Chapter 17
Development of Environmental Management Plan for Deep-Sea Mining

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Abstract Deep-sea mining is currently at a stage when several mine sites have been identified, mining technologies are under development, processing technologies are being tested, studies for assessing potential environmental impacts have been conducted by different contractors, and guidelines for monitoring the impacts have been issued by the International Seabed Authority. At this stage, it is essential to review the information acquired so far in relation to environmental impacts so as to enable development of an environmental management plan for deep-sea mining which will include analyses of the background resource and environmental data, prediction of potential environmental impacts of commercial mining, identification of mitigation measures, and ensure compliance with regulatory authority's stipulations.

17.1 Introduction

Deep-sea mining has generated significant interest around the world for over five decades, due to the potential of deep-sea minerals such as polymetallic nodules, ferromanganese crusts, and hydrothermal sulphides that occur on the deep seafloor and are considered as alternative source of strategic metals as the terrestrial reserves of some of these metals (e.g. Cu, Ni, Co) are depleting fast (Table 17.1). This chapter looks at the information available on potential impacts, mitigation measures, and regulations and suggests an outline for developing an environmental management plan for deep-sea mining.

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R. Sharma (ed.), *Deep-Sea Mining*, DOI 10.1007/978-3-319-52557-0_17

Table 17.1 Uses and status of selected metals found in deep-sea minerals

Metal	Uses[a]	World reserves on land[b]
Nickel	Making steel (46%), nonferrous alloys and superalloys (34%); electroplating (11%), coins, ceramics, batteries, hard discs	71 million tonnes
Cobalt	Alloys, magnets, batteries, catalysts, pigments and coloring, radio-isotopes, electroplating	6.6 million tonnes (52% in Congo)
Copper	Electrical, telecom and electronic applications such as generators, transformers, motors, PCs, TVs, mobile phones (65%), automobile (7%), anti-bacterial agent, and consumer products (coins, musical instruments, cookware)	140 million tonnes (low grade)
Manganese	Steel production (>85% of ore used for this), corrosion-resistant alloys (cans), additive in unleaded gasoline, paint, dry cell and alkaline batteries, pigments, ceramic and glass industry	540 million tonnes (metal)
Iron	Pig iron/sponge iron/steel (>90%), alloys, automobiles, ships, trains, machines, buildings, glass	160 billion tonnes (ore) and 77 billion tonnes (metal)

[a]www.wikipedia.com
[b]IBM (2010)

17.2 Potential Environmental Effects of Deep-Sea Mining

The probable causes for environmental impact from deep-sea mining could be broadly attributed to:

1. Quantity of substrate mined, methods of separation, and mechanism of discharge of effluents
2. Suspension of solids due to movement of the miner, crusher, lift mechanism, and discharge
3. Sub-system losses such as pipes, chains, tools, or any other hardware
4. Oil spills and leakages from mining and transport vessels
5. Ballast water discharge from transport vessels
6. At-sea processing waste including chemicals, debris, water
7. Human waste such as garbage including plastics, metals, glass, and other non-biodegradable items

The impact of deep-sea mining is expected to be at various levels in the water column that includes generation of plume at the seafloor, turbidity in the water column, and addition of bottom sediments to the surface waters resulting in change in the marine ecosystem (Fig. 17.1), as well as on land owing to collection, separation, lifting, transportation, processing, and discharge of effluents (Fig. 17.2). According to an estimate, for the cut off nodule abundance of 5 kg/m^2, an area of 300–600 km^2 will be disturbed every year for mining of 1.5–3 million metric tonnes of nodules per year (Sharma 2011), and with every tonne of manganese nodules mined from seabed, 2.5–5.5 tonnes of sediment will be resuspended (Amos and Roels 1977).

A summary of the probable impacts at various levels in the water column has been given in the following section (ISA 1999):

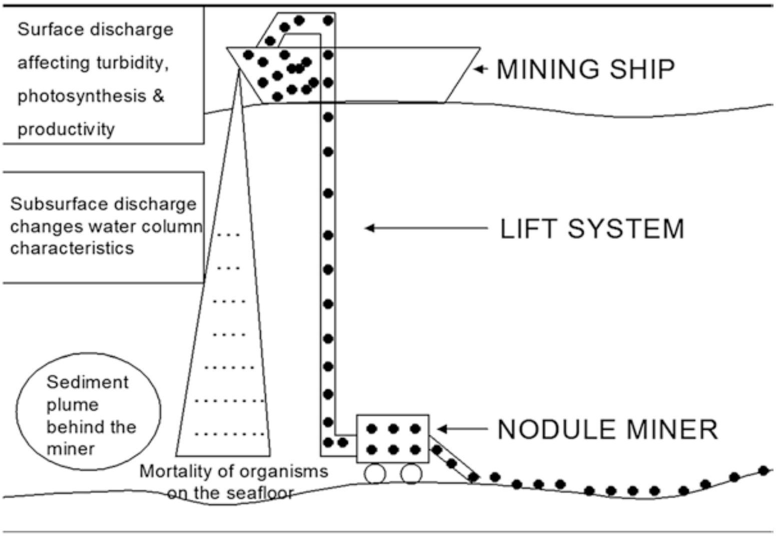

Fig. 17.1 Schematic for environmental impact of deep-sea mining

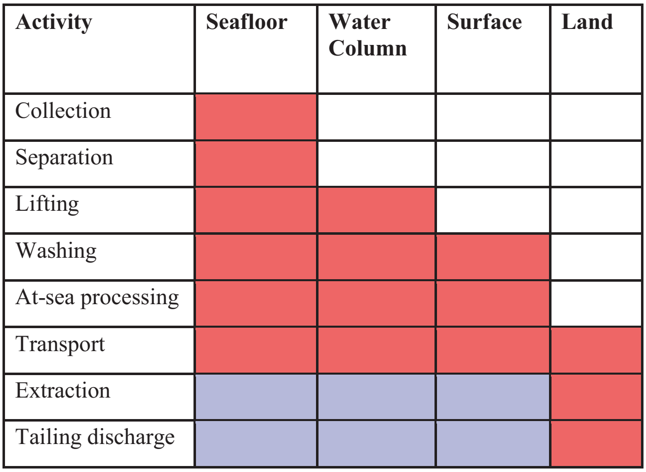

Fig. 17.2 Areas likely to be affected due to different activities of deep-sea mining

17.2.1 Potential Seafloor Impacts

It is anticipated that the primary benthic impacts caused by mining will be (Fig. 17.3):

- Direct impacts along the track of the nodule collector, where the sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed;

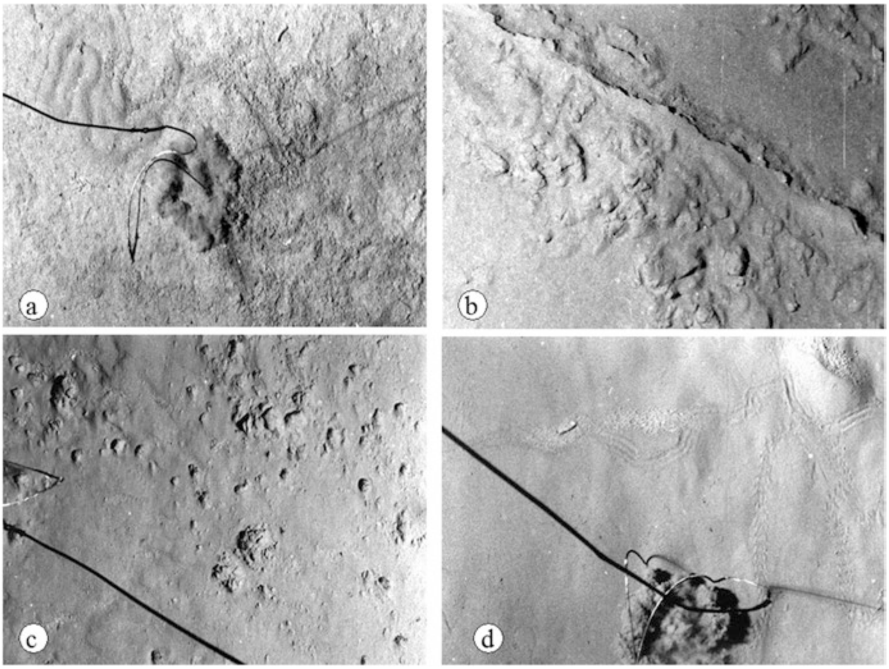

Fig. 17.3 (**a**) Seafloor with animal tracks before the disturbance, (**b**) 'disturber' track on the seafloor, (**c**) sediment lumps close to the disturber track, (**d**) resedimented surface after disturbance experiment

- Smothering or entombment of the benthic fauna away from the site of nodule removal, where the sediment plume settles; and
- Clogging of suspension feeders and dilution of deposit-feeders food resources.

17.2.2 Potential Water-Column Impacts

Discharge of tailings and effluent below the oxygen-minimum zone may cause some environmental harm to the pelagic fauna, such as:

- Mortality of zooplankton species at mid-water depths or that migrate to these depths
- Effects on meso-and bathypelagic fishes and other nekton caused directly by the sediment plume or associated metallic species or indirectly through impact on their prey
- Impacts on deep-diving marine mammals
- Impacts on bacterioplankton through addition of fine sediment in meso- and bathypelagic zones
- Depletion of oxygen by bacterial growth on suspended particles
- Effects on fish behaviour and mortality caused by the sediments or trace metals
- Mortality of and changes in zooplankton species composition caused by discharges

- Dissolution of heavy metals (e.g. copper and lead) within the oxygen-minimum zone and their potential incorporation into the food chain
- The possible clogging of zooplankton by filtering particles in the plume.

17.2.3 Potential Upper-Water Column Impacts

If tailings consisting of sediment and effluent are discharged in near-surface waters (and above the thermocline), then there are additional impacts to those listed above, as follows:

- The potential for trace-metal bioaccumulation in surface waters due to discharges from the test mining
- Reduction in primary productivity due to shading of phytoplankton by the surface discharge
- Effects on phytoplankton from trace metals in the surface discharge
- Effects on behaviour of marine mammals by the mining operation.

17.3 Global Efforts to Understand the Environmental Impacts

Several studies to assess the potential impacts of deep-sea mining have been carried out, most of them in the Pacific Ocean and one in the Indian Ocean. These are briefly described as under:

17.3.1 Deep Ocean Mining Environment Study by OMI and OMA, USA

The **D**eep **O**cean **M**ining **E**nvironment **S**tudy (DOMES, 1972–1981) conducted by National Oceanic and Atmospheric Administration (USA) monitored environmental impacts during two of the pilot scale mining tests conducted by the Ocean Mining Inc. and the Ocean Mining Associates (OMA) in 1978 in the Pacific Ocean. During the study, the concentration of particulates was measured in the discharge and the biological impacts in the surface as well as benthic plumes were assessed (Ozturgut et al. 1980).

17.3.2 Disturbance and Re-colonisation Experiment by Germany

The **DIS**turbance and Re-**COL**onisation (DISCOL) experiment was conducted by the scientists of the Hamburg University, Germany, in the Peru Basin in the Pacific Ocean from 1988 to 1998. Collection of pre-disturbance baseline environmental data was followed by the disturbance caused by a plough harrow in a circular area of 10.8 km^2 (Foell et al. 1990). Post-disturbance studies were carried out to monitor the impact and recolonisation after 6 months, 3, and 7 years. The results have shown that over a period of time, although certain groups of benthic organisms may show a quantitative recovery, the faunal composition is not the same as the undisturbed one (Schriever et al. 1997).

17.3.3 Benthic Impact Experiment by NOAA, USA

The **B**enthic **I**mpact **E**xperiment (NOAA-BIE) by the National Oceanic and Atmospheric Administration (NOAA, USA) was conducted in the Clarion Clipperton Fracture Zone (CCFZ) of the Pacific Ocean (1991–1993). After baseline studies in a pre-selected area, the Deep-Sea Sediment Resuspension System (DSSRS) (Brockett and Richards 1994) was used for 49 times in an area of 150 × 3000 m. The post-disturbance sampling indicated changes in the faunal distribution in the area (Trueblood 1993) and monitoring observations after 9 months indicated that, whereas some of the meiobenthos showed a decrease in abundance, the macrobenthos showed an increase in their numbers probably due to increased food availability (Trueblood et al. 1997).

17.3.4 Japan Deep-Sea Impact Experiment by MMAJ, Japan

The **J**apan deep-sea impact **E**xperimen**T** (JET, 1994–1997) was conducted by MMAJ (Metal Mining Agency of Japan) in the CCFZ of the Pacific Ocean in 1994 with the DSSRS. Disturbance was created during 19 transects over two parallel tracks of 1600 m length (Fukushima 1995). The impact was assessed from sediment samples, deep-sea camera operations, sediment traps, and current meters and the results show that the abundance of meiobenthos decreased in deposition areas immediately after the experiment and returned to originals levels 2 years later, but the species composition was not the same; whereas the abundance of certain groups of mega and macro-benthos was still lower than the undisturbed area (Shirayama 1999).

17.3.5 Interoceanmetal: Benthic Impact Experiment by East European Consortium

A **B**enthic **I**mpact **E**xperiment was conducted by Interoceanmetal (IOM-BIE) Joint Organisation, in CCFZ in Pacific Ocean in 1995, using DSSRS. In all, 14 tows were carried out on a site of 200 × 2500 m and the impact was observed from deep-sea camera tows and sediment samples (Tkatchenko et al. 1996). The results have shown that whereas no significant change was observed in meiobenthos abundance and community structure in the re-sedimented area, alteration in meiobenthos assemblages within the disturbed zone was observed (Radziejewska 1997).

17.3.6 Indian Deep-Sea Environment Experiment by NIO, India

The **In**dian **D**eep-sea **E**nvironment E**x**periment (INDEX) was conducted by National Institute of Oceanography (CSIR-NIO, Goa, India) in 1997 under the polymetallic nodules program of the Ministry of Earth Sciences in the Central Indian Ocean Basin. The DSSRS was used 26 times in an area of 200 × 3000 m, during which about 6000 m^3 of sediment was resuspended. The post-disturbance impact assessment studies have indicated lateral migration and vertical mixing of sediment leading to changes in physico-chemical conditions (Sharma et al. 2001) and reduction in biomass around the disturbance area (Ingole et al. 2001). Subsequent monitoring of the conditions showed that restoration and recolonisation process had started and the natural variations had taken over in the impacted areas.

17.4 Evaluating the Results of the Benthic Impact Experiments (BIEs)

17.4.1 Mechanism of the Experiments

The DISCOL experiment was conducted from multi-directions, in contrast to the other BIEs, which were conducted in single direction, thereby disturbing an elongated stretch of the seafloor. During the DISCOL, the emphasis was on scraping the seabed, as against the BIEs, which concentrated on sediment re-suspension. Both of these operations, being complimentary to each other in the actual mining scenario, contributed in different ways to study the potential impacts on the seafloor environment.

Whereas the device used in DISCOL (plough harrow) led to mixing up the seafloor sediments due to its ploughing action from different directions, the device used by other BIEs (DSSRS, also called as the 'disturber') not only compacted the sediment along its towing track, but also resuspended and redistributed the sediment to adjacent areas. The outcomes of these studies (other than DOMES) are given n Table 17.2. These experiments not only provided an opportunity for evaluation of baseline seafloor conditions associated with the mineral deposits not well known previously, but also produced results that initiated the understanding of the potential impacts that can now be extrapolated through suitable models.

17.4.2 Scale of the Experiments

A comparison of BIEs to commercial mining (Table 17.3) shows that whereas the operation time of the BIEs lasted for 18–88 h, a large-scale mining operation is expected to continue for about 300 days per year (UNOET 1987). The distance

Table 17.2 Sediment properties and outcomes of different Benthic Impact Experiments

Experiment name	No. of tows	Duration of disturbance (min)	Distance covered (km)	Average speed (km/h)	Water content (%)	Density (g/cm^3)	Sediment content (g/l)	Weight of sediment		Volume of sediment		Depth of excavation (mm)
								Dry (t)	Wet (t)	Recovered (m^3)	Discharged (m^3)	
(a) NOAA-BIE	49	5290	141+	1.6+	73.0+	2.7+	33.30	1500 (1332+)	4888	4000 (4049+)	4328 (6951+)	29+
(b) JET	19	1227	32.7	1.6+	78.5+	2.7+	38.30	355+	1651+	1427+	2495+	44+
(c) IOM-BIE	14	1130	35.0	1.8+	80.0	2.7+	42.10+	360+	1800	1573+	1300	45+
(d) INDEX	26	2534	88.3	2.1+	84.5	2.6+	30.23	580+	3737+	3380+	6015+ (2693+)	38+

Yamazaki and Sharma (2001)

Numbers given in the table with (+) are estimated by authors, the others are taken from

(a) Trueblood (1993), Nakata et al. (1997), and Gloumov et al. (1997)

(b) Fukushima (1995)

(c) Tkatchenko et al. (1996) and Kotlinski (personal communication)

(d) Sharma and Nath (1997), Sharma et al. (1997), and Khadge (1999)

Table 17.3 Scale of benthic impact experiments vis-à-vis commercial mining

Parameter	BIEs data	Commercial mining data
Duration	18–88 h	300 days/year
Distance/area	33–141 km	300–600 km^2/years
Recovery	0.77–1.4 m^3/min	37.5 m^3/min

Yamazaki and Sharma (2001)

(and area) covered during these experiments ranged between 33 and 141 km (or 10.8 km^2) as compared to that of commercial mining (300–600 km^2). Similarly, the volume of sediment recovered during different experiments (1.16 m^3/min for JET, 0.77 m^3/min for NOAA-BIE, 1.39 m^3/min for IOM-BIE, and 1.33 m^3/min for INDEX) ranges between 2 and 3.7% of the estimated volume of sediment (i.e. 54,000 m^3/day, i.e. 37.5 m^3/min) expected to be recovered during a commercial mining operation (Yamazaki et al. 1991). Hence, all these experiments can be considered as micro-scale experiments in terms of duration, area coverage as well as sediment re-suspension. In future, it may be advisable to conduct similar experiments on relatively larger scale in order to study the impacts of such a disturbance on the benthic ecosystem, because the scale directly affects the area and thickness of re-sedimentation.

The thickness of deep-sea sediment layer expected to be excavated by a commercial scale collector was calculated as 57 mm on the basis of 10,000 t/day nodule production rate in wet condition and other assumptions (Yamazaki et al. 1991). The estimated average depth of sediment excavated during different experiments is 29–45 mm (Table 17.2). Since most nodules range in size between 2–4 cm and many of them are half exposed on the seafloor, this depth of excavation appears to be adequate to simulate the depth of excavation for recovery of nodules.

17.4.3 Estimation of Weight and Volume of Sediment Discharge

Sediment properties such as water content and density play a key role estimation of weight and volume of sediments discharged during a mining operation as these sediments are responsible for the environmental impact on the seafloor. Whereas water content determines the weight of water and sediment discharged, the density helps determine the volume. The total weight divided by the total estimated volume also gives the bulk density of the sediment layer recovered from the seafloor, which is an important factor for the design of a mining system. The estimation of dry weight and wet volume of sediment at the discharge point are also important for calculating the weight and volume of sediment discharged during an operation. Whereas the dry weight of sediment is estimated in terms of weight per volume, the volume of sediment is the volume concentration ratio of the discharged sediment with respect to the total volume (Yamazaki and Sharma 2001).

17.4.4 Extrapolation to Commercial Mining

In spite of the data from different experiments and estimations based on these for evaluating the possible effects of future mining activities, many questions remain unanswered, due to the limited scope of these studies. One of the major questions is 'What will be a likely mining system or systems in next 20 years that can be a basis of environmental tests? It is difficult to specify 'commercial-scale' now, because commercial system size and type are likely different depending upon the use of nodule elements and production target, and can vary with metal market situation' (Chung et al. 2001). It has also been suggested earlier that for arriving at a proper design of a mining system to minimize the environmental impact, it is important that the scale of 'experimental' mining should be representative of commercial mining venture which should preferably be the pilot mining system (Markussen 1994).

17.5 Environmental Considerations for Deep-Sea Mining

As early as the 1970s, several studies had indicated the potential impacts of different mining systems such as Continuous Line Bucket, Air-Lift, Hydraulic-Lift (e.g. Amos et al. 1977) and some others also suggested procedures for safe deep-sea mining (e.g. Pearson 1975). This section summarises different measures that need to be taken into design considerations of the deep-sea mining system so as to minimise environmental impacts:

17.5.1 Collector Device

- There should be minimum interaction of the collector system with the seafloor environment, to keep it disturbance free.
- The separation of minerals from sediments (or other debris) should be as close as possible to the seabed, so that minimum water column is affected.
- Strip-wise (or 'patch') mining to be carried out, leaving alternate strips of undisturbed seafloor, to allow re-population by organisms from adjoining areas.

17.5.2 Surface Discharge

- Sediment discharge should be the least at the surface, to allow sufficient sunlight to penetrate for photosynthetic activity.

- Any surface water discharge can be sprayed over a large area so that it can get diluted without much delay.
- Discharge of bottom waters and debris should be at different levels of water column preferably below the oxygen minimum zone where the faunal density is relatively lower than in the levels above

17.5.3 At-Sea Processing, Ore Transfer, and Transport

- Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge.
- Proper care to be taken during transfer of ore from the collector to the mining platform as well as the transport vessels to avoid spilling.
- Oil spills from these ships also should be monitored.

Few other considerations to predict the severity of deep-sea mining could be as follows:

- The proportion of area that will be affected, with respect to total area
- Influence of surface and subsurface currents in different seasons
- Distance of coastal areas and inhabited areas from the area of influence
- Existence of fishing potential or any other commercial activity in the area of influence

17.6 Environmental Management Plan for Deep-Sea Mining

An Environmental Management Plan can be defined as 'The synthesis of all proposed mitigation and monitoring actions, set to a timeline with specific responsibility assigned and follow-up actions defined. The EMP is one of the most important outputs of the environmental assessment process' (World Bank 1999). It can also be defined as '..... a tool used to ensure that undue or reasonably avoidable adverse impacts of the construction, operation and decommissioning of a project are prevented; and that the positive benefits of the project are enhanced' (Lochner 2005).

Very often Environmental Management Plan (EMP) and Environment Impact Assessment (EIA) are used interchangeably. An EIA is a process of assessing and analysing the potential or actual environmental impacts (positive or negative) of a project. The output of this process is an EIA report which normally should culminate into an EMP. Hence, an EMP is essentially an action plan based on the results of the EIA study that would spell-out specific strategies to minimize the negative impacts. Environmental management plans are thus an outcome of a thorough environmental assessment process of any development activity.

There is a need, therefore, for environmental management actions to be properly addressed in EMPs and thereby improve the effectiveness of EIA (University of Manchester 2003).

The objectives of an EMP should include (World Bank 1999; Hill 2000):

- Ensuring compliance with regulatory authority stipulations and guidelines which may be local, provincial, national, and/or international;
- Ensuring that there is sufficient allocation of resources on the project budget so that the scale of EMP-related activities is consistent with the significance of project impacts;
- Outlining the mitigation measures for the anticipated negative impacts of the proposed activity
- Verifying environmental performance by monitoring the information on impacts as they occur;
- Responding to changes in project implementation not considered in the EIA;
- Responding to unforeseen events; and
- Providing feedback for continual improvement in environmental performance

Hence, an EMP would flow from the EIA and should continue throughout the life of the project. The format for an EMP and its contents would vary with the purpose for which it is being designed and the scale of the project. Another important feature of the EMP is that it should be dynamic. As the project gets into the operational stage, major impacts occur and as the processes keep changing, the impacts vary. Thus, a periodic review of the management plan is required. The extent to which EMPs should be reviewed and updated varies between and within sectors (World Bank 1999). Institutional arrangements should be made such that the implementation and review of the plan is built into the functioning of the system.

17.7 International Regulating Agencies for Deep-Sea Mining

17.7.1 United Nations Convention on the Law of the Sea

United Nations Convention on the Law of the Sea (UNCLOS), also known as the Law of the Sea Convention, defines the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. The members who ratify the Convention have the general obligation to prevent, reduce, and control pollution of the marine environment from any source, to monitor the risks or effects of pollution, and to assess the potential effects of activities under the States parties jurisdiction and control that may cause substantial pollution of or significant and harmful changes to the marine environment (UNCLOS 1982).

17.7.2 International Seabed Authority

The International Seabed Authority (ISA) is responsible for administering the mineral resources of the Area (i.e. areas beyond the Exclusive Economic Zones or national jurisdictions of any country), including prospecting, exploration, and exploitation activities for the resources (UNCLOS 1982). As part of its responsibility, the Authority is charged with taking the measures necessary to ensure effective protection of the marine environment from the harmful effects that may arise from such activities.

Thus, the ISA has laid down appropriate rules, regulations, and procedures that govern the actions of the Pioneer Investors (ISA 2011) with an aim to:

- Prevent, reduce, and control pollution and other hazards to the marine environment, including the coastline, that have the potential to interfere with the ecological balance of the marine environment. It states that attention is required to protect the environment from the harmful effects of all the activities such as drilling, dredging, excavating, disposing of waste, and constructing and operating or maintaining installations, pipelines and other devices;
- Protect and conserve the natural resources of the Area, preventing damage to the flora and fauna of the marine environment. (UNCLOS 1982).

In order to provide a guideline to the Contractors, ISA has developed preliminary requirements for EMP for the Clarion–Clipperton Zone of the Pacific Ocean (ISA 2011). Also, ISA has issued guidelines to Contractors for environmental monitoring due to exploration of polymetallic nodules (ISA 2013).

17.7.3 International Maritime Organization

International Maritime Organization (IMO) regulates the international shipping industry. Its main task is to develop and maintain a comprehensive regulatory framework for shipping (www.imo.org). As many of the proposed mine sites for the deep-sea minerals are in the international waters and might be falling in the way of some shipping routes, IMO must be informed and involved while planning the mining operations. International Convention on Preservation of Pollution from Ships (MARPOL) and International Convention on Safety of Life at Sea (SOLAS) are conventions under IMO which provide guidelines for prevention of pollution at seas and safety of life at sea, respectively. These govern all the merchant ships and could be applicable to the mining as well as transport ships as well.

17.7.4 World Meteorological Organization

World Meteorological Organization (WMO) provides framework for international cooperation in meteorology (weather and climate), operational hydrology, and related geophysical sciences (www.wmo.int). WMO can be helpful in providing real or near-real time data about the weather, environment, and natural disasters.

In addition to these, there would be several national agencies such as those dealing with mining, environment, and pollution that would also have a role in regulating activities within the EEZ as well as the territorial waters and on land once the ore is brought to shore for further processing.

17.8 Mitigation of Impacts Due to Different Activities

17.8.1 Components of Marine Mining and Their Mitigation Measures

The entire activity can be divided into four broad components such as exploration, environmental studies, mining, and processing (Fig. 17.4), which could further be divided into several sub-activities. It is expected that the place, type, and magnitude of environmental impact due to mining will vary depending upon the type and intensity of these sub-activities that will have to be compliant with guidelines laid down in international conventions (Table 17.4).

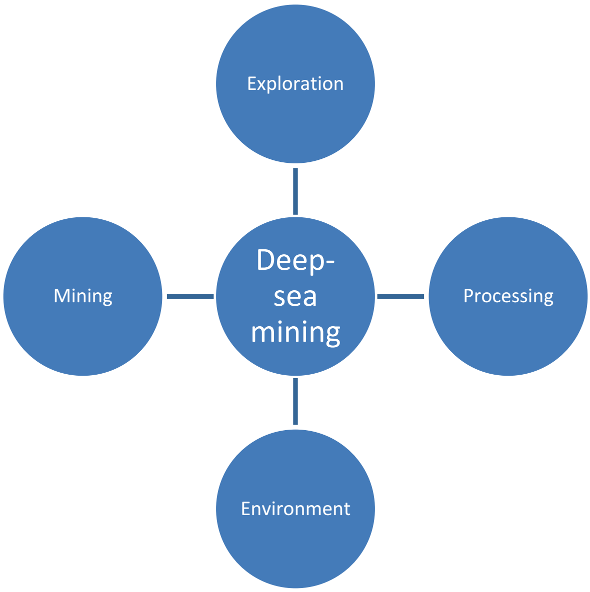

Fig. 17.4 Major components of deep-sea mining

Table 17.4 Activity-wise impacts and mitigation guidelines

Activity	Place of impact	Type of impact	Magnitude of impact	Mitigation guidelines
1. Exploration				
Cruising	Atmosphere, sea surface, water column, seafloor	Emissions, noise, heated water, oil, garbage (plastics, metal, glass, chemicals), human waste	Minor	As per SOLAS and MARPOL guidelines
On-board data collection (including radio communication and echo sounding)	Atmosphere, sea surface	Impacts on humans and marine animals due to propagation of waves through air and water	Minor	As per SOLAS guidelines (Chap. 4)
Sample collection	Water column, seafloor	Physical disturbance, chemical reactions, changes in faunal abundance and diversity, alteration in seafloor micro topography	Minor	As per MARPOL and ISA guidelines
2. Environment assessment				
Cruising	Atmosphere, sea surface, water column, seafloor	Emissions, noise, heated water, garbage (plastics, metal, glass, chemicals), human waste	Minor	As per SOLAS and MARPOL guidelines
Experimental EIA	Water column, seafloor	Turbidity, mixing of sediments, alteration in faunal assemblage	Medium	As per MARPOL and ISA guidelines
Baseline data collection and environmental monitoring	Water column, seafloor	Physical disturbance, chemical reactions, changes in faunal abundance and diversity, alteration in seafloor micro topography	Minor	As per MARPOL and ISA guidelines
3. Mining				
Cruising	Atmosphere, sea surface, water column, seafloor	Emissions, noise, heated water, oil, garbage (plastics, metal, glass, chemicals), human waste	Medium	As per SOLAS and MARPOL guidelines
Deployment and operation of equipment	Surface, water column, seafloor	Physical disturbance, chemical reactions, changes in faunal abundance and diversity, alteration in seafloor micro topography	Major	Minimum sediment penetration, avoid leakage/spillage, discharge below oxygen minimum zone, treat tailings before discharge

(continued)

Table 17.4 (continued)

Activity	Place of impact	Type of impact	Magnitude of impact	Mitigation guidelines
Ore transfer	Surface, Water column, Seafloor	Turbidity, mixing of sediments, alteration in faunal assemblage	Medium	As per SOLAS and MARPOL guidelines
Transport	Atmosphere, sea surface, water column, seafloor	Emissions, noise, heated water, oil, garbage (plastics, metal, glass, chemicals), human waste	Medium	As per SOLAS and MARPOL guidelines
At-sea pre processing	Surface, water column, seafloor	Turbidity, mixing of sediments, alteration in faunal assemblage	Medium to Major	As per SOLAS and MARPOL guidelines
Power generation (nuclear, solar or ocean thermal)	Surface, water column, seafloor	Alteration in the physico-chemical conditions, waste disposal	Medium to Major	As per SOLAS and MARPOL guidelines
4. Processing				
Transportation	Land, air	Emissions, noise, dust	Minor to Medium	As per national guidelines
Storage	Land, air, water	Growth of microbes and chemical alteration		As per national guidelines
Washing/pre-processing	Land, air, water	Leaching of clay particles, nodule fragments and massive microbes	Minor	As per national guidelines
Extraction	Land, air, water	Addition of chemicals and reagents to the environmental resources	Medium to Major	As per national guidelines
Waste disposal	Land, air, water, sea	Addition of slag to the environment	Major	As per national guidelines

17.8.2 Measures for Developing environmentally 'Safe' Mining System

Deep-sea mining is still in its developmental stages; hence the best environment management practices can be incorporated into the design, technology, scheduling, and monitoring of the activity. Some of the fundamental considerations to keep the impacts to a minimum level have been enlisted by ISA (2001) and are as under:

1. Minimize sediment penetration of collector and mining vehicle
2. Avoid disturbance of the more consolidated suboxic sediment layer
3. Reduce mass of sediment swirled up into the bottom near-water layer
4. Induce high rate of re-sedimentation from the plume behind the miner
5. Minimise the transport of sediment and abraded nodule fines to the ocean surface
6. Reduce the discharge of tailings into the bathyal or abyssal depth
7. Reduce the drift of tailings by increasing their sedimentation

17.8.3 Identification of Preservation Reference Zone (PRZ)

ISA defines Preservation Reference Zone as 'Areas in which no mining will occur to ensure representative and stable biota of the seabed in order to assess any changes in the flora and fauna of the marine environment.' The preservation reference zone(s) should be carefully located and large enough so as not to be affected by the natural variations of local environmental conditions. The zone(s) should have species composition comparable to that of the test mining area(s). The preservation reference zone(s) should be located upstream of the test mining area(s). The preservation zone(s) should be outside of the test mining area(s) and areas influenced by the plume (ISA 1999).

Further, ISA has also proposed certain guidelines for identifying/proposing preservation zone(s) (ISA 2008) as follows:

- The design and implementation should fit into the existing legal framework of the International Seabed Authority.
- The interest of all stakeholders should be incorporated into the design process. Stakeholders include ISA, signatories of UNCLOS, mining claim holders, non-governmental organization, and the scientific community.
- The conservation goals to be followed should consider preservation of marine biodiversity, unique marine habitats, and the ecosystem structure and function along with management of mining activity in a sustainable manner.
- The zones should be identified taking into consideration the productivity gradients in the ecosystem structure of the area.
- The boundaries of the preservation zones must be straight lines in order to facilitate rapid recognition.
- The core area of the preservation zone should be at least 200 km in length and width. This size of the area is required to maintain minimum viable population of the species.

- The preservation zone should contain full range of habitat types found within the region
- The preservation zone should be surrounded by a buffer zone of 100 km.

17.8.4 Hazard Management

Hazard management is an important part of the EMP. At the mine site, the hazards can be categorised as human-induced and natural. A brief description about these is as under:

17.8.4.1 Human-Induced Hazards

Safety of Life: The International Convention for the Safety of Life at Sea (SOLAS) specifies minimum standards for the construction, equipment, and operation of ships, compatible with their safety (www.imo.org). All mining activities along with its personnel will be required to abide by the convention which has provisions for the following:

- General Provisions regarding survey and documentation
- Stability of the vessel, machinery, and electrical installations
- Fire protection, detection, and extinction
- Life-saving appliances and arrangements
- Radio-communications
- Safety of navigation
- Carriage of cargoes and dangerous goods
- Nuclear ships
- Management of Safe Operations of ships
- Special measures to enhance maritime safety

Pollution hazards: The International Convention for the Prevention of Pollution from Ships (MARPOL) deals with prevention of pollution of the marine environment by ships from operational or accidental causes (www.imo.org). As marine mining will comprise of a stationed ship as its base as well as several ore carriers and supply vessels, these will be governed by MARPOL as per the following regulations:

- Regulations for the Prevention of Pollution by Oil
- Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk
- Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form
- Prevention of Pollution by Sewage from Ships
- Prevention of Pollution by Garbage from Ships
- Prevention of Air Pollution from Ships

Pirate attacks and role of defence agencies: Piracy and marine robbery are threats to the safety of the personnel and the mining equipment deployed at the mine site. International Maritime Bureau (IMB) deals with all types of maritime crimes and malpractices (www.icc-ccs.org). As incidents of piracy at high seas are reported frequently, adequate measures may have to be taken by the concerned national and international agencies to ensure safety of their personnel and machinery.

17.8.4.2 Natural Hazards

Hazards related to natural conditions such as cyclones, winds, waves, and currents will also have to be monitored either based on meteorological data provided by World Meteorology Organisation (www.wmo.int), local weather forecasting stations, or by deploying weather data stations in and around the mining areas and contingency plans for evacuation, maintenance, repairing as well as meeting with any emergency situation will have to be put in place in the EMP by each Contractor.

17.9 Institutional Set-Up and EMP Framework

17.9.1 Establishment of Environmental Monitoring Office

For the effective implementation of the proposed plan, institutional mechanisms need to be in place right from the beginning and the monitoring activities scheduled appropriately. Thus, a dedicated Environmental Management Office (EMO) must be set up by the Contractor with clear roles, responsibilities, and authorities. A probable structure of the EMO along with other departments/offices under the Contractor is given in Fig. 17.5.

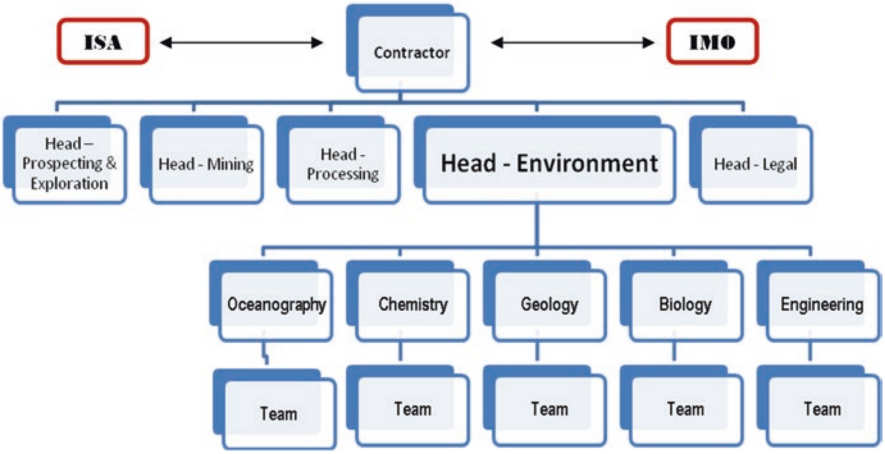

Fig. 17.5 Proposed structure of the Environmental Management Office

The structure proposes that the EMO and its Head, Environment be given equal status and importance as that of the other major departments. This would grant them authority to implement the EMP properly. The EMO should be advised by an Environmental Consultant, who keeps the office abreast with the latest developments on the subject, including assessment, monitoring, and mitigation techniques and ensures compliance with international regulations. Environment being a multidisciplinary field, the composition of EMO should have scientists and technicians from oceanography, chemistry, biology, geology, and engineering who would be involved in data collection in the field as well as analyses and report preparation in the office as per the guidelines and requirements of the regulating agencies.

Roles and Responsibilities of the EMO will include the following:

- Monitor all environmental parameters for assessment of effects of all activities related to mining
- Develop mitigation techniques in consultation with other departments
- Review and adopt new technologies for environmental monitoring and management
- Organise awareness and training programmes
- Coordinate with ISA and other agencies
- Continuously improvise the EMP
- Prepare a mine closure plan and ensure its implementation

17.9.2 Proposed Framework for EMP

A broad framework of the EMP is proposed as follows:

Section	Chapter	Contents
Section 1	Project description	Contractor brief
		Geographical area
		Economic feasibility
		Mining area delineation and estimation of area to be mined
		Concepts of proposed mining activity
Section 2	Environmental assessment	Results of experimental mining (or based on other studies)
		Potential impacts of commercial mining
Section 3	Mitigation of impacts due to various activities	Major components of marine mining
		Detailed sub-activities with mitigation measures
		Measures for developing environmentally safe mining system
		Identification of Preservation Reference Zone
		Hazard management
Section 4	Institutional set-up and monitoring	Institutional set-up
		Monitoring method and schedule
		Review

The EMP thus prepared for deep-sea mining should be reviewed from time to time for updating and to bring about necessary modifications depending upon the changes in technology or operating methods.

The review may be conducted at following intervals:

- Before commencement of the mining operation—once every 2 years
- During mining operation—every year
- After mining operation—every year until closure is filed

17.10 Conclusions

The world is on a path of rapid growth and development which are propelled extensively by non-renewable sources of energy. Minerals and metals play a vital role in the growth-driven economy. Man has been excavating the minerals mostly from the land. However, as the land resources are depleting at a fast rate and the demand of metals for industrial growth is increasing, man has discovered marine minerals which are a potential source of strategically important metals for industrial growth.

As marine mining evolved, it has passed through various stages of exploration, development of technology, as well as setting up of international regulating agencies for developing framework for eventual mining. Deep-sea mining system will consist of a surface platform, a miner device, and a riser which connects the two as well as several transport and supply vessels. The operations are expected to have certain environmental impacts not only at the seafloor where the minerals will be mined, but also the sea surface from where most of the activities will be conducted and the water column through which the ores will be lifted and unwanted material be discharged. The miner will crush the benthic organisms and lead to dispersion of the sediments associated with the minerals. Discharge of tailings, sediments, and effluent in the near surface waters will have adverse effects on the water quality and in turn affect the biota of the region and spillage will impact the water column.

Different Contractors have carried out baseline studies and experimental mining in order to understand the marine environment and the possible effects mining could have on it. With the entire world becoming increasingly aware about the conservation of environment, adopting sustainable practices from the developmental stages has given rise to the need for developing an environmental management plan for marine mining.

An environmental management plan is an outcome of the environmental impact assessment process which contains mitigation and monitoring plans to ensure undue and reasonably avoidable adverse impacts of various activities involved in the project. It would also ensure compliance to the guidelines laid down by the regulating authorities and allocation of resources for its strict adherence. This chapter reviews the likely impacts of deep-sea mining, evaluates the results of benthic impact experiments, discusses measures for reducing environmental impacts, highlights the role of various regulating agencies as well as proposes a framework for preparation of an environmental management plan that could be adopted for conservation of marine ecosystem.

Acknowledgment The author acknowledges the contribution of Ms. Pooja Kamat in compiling information for certain sections of this chapter during her internship at the Institute.

References

Amos AF, Roels OA (1977) Environmental aspects of manganese nodule mining. Mar Pol Int Bull 1:160–162

Amos AF, Roels OA, Garside C, Malone TC, Paul AZ (1977) Environmental aspects of nodule mining. In: Glasby GP (ed) Marine manganese deposits, Elsevier Oceanographic series 15. Elsevier Scientific, Amsterdam, pp 391–438

Brockett T, Richards CZ (1994) Deep-sea mining simulator for environmental impact studies. Sea Technology, August, pp 77–82

Chung JS et al (2001) Deep seabed mining environment: preliminary engineering and environment assessment. Special report OMS-EN-1, International Society of Offshore and Polar Engineers. ISBN: 1-880653-57-5, pp 1–19

Foell EJ, Thiel H, Schriever G (1990) DISCOL: a longterm largescale disturbance—recolonisation experiment in the abyssal eastern tropical Pacific Ocean. In: Proc of offshore technology conference, Houston, USA, Paper No. 6328, pp 497–503

Fukushima T (1995) Overview "Japan Deep-sea Impact Experiment = JET". In: Proc. of 1st ISOPE ocean mining symp, Tsukuba, Japan, ISOPE, pp 47–53

Gloumov I, Ozturgut E, Pilipchuk M (1997) BIE in the Pacific: concept, methodology and basic results. In: Proc. of Int. Symp. Environmental Studies for Deep-sea Mining, Metal Mining Agency of Japan, Tokyo (Japan), pp 45–47

Hill RC (2000) Integrated environmental management systems in the implementation of projects. S Afr J Sci 96:50–54

IBM (2010) Indian Bureau of Mines Year book 2010

Ingole BS, Ansari ZA, Rathod V, Rodrigues N (2001) Response of deep-sea macrobenthos to a small-scale environmental disturbance. Deep Sea Res II 48(16):3401–3410

ISA (1999) Deep seabed polymetallic nodule exploration: development of environmental guidelines. In: Proc ISA workshop, Sanya, China, 1–5 June 1998, The International Seabed Authority, Pub No ISA/99/02, pp 222–223

ISA (2001) Recommendations for guidance of contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area. International Seabed Authority, Jamaica. ISBA/7/LTC/1/Rev.1

ISA (2008) Rationale and recommendations for the establishment of the preservation reference areas for nodule mining in the Clarion-Clipperton Zone. International Seabed Authority, Jamaica. ISBA/14/LTC/2

ISA (2011) Environmental Management Plan for the Clarion Clipperton Zone. International Seabed Authority, Jamaica. ISBA/17/LTC/7

ISA (2013). Recommendations for the guidance of contractors for the assessment of the possible environmental impacts rising from exploration for marine minerals in the area. International Seabed Authority, Jamaica, ISBA/19/LTC/8, pp 32

Khadge NH (1999) Effects of benthic disturbance on geotechnical characteristics of sediment from nodule mining area in the Central Indian Basin. In: Proc. of the third ISOPE—ocean mining symp., Goa (India), pp 138–144

Lochner P (2005) Guideline for environmental management plans. CSIR report no ENV-S-C. 2005-053 H. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town

Markussen JM (1994) Deep seabed mining and the environment: consequences, perception and regulations. In: Bergesen H, Parmann G (eds) Green Globe Yearbook of international cooperation on environment and development. Oxford Univ. Press, London, pp 31–39

Nakata K, Kubota M, Aoki S, Taguchi K (1997) Dispersion of resuspended sediments by ocean mining activity—modeling study. In: Proc. of int. symp. environmental studies for deep-sea mining, Metal Mining Agency of Japan, Tokyo (Japan), pp 169–186

Ozturgut E, Lavelle JW, Steffin O, Swift SA (1980) Environmental investigation during manganese nodule mining tests in the North Equatorial Pacific, in November 1978. NOAA Tech. Memorandum ERL MESA-48, National Oceanic and Atmospheric Administration, USA, 50

Pearson JS (1975) Ocean floor mining. Noyes Data Corporation, Park Ridge, 201pp

Radziejewska T (1997) Immediate responses of benthic meio- and megafauna to disturbance caused by polymetallic nodule miner simulator. In: Proc int symp environmental studies for deep-sea mining, Metal Mining Agency of Japan, Tokyo, Japan, pp 223–236

Schriever G, Ahnert A, Borowski C, Thiel H (1997) Results of the large scale deep-sea impact study DISCOL during eight years of investigation. In: Proc int symp environmental studies for deep-sea mining, Metal Mining Agency of Japan, Tokyo, Japan, pp 197–208

Sharma R (2011) Deep-sea mining: economic, technical, technological and environmental considerations for sustainable development. Mar Technol Soc J 45:28–41

Sharma R, Nath BN (1997) Benthic disturbance and monitoring experiment in Central Indian Ocean Basin. In: Proc 2nd ISOPE ocean mining symp, Seoul, Korea, ISOPE, pp 146–153

Sharma R, Parthiban G, Sivakholundu KM, Valsangkar AB, Sardar A (1997) Performance of benthic disturber in Central Indian Ocean. National Institute of Oceanography, Goa (India), Tech. Report NIO/TR-4/97, 22

Sharma R, Nath BN, Parthiban G, Sankar SJ (2001) Sediment redistribution during simulated benthic disturbance and its implications on deep seabed mining. Deep Sea Res II 48:3363–3380

Shirayama Y (1999) Biological results of JET project: an overview. In: Proc 3rd ISOPE ocean mining symp, Goa, India, ISOPE, pp 185–190

Tkatchenko G, Radziejewska T, Stoyanova V, Modlitba I, Parizek A(1996) Benthic impact experiment in the IOM pioneer area: testing for effects of deep-sea disturbance. In: Int seminar on deep sea-bed mining tech, China Ocean Mineral Resources R&D Assoc., Beijing, China, pp C55–C68

Trueblood DD (1993) US Cruise Report for BIE—II Cruise. NOAA Technical Memo OCRS 4, National Oceanic and Atmospheric Administration, Colorado, USA, pp 51

Trueblood DD, Ozturgut E, Pilipchuk M, Gloumov IF (1997) The echological impacts of the joint U.S.-Russian benthic impact experiment. In: Proc. int. symp. environmental studies for deep-sea mining, Metal Mining Agency of Japan, Japan, pp 237–243

UNCLOS (1982) United Nations Convention on the Law of the Sea. pp 7–202

University of Manchester (2003) EIA Centre. EIA Newsletter 12. www.art.man.ac.uk/EIA/publications/newsletters

UNOET (1987) Delineation of mine sites and potential in different sea areas. UN Ocean Economics and Technology Branch and Graham & Trotman Limited, London, 27pp

World Bank (1999) Environment management plans. Environ Assess Sourcebook Update 25:1–8

Yamazaki T, Sharma R (2001) Estimation of sediment properties during benthic impact experiments. Marine Georesour Geotechnol 19:269–289

Yamazaki T, Tsurusaki K, Handa K (1991) Discharge from manganese nodule mining system. In: Proc. of the first int. offshore and polar eng. conf., Edinburgh, UK, vol 1, pp 440–446

Websites (Accessed Between 10 June 2012 and 20 July 2012)

International Seabed Authority. www.isa.org.jm
International Maritime Organization. www.imo.org
International Maritime Bureau. www.icc-ccs.org/icc/imb
Wikipedia. www.wikipedia.org
World Meteorological Organization. www.wmo.int

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