e.g., macrofauna) to within xx m of mine site*
- *Limit noise intensity and frequency: <xx dB and xx to yy Hz (anywhere)*
- *Slow start to mining (dependent on ability to meet mitigation targets)*
- *Spacing and timing of mining (dependent on ability to meet mitigation targets: xx mining events within xxx km per xx years*
- *Identification of thresholds and triggers associated with significant impact*
- *Clear and well-defined decision rules about the extent of changes in monitored parameters before mining starts*

## ANNEX

**Surface to bottom identified pressures, state, and impact monitoring targets, possible mitigation, and required regulation**

### PLUMES

| | ***Surface*** | ***Midwater*** | ***Seafloor*** |
|---|---|---|---|
| ***Source*** | *Accidental spills, leakage, trans-shipping discharge, ballast water* | *Return plume, cutting plume, riser accident, lifting up of tools* | *Return plume, cutting plume, plume generated by tool movements* |
| ***Effect*** | *Toxicity, oxygen level reduction, reduced visibility (visual predators) reduced light penetration (photosynthesis), clogging of plankton, nutrient enrichment, physico-chemical properties changes* | *Toxicity, oxygen level reduction, reduced visibility, clogging of plankton, nutrient enrichment, physico-chemical changes* | *Toxicity, physico-chemical property changes, reduced visibility (bioluminescence), clogging of plankton and benthic organisms, burial (all life-history stages), substrate change (physico-chemical), nutrient enrichment, change of microbial productivity, habitat heterogeneity (topography)* |
| ***Measure/Tools*** | *ADCP, transmitter, chemical measurements, echosounder, sediment traps w/cameras, 3D-reconstruction, CTD, imaging (AUV, ROV, towed frame, platforms), coring, environmental/specimen DNA, sorting and taxonomic work at specific sites* | | |
| ***Gap*** | *Technology (scale/type of plume), ground truth (dynamics, sedimentation rates, etc.), community composition, impact on organisms, tolerance (feeding, respiration, toxicity)…* | | |
| ***Mitigation*** | *Minimize the plume (quantity, extension) and its impact (particle size, filtration…), choice of place/time of release, minimize operations duration, barrier of confinement* | | |
| ***Regulation*** | *Limit spread of cutting and return plumes by <xx mm sedimentation per yy within xx m of mine site and using LD50 (or other metric, e.g. bioaccumulation of metals by larvae when methods become available) of key indicator taxa or faunal groups (e.g., macrofauna) to within xx m of mine site* | | |

## NOISE

| | ***Surface*** | ***Midwater*** | ***Seafloor*** |
|---|---|---|---|
| ***Source*** | *Ship/barge, trans-boarding between vessels, dewatering, activities on board, ROVs/MT deployment* | *Riser, pumping* | *Mining tools, cutting activities, removal, crushing* |
| ***Effect*** | *Behavioral effects: avoidance, disorientation, attraction, physiological effects depending on species (mammals/fishes)* | | |
| ***Measure/Tools*** | *Hydrophones, tagging* | *Hydrophones, acoustics, sonar* | *Hydrophones, acoustics, sonar* |
| ***Gap*** | *Measuring physiological changes, behavioral changes, quality of noise* | *Life history stages response to noise, quality of noise* | *Life history stages, response to noise, quality of noise* |
| ***Mitigation*** | *Limit noise intensity, refine frequency used, soft start, use of repellants, deterants, barrier of confinement* | | |
| ***Regulation*** | *Limit noise intensity and frequency: xx dB and xx to yy Hz (anywhere), soft start regarding noise* | | |

## HABITAT LOSS

| | *Surface* | *Midwater* | *Seafloor* |
|---|---|---|---|
| ***Source*** | *Shading by vessels, effects of discharge plumes from the vessel at surface* | *Plume could easily reduce habitat suitability for midwater organisms impairing vision, feeding etc.* | *Excavation operations, movement of mining tools, plume* |
| ***Effect*** | *Substrata removal and characteristics modifications (compaction, etc), topographic modification, fluid fluxes modification, habitat reduction/ creation, biogenic habitat removal, loss of habitat heterogeneity…* | | |
| ***Measure/Tools*** | *Species richness/-omics, distribution of organisms/spatial patterns, community structure, presence/biomass of habitat forming species, substratum characteristics and sediment properties, mapping, etc….* | | |
| ***Gap*** | *Recovery processes (natural or facilitated), tolerance thresholds, natural variability, connectivity (migration, larval supply), cumulative impacts, biological dynamics (recruitment, growth rates…), effects on peripheral communities* | | |
| ***Mitigation*** | *Spatial management, strategic networks of MPAs (connectivity), facilitated recovery (artificial substrate), mine planning (temporal/spatial planning to avoid sensitive habitats), technology adaptation/management of operating tools, tailing placement…* | | |
| ***Regulation*** | *Marine Protected areas (strategic networks of different kinds of MPAs taking into account connectivity)*<br>*Spacing and timing of mining (dependent on ability to meet mitigation targets: xx mining events within xxx km per xx years* | | |

## TOXIC CONTAMINANTS

| | ***Surface*** | ***Midwater*** | ***Seafloor*** |
|---|---|---|---|
| ***Source*** | *Transfer, discharge, leakage, tools coming up and down* | *Cutting and return plumes, leaks from riser, tools coming up and down* | *Release from crushed minerals, cutting and return plumes, leaks from excavating tools, creation of new fluid release points, chemical processing on the seafloor* |
| ***Effect*** | *Lethal (poisoning), sublethal effects on organisms, bioaccumulation (trophic, foodweb effects), unbalanced microbial populations, modification of community structure and abundance patterns, loss of fucntions* | | |
| ***Measure/Tools*** | *Health status (fish condition, respiration rates), Transcriptomics (stress gene expression levels…), biomarkers, LD50 of indicator species, tissue chemical levels, densities (mortality), community structure, water contaminants levels* | | |
| ***Gap*** | *Baseline data (natural level of stress genes, community structure, function), experimental (in situ/in vivo) data from deep sea species, development of testing protocols (e.g., how to measure LD50?), definition of time-scale of measurements, definition of thresholds and cumulative effects, research on neutralization of toxics* | | |
| ***Mitigation*** | *Minimize sources of toxics (minimize crushing, use of biodegradable oils…), absorption/chelation of toxics, bioremediation* | | |
| ***Regulation*** | *Measure LD50 (or other appropriate metrics, e.g., bioaccumulation of toxic compounds by organisms) of key indicator taxa or faunal groups (e.g., macrofauna) to within xx m of mine site, over a xx period of time* | | |