ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

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Environmental Impacts of Deep-Sea Mining

Alexandra Antonopoulou

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Abstract

The urbanization, the rising of the population, the development of technology along with the elevating level of our everyday lives increase the need for mineral resources, which have multiple appliances. Until now, such deposits were found in terrestrial sites, which however, will soon expire. Therefore, the deep sea mining could be the solution to cover humanity's needs. However, the limited knowledge on deep sea ecosystems and restricted environmental baseline information currently available are prohibiting to move towards the mining of deep-sea resources, as serious harm can be caused to the environment. As the sea has no boundaries, mining activities can have impacts in various places and users of the marine area. To date, only test mining and exploration activities have taken place worldwide, without however moving to the next phase, which is the exploitation of the available deposits.

The Authority which regulates the deep-sea area (meaning the marine area beyond national jurisdiction) is the International Seabed Authority which, via a set of regulations and various recommendations and guidelines, controls the mining activities in the deep sea. The International Seabed Authority supports that the activities should take place basis a precautionary approach, adaptive management and to conduct Environmental Impact Assessment and Environmental Management Plans, as the goal is to proceed with mining in the future, but in a sustainable manner, to protect the deep sea environment for our sake and the generations to come.

Through studying the case of Clarion- Clipperton Fracture Zone, one of the areas with growing interest for its mining due to high concentration in polymetallic nodules, it has become apparent that the scientific knowledge is still limited, and it is the needful factor to address environmental thresholds in order to proceed with the mining phase. By raising scientific knowledge, and understanding the ecosystems and their connectivity, the environmental thresholds can be managed and understood, in order to avoid irreversible environmental harm.

Keywords: deep seabed mining, International Seabed Authority, Mining Code, deep sea deposits, Clarion- Clipperton Zone, polymetallic nodules, Areas of Particular Environmental Interest, impacts of deep seabed mining

Chapter 1: Introduction

1.1. Purpose of the study

To date, the supply of minerals is sought through mining in terrestrial sites. However, it is becoming apparent that such deposits will soon not suffice to cover our growing and demanding needs. Marine mining could therefore secure the supply for our needs, especially since the trend of such minerals are increasing worldwide, due to high technologies, which require rare earth elements, cobalt, titanium and others (Watzel et al., 2020; Navarre et al., 2017).

The main reasons for the rising demand of the seabed resources, is the raw materials demand, due to the rising of the global population, urbanization, the prosperity of emerging and developing countries, along with the prompt development of technology and its innovations. The global needs in raw material are caused because of the development in electric mobility, the continuous enlargement of renewable energy in industrial countries and the evolution of infrastructure in developing countries (Navarre et al., 2017). The principal factor forcing humankind to turn towards deep-seabed mining or other solutions, is that the demand for such minerals will keep increasing in the future, while the supply from ashore will, at some point, decrease and eventually, expire (Kim et al., 2017).

The deep-seabed mining constitutes a technological challenge. Seabed mining operations take place at a very technical and demanding environment, where groundbreaking solutions and best practice are needed, in addition to safety standards, which should be carried out with the aim of overcoming the challenges and obtain enormous economic benefits (Ranjith et al., 2017).

Starting from the late 1970, it has become apparent through various studies, risk assessments and experiments throughout the years, that the deep-seabed mining cannot be conducted without causing significant environmental adverse impacts

(Christiansen et al., 2020). So, beside the economical and societal aspects, it is extremely important to have an environmental scope as well. It is well known that the knowledge on the marine environment is limited. It is imperative to turn into science and education, in order to gain baseline knowledge in the marine mining sites, biodiversity and ecosystems, adopt a long-term strategy and proceed with precautionary approach to avoid any serious or irreversible damage to the environment. The knowledge gained from the research the last years, should also be turned to proper governance and policy, to preserve resources for generations to come (Fouquet Y. and Lacroix D., 2014).

This Master Thesis is focusing on the environmental impacts of Deep Seabed Mining, taking as a case study the Clarion Clipperton Fracture Zone. Firstly, it introduces the International Seabed Authority and describes the main three categories of interest, of Deep Seabed Deposits. Secondly, it presents the existing regulations, guidelines, and tools for Deep Seabed Mining. Thirdly, it presents the characteristics of Clarion Clipperton area, basis previous surveys, and experiments and the potential environmental impacts once exploitation of polymetallic nodules takes place. Finally, it discusses the growing need for deep seabed mining, compares mining in the deep sea and terrestrial sites, mentions circular economy and provides some proposals for minimizing environmental impacts basis current developments.

1.2. Deep Seabed Mining and the need for it

The deep-sea mining has been classified as one of the potential blue growth sectors, induced by the rising demand for ore (MIDAS, 2014). The growing interest for seabed mining is evident, as the signed exploration contracts of the Area[1] have increased over the last years (Watzel et al., 2020; Navarre et al., 2017).

The mining of the deep sea has the potential of becoming a highly valued industry, which is expected to take place within the forthcoming 25 years. The mining of the deep sea is now possible due to the development of technology, which has made it feasible to reach depths, spot places and resources which are now withing reach. As it is a complicated procedure, including also various stakeholders and scientists of different fields, it seems that it has conglomerate potential with the capacity to evolve and break into several highly prized industries (Montserrat et al., 2019).

Stakeholders are considered the potential contractors, sponsoring states, the international regulating parties and agencies, environmental organizations, researchers, financial institutions etc. These stakeholders may be a part of the International Seabed Authority's (ISA)[2] structure (ex. potential contractors of States), or not (ex. researchers) (Sharma, 2019).

It has been hypothesized that deep seabed mining can provide sustainable development through economic interests, which will be divided legitimately between the countries. Some opponents of seabed mining support that more competitive quotations will be provided by the ISA, in comparison to terrestrial mining, taking however into account the existing governance for the mining of the seabed. Keeping such presumption in mind, the benefits emerging would be moderate. Therefore, it is implied that the greatest benefit arising from seabed mining is the availability of useful and important to our everyday lives' minerals, which would profit the industrialized States, while the other ones will hardly recognize an economic impact. On the other hand, the supporters

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[1] *Area: the area beyond the States' national jurisdiction, in the deep sea, where, as per the United Nations Convention of the Law of the Sea (UNCLOS), all rights of the seabed's natural resources are entrusted in mankind.*

[2] *ISA is the organization through which all State Parties to United Nations Convention of the Law Of the Sea organize and control the mineral-resources-related activities in the Area for the benefit of mankind as a whole. In doing so, ISA has the mandate to ensure the effective protection of the marine environment from harmful effects that may arise from deep-seabed related activities.*

of seabed mining claim that through the availability of such minerals, ecological friendly technologies can be invented, which could be available at better prices (Kim et al., 2017).

Chapter 2: Deep Sea Mining Concept

2.1. International Seabed Authority (ISA)

2.1.1. The role of ISA

ISA was set up in 1994 under the 1982 UNCLOS and the 1994 Agreement identified the Implementation of Part XI of the UNCLOS, concerning the Area, its governance, and resources. To date, the ISA has approved 30 contracts for the exploration in the Area, with 21 contractors for the exploration of polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts (www.isa.org.jm).

The ISA is preparing regulations for the extensive exploitation of the seabed along with full ramifications on the environment, including the establishment of an Environmental Impact Assessment, the monitoring of the site and ecosystem conservation. This regulation concerns the Area (international waters), but also extends for mining operations within the Exclusive Economic Zones of the interested counties (Smith et al., 2020). One of the ISA’s main commitments is to balance the mining operations and the protection of the environment, safeguarding that the resources of the Area are beneficial to humankind (Tunnicliffe et al., 2018).

The ISA consists of three principle organs and subsidiary organs. The main organs are:

1. The Assembly, consisting of all the Member States that have ratified the UNCLOS.

2. The Council, consisting of 36 Member States elected by the Assembly.
3. The Secretariat, which provides facilitation to the Assembly and the Council.

The Council is the organ that ratifies the Regulations with regards to the seabed mining and the ultimate approval is provided by the Assembly.

One of the subsidiary organs is the Legal and Technical Commission (LTC) consisting of independent experts on marine geology, oceanography and experts relevant to legal and economic issues that may arise from the mining of the Area. They provide recommendations on scientific and technical matters concerning the Activities in the Area. The LTC has therefore various responsibilities, such as providing guidelines to the Council and Contractors, forming drafts of regulations, reviewing contractor applications and their annual reports and assessing the environmental impacts (Turner, 2018). It also has the power to disapprove mining in certain areas and to provide urgent recommendations during the conduction of activities, for the preservation of the environment and the avoidance of harm (Levin et al.,2016).

2.1.2. The Mining Code

The deep- seabed mining is a serious matter that has attracted policy attention. For the time being, ISA has demonstrated regulations, called the Mining Code. The Mining Code contains three sets of regulations that include information for all three phases (namely prospecting, exploration and exploitation) and a general framework for the marine environment protection. It is the Authorities' responsibility to identify how to incorporate such environmental concerns and ecosystem protection, while mining operations take place (Tunnicliffe et al., 2018, Turner, 2018).

It is important to define each phase as previously mentioned:

1. Prospecting phase: refers to the search of deposits without, however, any rights to the findings.
2. Exploration phase: refers to the search of deposits within the Area, in which there are exclusive rights. During this face, there is analysis of the deposits, testing and collection of systems and equipment, development of studies, etc.
3. Exploitation phase: refers to the recovery of the deposits from the seabed (Lodge, 2002).

The development of the Mining Code has two phases; the first is the development of regulations for the exploration and prospecting of the resources and the second phase the regulations concerning the exploitation of the seabed, which are currently under development. The ISA's goal is to carry deep-seabed mining in a way as to promote development in the world's economy, sustainability of resources for future generations and equal economic development to all states (including the land locked and developing ones) (Turner, 2018).

2.1.3. ISA's Contracts

One of the central roles of the ISA is to govern the resources of the Area. The exploration and exploitation of the resources should be conducted under a contract issued by the Authority. The contractors can be the Member States, or a third party, meaning a State- owned party or a private corporation sponsored by the State and effectively controlled by it (Turner, 2018).

To date, ISA has granted exploration permission with 21 contractors and a total of 30 fifteen-year-old contracts, where 18 of them are for polymetallic nodules, 7 for polymetallic sulphides and 5 for cobalt-rich ferromanganese crusts. Below map outlines the Member States or third parties that have been granted permission for exploration activities (www.isa.org.jm):

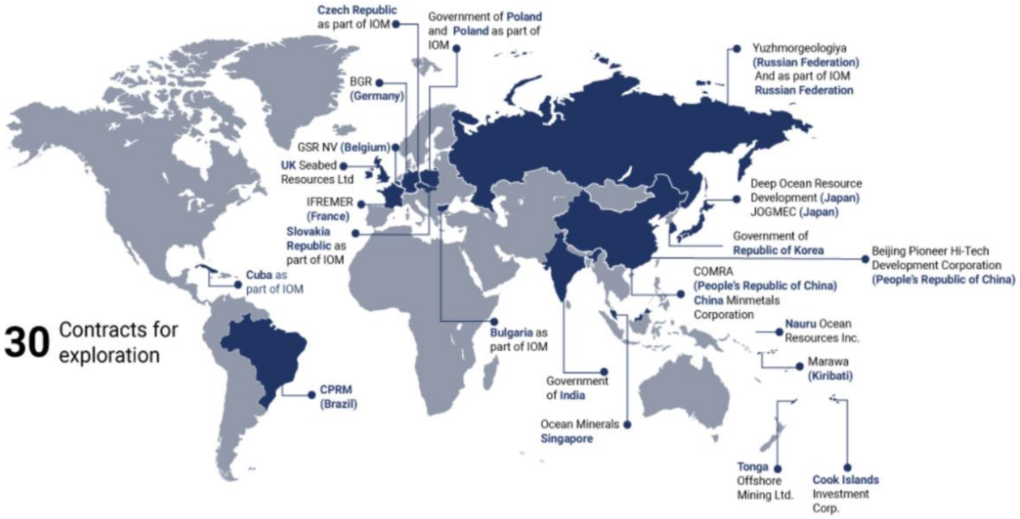

Figure 2.1. Member States and third parties holding exploration Contracts
Source: www.isa.org.jm

Prior to signing a contract for exploration, the ISA requests from the contractors to advice a program of activities for the exploration for a 5-year period and the collection of baseline environmental information. This way, an assessment of exploration and future exploitation can be conducted, reducing the possibility of uncertainties with regards to the environment. Those information and reports are also reviewed by the Legal and Technical Commission (LTC), which provides information on how to conduct such studies and how to standardize such collection of information methods. From the contractor, it is also required to submit an annual report on the mining activities, including the impact of the operations to the marine environment. Due to transparency, such reports are not accessible to the public, which is a fact however, that has raised concerns. The Authority also requires an Environmental Scoping Report, which construes the proposed activities, environmental objectives, and primary identification of the impacts (environmental, social, cultural and cumulative) (Turner, 2018).

2.2. Deep Sea Deposits

2.2.1. Seafloor Massive Sulfides (SMS)

Occurrence

The Seafloor Massive Sulfides could be characterized as vents, with height of about 40m, termed as “black smokers”. They are mostly found along the borderlines of the tectonic plates, which can have a length of approximately 60.000km and within volcanic locations, in depths of 1000–4000m. However, the deposits raising the most economic interest are located at depths between 1,500 to 3,500meters (Turner, 2018; Navarre et al., 2017).

The SMS are structured on hydrothermal places, where the sea water penetrates to the deep cracks, and it ingests metal sulfides and heat. This liquified mix is then discharged back to the cold ocean. SMS are accelerated of copper, zinc and other metals (such as gold and silver) that form where hydrothermal vent fluid is emitted from fractures in the seafloor. Due to high temperatures that can reach up to 450 degrees Celsius, the fluids containing metal encountering the seawater, which has much lower temperature, precipitates the particles of metal sulfide. Such particles afterwards accumulate into amounts of metal-rich sulfides (vents) that could still be active or inactive (Turner, 2018; Navarre et al., 2017).

The active vents, where fluid is still being emitted, are calculated to cover approx. $50km^2$ (Van Dover et al., 2017). The rareness of active hydrothermal vents creates many considerations with regards to the environmental management and the relevant ecosystem (Turner, 2018).

It is important to note however, that the mining of such deposits can only be conducted in inactive hydrothermal sites, as the mining in active ones is impossible due to the high temperature and the acidity, which will damage the mining equipment (Navarre et al., 2017). Moreover, even though exploitation is to take place at inactive vents only, they have particular synthesis and there is still, admittedly, limited environmental knowledge (Smith et al., 2020).

Polymetallic sulfides have a high composition of metal contents, making them the most invaluable choice for deep-sea mining. Sulfides can also contain concentration in gold, as high as 20gr per ton, while in the land deposits even 1 gr of gold is found in a site, it is considered a conclusive reason to proceed with mining operation (Navarre et al., 2017). Apart from gold, the seafloor massive sulfides also contain concentrations of silver, which have attracted various companies in the past for their mining, both in the East Pacific but also in the Red Sea (Boschen et al., 2013).

In mining sites of interest, there are usually both active and inactive vents. Each deposit supports different communities and therefore has different vulnerabilities to consider and to be assessed (Levin et al., 2016). However, for the purpose of this study, we will mainly focus on the inactive vents, which are also the ones that could potentially be mined in the nearest future.

Extraction

For the SMS mining, it is envisioned that machines on the seafloor will cut, crush, and gather the ore, which is to be sent to a supporting vessel on the surface, though an enclosed riser/ lifting system. When the ore reaches the support vessel, it should be collected, and seawater along with fine particles can be discharged back to the sea, in a depth, however, which is close to the seafloor. The supporting vessel could thereafter sail to the land for further processing of the ore (Levin et al., 2016).

A graph of the mining process can be found below (Miller et al., 2018):

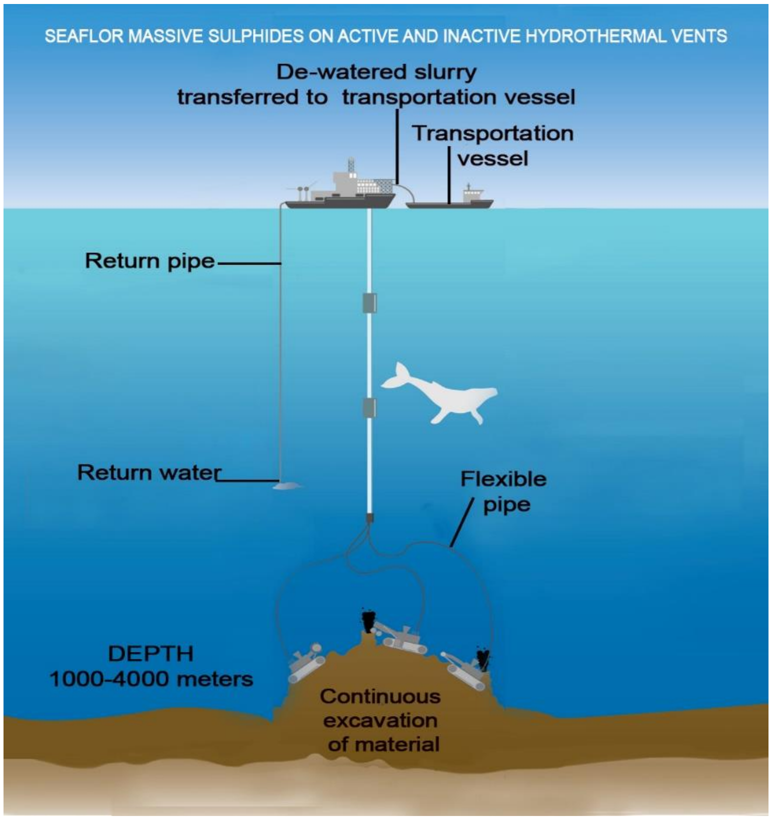

Figure 2.2. Scheme of SMS extraction
Source: Miller et al., 2018

Impacts

As previously mentioned, there is limited knowledge of fauna on inactive vents. However, with one mining event, the local fauna will be eliminated, causing harm. The extension of such harm is not known, especially if fauna is endemic. If the fauna is also found in the substrata, the harm might be reduced in terms of biodiversity reduction. However, if taxa habitats are relatively large, they could be important to maintain populations elsewhere "through the supply of larval recruits". Also, if there is a rare and endemic fauna, the mining will cause adverse impact, which can include the extinction of taxa (Levin et al., 2016).

In all cases of mining operations, there is a concern for the light which will be used by the equipment, which will most certainly affect the species of the marine environment, which are used into living in the dark. There are also concerns from the noise and vibration arising from the mining equipment that can affect the specie’s abilities for food, communication, mating, production, and other activities (Navarre et al., 2017).

In the mining of inactive vents, there will be removal of vertical topography, which will alter seafloor texture and effect habitat heterogeneity, which will most probably be a permanent effect. In case the inactive vent becomes active, if the ore has been removed, the physiography, biodiversity and connectivity would be altered and could be enhanced (Nakajima et al., 2015).

In some cases, in one mining site, there could be active vents as well, as previously mentioned. In such cases, the bio community could benefit by the increased food availability that can provide support to large populations of filter/suspension-feeding fauna that could also be long-living, such as corals. The recovery rates of the inactive sites can last as long as hundreds of years, and the mining operations can alter the connectivity of taxa relying on larval supply from the inactive vents populations (Levin at al., 2016).

The plumes arising from the mining operations will be enriched in toxic metals. This can affect the benthic and pelagic biota, even though the extension of such adverse impacts is not known and impacts are not presented immediately (Levin et al., 2016). The toxicity of those plumes can contaminate the fauna and flora, leading to the contamination of the food chain and eventually to human diet. Additionally, the release of plumes will cause the suffocating of benthic organisms that do not have the capacity to handle large quantities of sediment deposit (Navarre et al., 2017).

2.2.3. Cobalt Rich Crusts

Occurrence

Cobalt rich crusts cover almost 1.7% of the ocean’s surface, in depths between 800 to 2500meters. They are a compact and solid overlay in the ocean’s seamounts, attracting a lot of attention due to potential economic benefits. Their thickness could vary from a few centimeters to 25cm. They could cover a surface of several square kilometers and they are usually located in indurate seafloor (usually in previous underwater atolls or near volcanoes) (Fouquet Y. and Lacroix D., 2014).

Cobalt rich crusts mostly consist of iron and manganese. However, other elements of interest which can be found in these deposits are nickel, molybdenum, cobalt, and rare earth elements (Navarre et al., 2017). Cobalt is of specific interest, as it has ranging uses, including battery technology and aircraft engines (Miller et al., 2018).

Cobalt rich crusts exist in all oceans, however, the ones that are of interest are located at depths between 1.500 to 2.500 meters, especially in the Exclusive Economic Zone of the French Polynesia in the Pacific Ocean, where they are enhanced in cobalt and platinum, raising the economic interest of their mining even more (Navarre et al., 2017). A special interest at the Pacific is due to the frequencies of the seamounts and the small submarine volcanoes (knolls) existing in the area, however there is also commercial interest in the NE Atlantic margin, the SW Atlantic, the Indian Ocean and the NW Pacific Ocean. (Turner, 2018).

Cobalt-rich crusts may consist of iron, cobalt, nickel, and manganese that accumulate, forming ridges and plateaus. The accumulation process is going on for millions of years, solidifying from the water onto rocks (Levin et al., 2016). The abyssal plains provide steady physical conditions, having low rates of sedimentation and low current speeds (Levin et al., 2016).

In the seamounts coral and sponge communities prevail, that form structures like reefs, providing a safe environment, where invertebrates and fish can be found (Turner, 2018). Ferromanganese crusts provide a location of biodiversity that is different from an area to another. If a mining operation extracts such a crust or sinks such habitats, the fauna will be harmed, or dismantled (Smith et al., 2020).

Cobalt-rich crusts are located in the summits and slopes of seamounts. Such seamounts provide support in primary productivity and can provide a habitat for various pelagic species. Seamounts, therefore, provide connectivity for pelagic and benthic species. For instance, fish and mammals use seamounts to rest, foraging or hunt. On the other hand, there is physics associated with currents and seamounts which indicate that the latter provide oceanographic upwelling delivering nutrients to surface waters, promoting growth to animals such as sponges, corals, anemones etc. (Miller et al., 2018).

Extraction

The mining of cobalt-rich crusts will be technologically challenging in some areas, as the crusts are attached to the underlying hard substrate and as previously mentioned, are usually located in areas with irregular geomorphology (ECORYS, 2014a; Miller et al., 2018). It is expected that during mining, an amount of substrate will be extracted as well (ECORYS, 2014b).

The mining of cobalt-rich crusts is envisioned to use a remotely operated machine, which would dig, cut and crush the mineral and send it to a production support vessel through a riser and lifting system, as a rock material. Due to the thickness of the crusts, which will be collected with rugged seamount, it is expected that the operation will be more difficult than other minerals' mining. In any case, once the ore is onboard the vessel, it will be separated, and the remaining sediments would be discharged into the ocean. The support vessel could then sail to the land for the mineral's further process (Levin et al., 2016).

A graph of the abovementioned mining process is presented below (Miller et al., 2018):

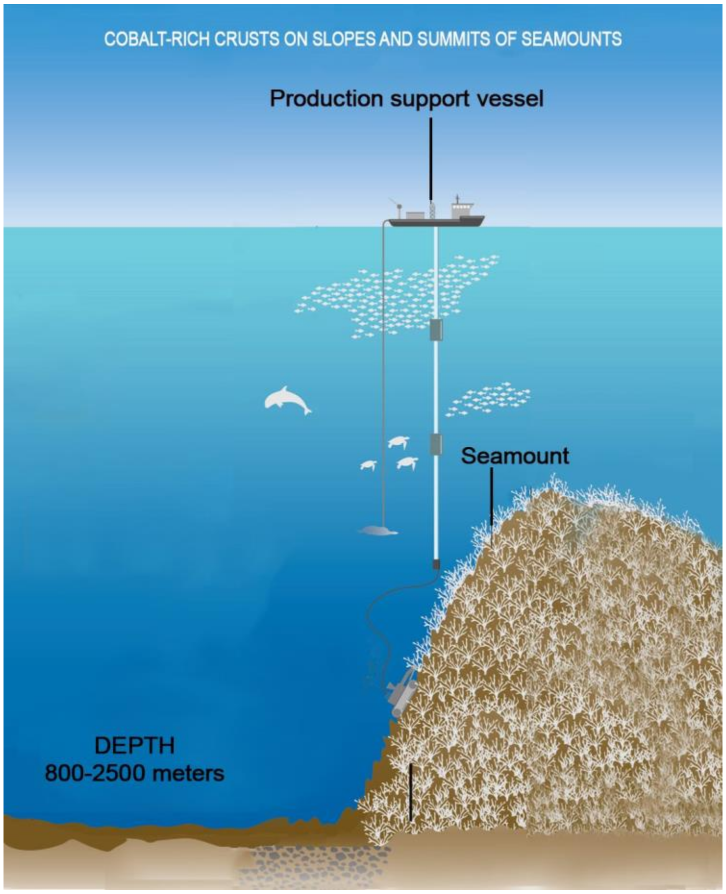

Figure 2.3. Scheme of Cobalt-rich crusts extraction
Source: Miller et al., 2018

Impacts

The mining impacts of mining cobalt-rich crusts, would be severe, as in this case, there will be changes in the seafloor, relieving the surface of the seamount, which will be flattened to some extent, and the soft sediment will be revealed. Therefore, there will be impacts in the water column, and in the ocean surface as well. This will lead to reduction of habitat heterogeneity and alterations to the geochemical characteristics of the seafloor sediments (Levin et al., 2016). The removal of substrata along with slow species recovery, could lead to irreversible changes into the benthic and likely pelagic communities allocated around the seamounts (Miller et al., 2018).

The mining of cobalt-rich crusts will generate plumes, which will be discharged back to the ocean. Such sediments will bury the habitats and clog their feeding structures and have adverse impacts into colonization (Levin et al., 2016).

In this deposit mining, there is as well disruption from the noise, light and vibrations of the machinery that will be used for the mining operations, affecting the pelagic species (Miller et al., 2018).

Due to plumes being released, there will also be metal release, which will be accumulated through the food chain. Such release is expected to impact the mining location but also adjacent areas. As the plumes will most probably include fines and small rocks, there will also be effects on plankton and fish communities through the water column (Levin et al.,2016).

As the seamounts provide biodiversity, with the removal of the crusts, it is expected that there will be loss of such faunal biodiversity and adverse impacts in fisheries, along with faunal cover and abundance (Miller et al., 2018).

Overall, the adverse impacts of mining cobalt-rich crusts include potential oxygen depletion, alteration of water transparency, affecting predator's visual capacities, toxic effects for early life history stages, such as larvae and mortality of plankton and mesopelagic fish (Levin et al., 2016).

2.2.3. Polymetallic Nodules

Occurrence

Polymetallic nodules are small pebbles found in the abyssal plains in depths between 3.000m- 5.500m. They have a size of approximately 5 to 10cm in diameter (Navarre et al., 2017). They mainly consist of manganese and iron, even though there are other metals found in these structures such as nickel, copper, cobalt, rare earth elements, which are of interest, as well as traces of other metals that can be used in technological products (photovoltaic cells, catalytic technology) such as platinum, tellurium etc. (Miller et al., 2018). The metal concentration of the nodules along with their abundance vary depending their location, however, the main locations of commercial interest are the Clarion Clipperton Zone in the Eastern Pacific, in the Exclusive Economic Zone of the Cook Islands in the South West Pacific and in an area of the Central Indian Ocean Basin (ECORYS, 2014a).

Nodules are classified in smooth type (S-type), rough type (R-type) and smooth- rough mixed type (S-R type), depending on their size, texture, morphology etc. (ISA, 2010). The nodules are immensely slow in their formulation, which is approx. 2-15mm per million years (Levin et al., 2016) and their growth is also slow, with rates of 1-5mm per million years (Sharma, 2017).

The nodules usually occur, in the open ocean, due to highly stable environments and low productivity, away from land influences, where sediments fall into the seabed as a particulate rain from the sunlit surface. The organisms existing on the seabed rely on this gradual downward movement of organic matter for their survival. In these areas there is high species diversity, with organisms living in the sediment of the seafloor, its surface attached to the nodules and in the overspreading water column (ECORYS, 2014a). However, there are nodules found in shallower waters, such as in the Baltic sea and in lakes with freshwater, which however, contain considerably lower concentration in metals of interest (Sharma, 2017).

Finally, it is important to note that the fauna quantities are equivalent to the nodule density, which is making the balance between commercial objectives and environmental ones a struggle. The existence of nodules furnishes a hard substrate, which upholds a range of specialized fauna (for instance, sponges, barnacles, corals etc.) (Turner, 2018).

Extraction

For the nodule extraction, it is envisioned that there will be harvesters into the seabed, which will collect the whole nodules or might crush and collect them. Afterwards, they will be pulled up to a support vessel, through a riser pipe, running through the surface. The support vessel will then discharge the sediments back to the ocean, and then sail to transfer the nodules to the land for further process (Levin et al., 2016).

A scheme of the above process is presented below (Miller et al., 2018):

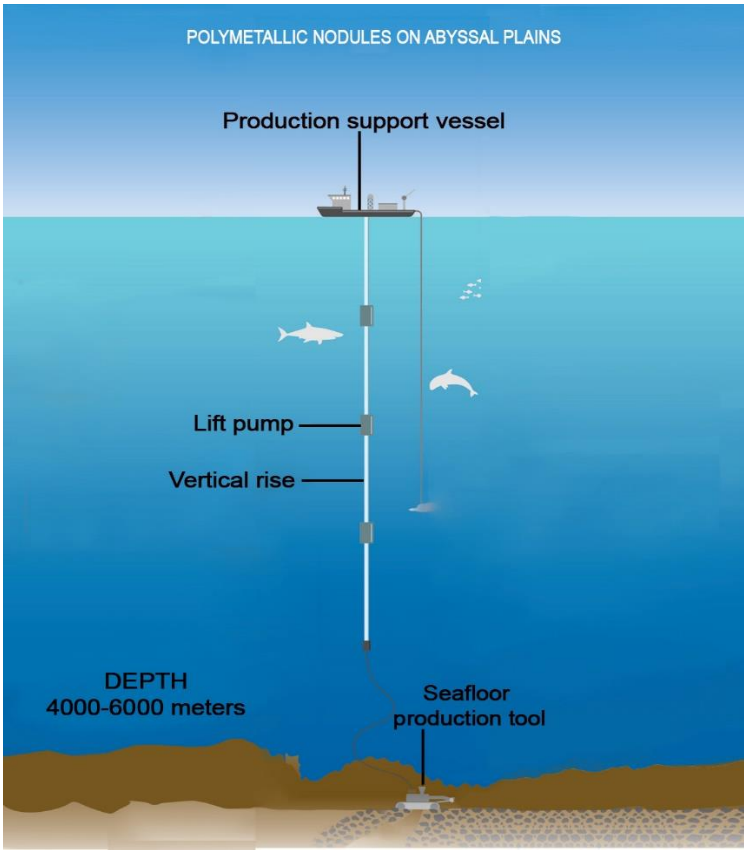

Figure 2.4. Scheme of Polymetallic nodules extraction
Source: Miller et al., 2018

Impacts

The removal of nodules will also remove fauna that lives on the nodules, along with other organisms living in the sediment under and between the nodules (Peukert et al., 2018).

Moreover, due to the extraction mining process of the nodules, plumes will be discharged, also affecting hundreds of kilometers adjacent to the area mined. These plumes will bury the organisms and habitats living on the seafloor, obstructing larval settlement, effecting colonization. The plumes dispersing in the water column, will mostly affect food poor areas, as they could clog the membranes of filtering of fauna. Also, the settling of the sediments can release pores that are oxygen-depleted or chemicals such as heavy metals that could have biochemical ecotoxicological impacts. Such sediments can have adverse effects in the pelagic environment, causing impacts such as affecting vision, feeding and communication process, pray avoidance. Also, throughout the mining process, there might be sediment leakage in the pipe going all the way to the water column or the support vessel itself, which will have impacts in the photosynthetic productivity of the surface waters (Levin et al., 2016).

During the extraction, the equipment will agitate and remove about 15-40cm of the top sediment, which provides food to the organisms of the area, which are of high diversity. The equipment used will also compress the top sediment of the seafloor, affecting the biota living in the top level of the sediment, colonization and changing the seafloor's biochemistry (Vanresuel et al., 2016).

Noise coming from watercrafts and related anthropogenic noise is already known to cause adverse impacts to marine mammals (Erbe et al., 2019), however such effects are understudied for other benthic and pelagic organisms. Moreover, the light used for the mining operations can result to blindness, attraction, or misdirection of organisms, changing their visual capacity, communication, finding their mate or even prey avoidance capability (Levin et al., 2016).

Furthermore, the sediment disturbance along with the plumes disturbances can result into habitat complexity reduction, the ecosystem function, and the reduction of biodiversity, on larger spatial level, effecting both the water column and the seafloor. A major concern is that these impacts will persist in long-term (millennia), due to the time of nodules formulation, affecting the habitats and heterogeneity of the area (Vanreusel et al., 2016).

Also, depending on the location that the mining is taking place, the plumes spread will have impacts to adjacent locations. For instance, if the mining takes place in the

Exclusive Economic Zone of one county, it can also affect the waters of an adjacent one, creating conflicts in between the two states and affecting the marine environment of the neighboring countries (Navarre et al., 2017).

Finally, taking under consideration that the polymetallic nodules are found in abundance in regions with generally extremely stable conditions, in terms of sedimentation rates, current velocity, and suspension events rarely happening, their mining will motive substantial change to the ecosystem. Such changes may spread causing harmful effects to vulnerable marine ecosystems and maybe to the wider marine environment (Levin et al., 2016), through space and time (Turner, 2018).

Chapter 3: Regulations Tools and Guidelines for DSM

ISA has an experience of 25 years in developing, implementing, and reviewing rules, regulations and procedures to ensure effective protection for the marine environment from harmful effects which may take place in the Area (ISA, 2020; UN, 2019). Prior to proceeding with seabed mining, the compliance with international and national regulations should be ensured, using environmentally good practices and guidelines and taking under consideration the knowledge gained from related industries to keep the environmental impacts at minimum levels. In order to be effective, the Industry has to develop and maintain high standards of the activities throughout the entire development cycle. Such management procedures would rely on extensive developing, documentation, consultancy, reviewing and refining activities (Jones et al., 2019).

There is an opportunity to gain knowledge from other industries with regards to safety and environmental management practices (Jones et al., 2019). ISA is promoting an adaptive approach based on changing technology and incorporation of best environmental practices for the development of rules, regulations and procedures (UN, 2019). As the seabed mining is a new Industry, it has the potential to optimize previously examined procedures and good practices and adapt them. It is surely acknowledged that the seabed mining differs from other industries, as there is particularly lack of knowledge and lack of information of potential harmful effects occurring from its activities. It also has another peculiarity; having an international legislation that determines the avoidance of “serious harm”[3] (Jones et al., 2019).

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[3] Serious harm: any effect from activities in the Area on the marine environment which represents a significant adverse change in the marine environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally recognized standards and practices.

3.1. Regulations ISA

Regulations for the prospecting and exploration of manganese nodules (2000), seafloor massive sulfides (2010) and cobalt-rich crusts (2012) have already been adopted. Such regulations set mandates for contractors to eliminate pollution and other hazards to the environment, proceed with precautionary approach, requiring that all actions are to take place reducing harm (even if the level of harm is not certain) and to conduct best environmental practices, in line with their environmental management strategy (Turner, 2018).

The regulations on prospecting and exploration for Polymetallic Nodules (ISBA/19/C/17 and ISBA/19/A/9), Polymetallic Sulphides (ISBA/16/A/12/Rev.1) and Cobalt rich Ferromanganese Crusts (ISBA/18/A/11) were established between 2010 and 2013 by the ISA Assembly (Bräger et al., 2018).

Part XI of the Convention and the 1994 Agreement, together with rules, regulations and procedures that have been developed by ISA since 1994, contain a comprehensive and evolving body of international law governing environmental management of deep sea mineral activities (ISA, 2017). As per UNCLOS, within a Coastal State's jurisdiction, the State has the rights to exploit and explore the natural resources in the Area (whether such resources are living or non-living). However, with such right comes the great responsibility of safeguarding the marine environment, through relevant policies. The objective in UNCLOS is the promotion of sustainability and conservation of marine biodiversity; a concept also supported in the Millennium Development Goals (MDG; 2000–15), United Nations Sustainable Development Goals (SDG; 2015–30) and the Convention on Biological Diversity's Aichi Biodiversity Targets (Turner, 2018). In accordance with the Convention, States have the obligation to assess the potential effects of activities under their jurisdiction, control of substantial pollution or significant and harmful changes to the marine environment and to publish those assessments. These obligations apply to activities wherever they are conducted, both within and beyond national jurisdiction (ISA, 2017).

ISA is also working on 107 draft regulations for exploitation of mineral resources in the Area, which also include detailed and sophisticated provisions relating to EIA. The draft regulations concern the development of standards and guidelines including environmental standards, which would cover environmental quality objectives, monitoring procedures and mitigation measures (ISA, 2019). Apart from environmental regulations for the exploitation phase, the requirements for environmental monitoring and commercial mining are still under development (Jones et al., 2020).

Meanwhile, the Authority's current draft regulations include also detailed provisions relating to EIA. The ISA, sponsoring States and Contractors will have the general obligation to promote accountability and transparency in the assessment, evaluation, and management of environmental effects from exploitation activities. Contractors are obligated to submit an Environmental Impact Statement (EIS) to document and report the results of the Environmental Impact Assessment (EIA) which must be designed to identify, predict, evaluate and mitigate the biophysical, social and other relevant effects of the proposed mining operation. Contractors would also be required to prepare an Environmental Management and Monitoring Plan (EMMP) (ISA, 2019).

The most important of those regulations which are necessary to be referred on the current thesis are the below (ISA, 2019):

- *Regulation 44: General obligations*

"The Authority, sponsoring States and Contractors shall each, as appropriate, plan, implement and modify measures necessary for ensuring effective protection for the Marine Environment from harmful effects in respect of activities in the Area. To this end, they shall: (a) Apply the precautionary approach; (b) Apply the Best Available Techniques and Best Environmental Practices in carrying out such measures; (c) Integrate Best Available Scientific Evidence in environmental decision making; and (d) Promote accountability and transparency in the assessment, evaluation and management of Environmental Effects from Exploitation in the Area, including through the timely release of and access to relevant environmental data and information and opportunities for stakeholder participation."

- *Regulation 47: Environmental Impact Statement*

"The purpose of the Environmental Impact Statement is to document and report the results of the environmental impact assessment. The environmental impact assessment: (a) Identifies, predicts, evaluates and mitigates the biophysical, social and other relevant effects of the proposed mining operation; (b) Includes at the outset a screening and scoping process, which identifies and prioritizes the main activities and impacts associated with the potential mining operation; (c) Includes an impact analysis to describe and predict the nature and extent of the Environmental Effects of the mining operation; and (d) Identifies measures to manage such effects within acceptable levels, including through the development and preparation of an Environmental Management and Monitoring Plan. An applicant or Contractor, as the case may be, shall prepare an Environmental Impact Statement in accordance with this regulation. The Environmental Impact Statement shall be: (a) Inclusive of a prior environmental risk assessment; (b) Based on the results of the environmental impact assessment; (c) In accordance with the objectives and measures of the relevant regional environmental management plan; and (d) Prepared in accordance with the applicable Guidelines, Good Industry Practice, Best Available Scientific Evidence, Best Environmental Practices and Best Available Techniques."

- *Regulation 48: Environmental Management and Monitoring Plan*

"The purpose of an Environmental Monitoring and Management Plan is to manage and confirm that Environmental Effects meet the environmental quality objectives and standards for the mining operation. The plan will set out commitments and procedures on how the mitigation measures will be implemented, how the effectiveness of such measures will be monitored, what the management responses will be to the monitoring results and what reporting systems will be adopted and followed. An applicant or

Contractor shall prepare an Environmental Management and Monitoring Plan in accordance with this regulation. The Environmental Management and Monitoring Plan shall cover the main aspects prescribed by the Authority in annex VII to these regulations and shall be: (a) Based on the environmental impact assessment and the Environmental Impact Statement; (b) In accordance with the relevant regional environmental management plan; and (c) Prepared in accordance with the applicable Guidelines, Good Industry Practice, Best Available Scientific Evidence and Best Available Techniques, and consistent with other plans in these regulations, including the Closure Plan and the Emergency Response and Contingency Plan."

- *Regulation 49: Pollution control*

"Contractor shall take necessary measures to prevent, reduce and control pollution and other hazards to the Marine Environment from its activities in the Area, in accordance with the Environmental Management and Monitoring Plan and the applicable Standards and Guidelines."

- *Regulation 50: Restriction on Mining Discharges*

"Contractor shall not dispose, dump or discharge into the marine environment any mining discharge, except where is permitted discharge is permitted in accordance with the assessment framework for Mining Discharges as set out in the Guidelines and the Environmental Management and Monitoring Plan. The above shall not apply if such disposal, dumping or discharge into the Marine Environment is carried out for the safety of the vessel or Installation or the safety of human life, provided that all reasonable measures are taken to minimize the likelihood of Serious Harm to the Marine Environment, and such disposal, dumping or discharge shall be reported forthwith to the Authority."

- *Regulation 53: Emergency Response and Contingency Plan*

"Contractor shall maintain the currency and adequacy of its Emergency Response and Contingency Plans based on the identification of potential Incidents and in accordance with Good Industry Practice, Best Available Techniques, Best Environmental Practices and the applicable standards and Guidelines."

3.2. Tools

3.2.1. Environmental Impact Assessment

The Environmental Impact Assessment (EIA) is an imperative procedure, through which the progress outcomes are collected in order to aid in the decision-making process for the effective managements of a potential deep-sea mining operation (Clark et al., 2019). The EIA is a tool through which an assessment of the current environmental conditions along with the identifications, forecasts and appraisal of environmental impacts derived from a project lead to the reduction of such impacts. The results are included into the Environmental Impact Statement (EIS) and include socioeconomic impacts, environmental impacts, and impacts emerging from health, culture, and history (Turner, 2018). There is therefore a good chance during the early stages to assess if learning can be conducted through previous EIAs and to be applied for the improvement of its effectiveness during the Industry development (Clark et al., 2019).

The environmental impacts are expected to be at the sea floor and may also occur at any depth in the water column. The impact assessment should address both areas that are directly affected by the activity and the wider region impacted by seabed-disturbance plumes, the discharge plumes and any materials that may be released by transporting the minerals to the ocean surface, depending on the technology used. An environmental impact assessment is required to assess whether there would be environmental changes from the discharge plumes resulting in the alteration of food chains with the potential to disturb vertical and other migrations (ISA, 2017).

3.2.2. Environmental Management Plans

It is understandable that the oceans know no boundaries, and the environmental effects of mining on one site, can affect other places as well. It is for those reasons therefore that the exploitation of minerals has not taken place anywhere in the world, up to this date, even though spatial planning is intensively considered for the areas to be exploited. The Environmental Management Plans (EMPs) for deep sea mining regionally, mainly concentrates on area-based conservation measures (Tunnicliffe et al., 2018).

Below is presented a graph of the available tools for environmental management for deep seabed mining operations. The external assessment can be provided by the various stakeholders and may affect the regulating procedure (Jones et al., 2019):

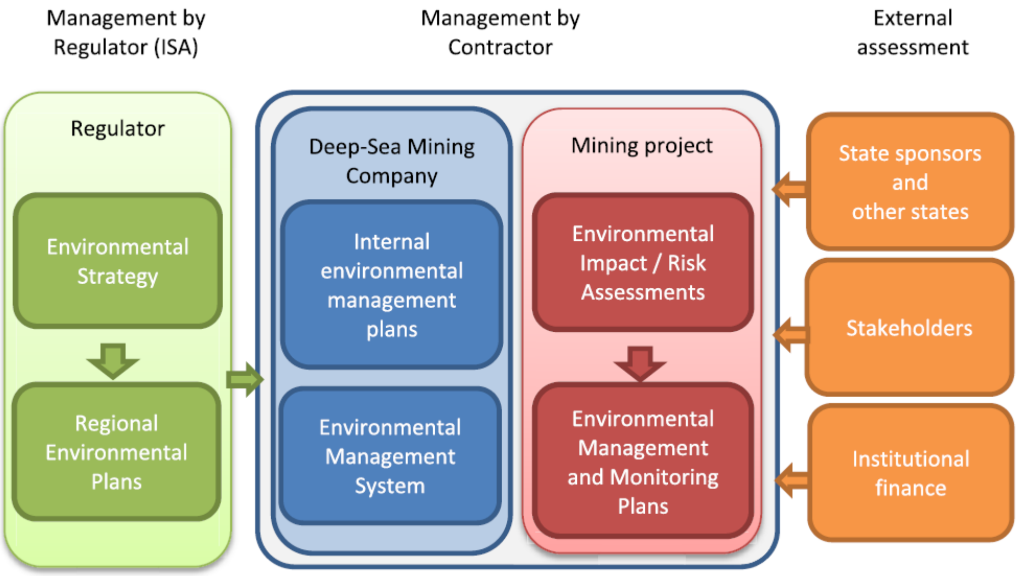


Figure 3.2. Tools for environmental management in the DSM
Source: Jones et al., 2019

Strategic Environmental Management Plan

The Strategic Environmental Management Plan (SEMP) is a plan contemplated by the ISA, but not yet realized. It is expected to enclose general environmental targets and biodiversity objectives, related to all mineral resources and the seabed of the Area (Turner, 2018).

Regional Environmental Management Plan

Regional Environmental Management Plans (REMPs) are instruments of environmental policy of ISA and are adapted to grant effective protection of the marine environment in a specific location which contains mining resources, within the Area (Turner, 2018). The first REMP, for the Clarion-Clipperton Fracture Zone, was approved by the Council in 2012, establishing 9 Areas of Particularly Environmental Interests (APEIs) where no mining activities will take place (ISBA/17/LTC/7). More information on the APEI will be presented in Chapter 4.2, in the case study of Clarion- Clipperton Zone.

In most deep-sea mining sites, there are common environmental issues. Therefore, by aligning the environmental management measures the deep-sea mining development could benefit. For instance, potential risks could extend far and beyond the boundary of a targeted mining site, or cumulative impacts could occur from multiple mine sites within a single region, from interactions from other uses of the marine space (for example fisheries). Therefore, the impacts should be considered at a regional level and relevant environmental procedures may be needed to be customized into the resources and ecosystems which are under pressure, while collaborating with other users or stakeholders and regulatory bodies. It is therefore important to adapt approaches for the environmental management within a regional level, which is also a more strategic approach. This also highlights the need to manage the marine environment at bigger scales, across business sectors, rather than a single activity. Consequently, Regional Environmental Assessment can be considered as a subset of Strategic Environmental Assessment, as such processes are an initial management action, allowing biodiversity and other considerations to be embodied in the development of new programs (Jones et al., 2019).

3.2.3. Precautionary Approach

ISA is required in cooperation with sponsoring States, to apply a precautionary approach to such activities based on recommendations by the Legal and Technical Commission (ISA, 2020). The precautionary approach is to be enacted when an activity can raise threats for harm to human health or the environment. As such, the precautionary measures should be adopted in case there are impacts in relationships that are not fully formed scientifically. In the case of seabed mining, the precautionary approach constitutes an important tool to address the environmental protection challenges, with regards to the regulatory level but also for the management by the Contractor. It can be included to all decisions with regards to seabed mining, with regards to environmental risks and impacts, the effective and proportional potential protective measures to be enforced but also for any counter effects of these measures. The precautionary approach is beneficial both in the evaluation of an EIA or EMP and facilitates a precautionary decision-making, considering the existent scientific knowledge and the recognition and exploration of any uncertainties that may exist (Jones et al., 2019).

3.2.4. Adaptive Management

For projects of great uncertainty, with regards to the environmental management, the adaptive approach is also highly suggested. Adaptive management is a tool for environmental risk management of specific projects that facilitates a structured decision making (ISA, 2017) and which also addresses the existing uncertainty, through monitoring the impacts of the prescribed management plan and by assessing the results of such monitoring, with the goal to gain knowledge from the results and embody any findings into revised management actions and relevant models (Jones et al., 2019).

The application of adaptive management is a complex procedure for the mining of the Area, as there is high vulnerability of the deep sea marine environments and there is a high risk of serious and irreversible harm occurring from commercial deep sea mining

(Jones et al., 2019). When the adaptive management is used, it should be considered as part of the Environmental Management and Monitoring Plan (ISA, 2017). Furthermore, the adaptive management approach should be a part of the Contractor's environmental management planning, and basis the results, the Contractor should carefully monitor, as it might be needed to adjust the planned activities accordingly. Adaptive management could be enforced both by the regulator via the provided framework and guidelines and by the Contractor, by improving the environmental management activities throughout the project (Jones et al., 2019).

3.3. ISA Guidelines

As previously mentioned, the ISA, should balance the mining operation in accordance to safeguarding the marine environment. However, as per the UNCLOS, there are no clear guidelines as to how to ensure that measurable targets are met. Therefore, setting definite goals, objectives, and measures is imperative, ensuring that both ISA and Member States pursue their mandate to protect the environment (Tunnicliffe et al., 2018). The Commission has recommended that guidelines should be developed for Environmental Impact Assessments, Environmental Management and Monitoring Plans, Environmental Management Systems and baseline data collection should be completed by or after the summer of 2020 (UN, 2019).

The Commission has decided to support the development of several environmental guidelines, and recommended processes for the development of standards and guidelines, including opportunities for stakeholder consultation and comments by establishing two technical working groups (UN, 2019).

Each one of work plans for exploration for marine minerals shall take into consideration the following three phases of environmental studies:

1. Environmental baseline studies to obtain sufficient information from the area to document the conditions that characterize its natural environment,
2. Monitoring to ensure that no serious harm is caused to the marine environment from activities during prospecting and exploration, and
3. Monitoring during and after testing of mining components to record changes resulting from these activities and to predict impacts in order to address them successful.

From 2011 to 2015, the LTC issued three documents containing guidelines to the contractors for the collection and creation of environmental baseline information (Bräger et al., 2018):

1. Environmental Management Plan for the Clarion-Clipperton Zone (ISBA/17/LTC/7)

2. Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area (ISBA/19/LTC/8)

3. Recommendations for the guidance of contractors on the content, format and structure of annual reports (ISBA/21/LTC/15).

The ISA has provided a draft for the EIA and instructions on the EMMPs in the realm of the exploitation regulations. As per these guidelines, the EIA should include a plan for the exploitations, results of the baseline assessments of the exploration, an assessment of exposures to the environment and the description of the protected areas. Such areas can include (Turner, 2018).:

1. Impact Reference Zones (IRZs), in which the impacts of the operations are monitored.
2. Preservation Reference Zones (PRZs), in which no mining will occur, but they are used as indications, enabling scientists to monitor changes in the environmental status.

The criteria included in the EIA, should fit the below (Clark et al., 2019):

- Being sufficiently informative, to facilitate in the decision-making process.
- Applying best scientific practices.
- Being practical in the sense of providing useful results with regards to data and outputs.
- Including useable and relevant information.
- Concentration in significant matters.
- Without compromising the overall procedure, to provide adjustable information for the situation.
- Involving various techniques and scientists from different fields.
- To be credible in the sense of the process being subject to independent verification.
- To consider the social, economic, and biophysical aspects of the process.
- Having a systematic approach, this will include all the relevant information and alternatives.

A PRZ may be a single large area or a series of smaller areas. In both cases, the PRZ should be large enough to include representative habitats and biodiversity that may be impacted by mining operations. On the other hand, the IRZ should be defined as any area that is going to be impacted by mining operations, extending to a distance where impacts can no longer be detected. A PRZ is acting as a control area to measure natural variability against which future changes in the IRZ are to be compared (ISA, 2018). As per current draft exploitation code, Contractors should include the abovementioned zones into their mining claim area, into their environmental management plan. They are also required to minimize potential impacts in such zones (Jones et al., 2020). Therefore, the contractor should monitor both zones for the duration and the closure plan of any mining activity, to assess important mining impacts and evaluate if any longer-term effects need to be monitored further (ISA, 2018). At the same time, the ISA will consider the potential as well for impacts in established preservation zones during evaluation process for a mining license (Jones et al., 2020).

Chapter 4: Case Study

4.1. Location of CCZ

Clarion Clipperton Fracture Zone is located in the eastern central Pacific Ocean into the south and south-east of the Hawaiian Islands, in international waters, therefore within the Area (Agarwal et al., 2012), falling under the legal mandate of the ISA.

A map showing the location of the CCZ along with the location of all three main marine mineral deposits is presented below (Miller et al., 2018):

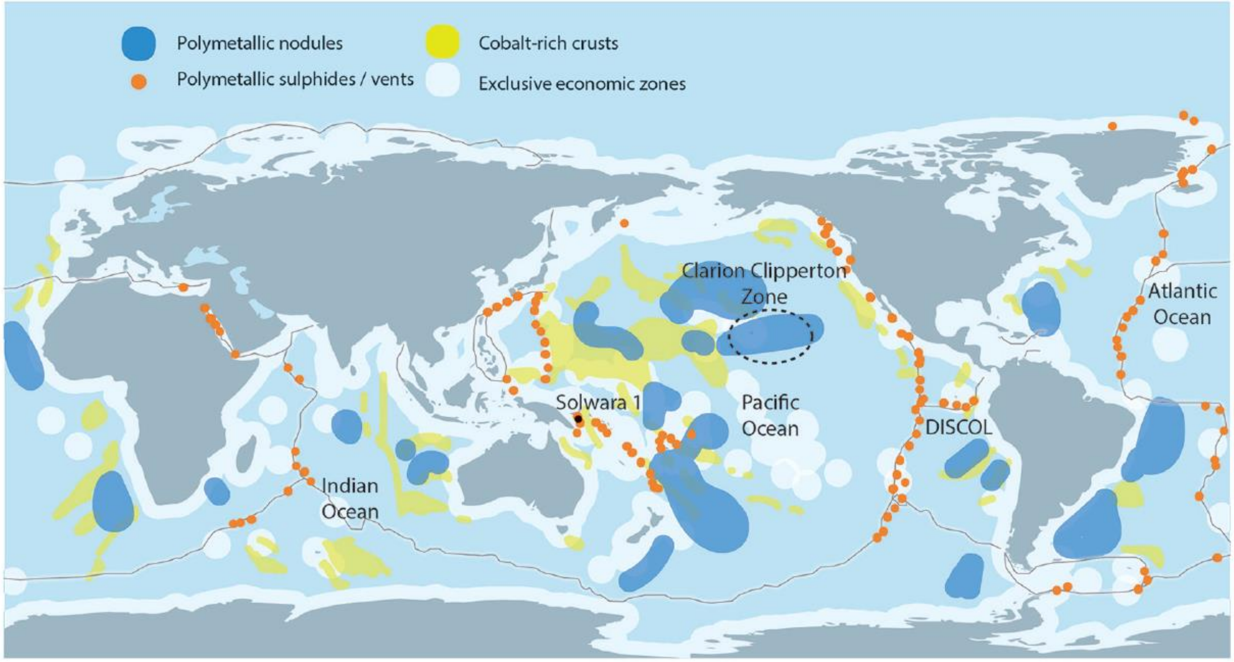


Figure 4.1. Map of mineral deposits
Source: Miller et al., 2018

More specifically, it is spread from 0°N – 23°30'N, and from 115°W – 160°W, an area of approximately 4.5×10^6 km^2 in total (Agarwal et al., 2012).

4.2. Mandate of the CCZ and the APEIs as part of the EMP

Among other requirements and guidelines, the ISA has adopted an EMP since 2014, specifically for the CCZ, due to the intense commercial interest and nodules abundance (Filho et al., 2020). Such EMP is to be subject to periodic external review from the LTC of ISA every 5 years (Jones et al., 2019; ISBA/17/LTC/7, 2011).

It has been estimated that once the mining operations in the CCZ commence, approximately 300-800km2 of the seafloor per mining operation, per year will be disturbed (Harbour et al., 2020). It is for this reason that the protection of the environment should be considered. As previously advised in Chapter 3, one of the environmental management tools is the setting of Areas of Particular Environmental Interest (APEI), as part of a Regional EMP, on a regional scale (Smith et al., 2020), covering approximately the 25% of the CCZ (Lodge et al., 2014).

The ISA has issued an EMP specifically for the CCZ, which aims to enable the preservation of representative and unique marine ecosystems, via the setting of nine APEIs (Jones et al., 2019). Trough the setting of the APEIs, the aim is to maintain the minimum viable population sizes and to capture the full range of habitat biodiversity within each sub-region (Madureira et al., 2016). Each APEI is at least 200km in length and width, and there is an extra adjacent area of 100km, which is used as a buffer zone, to ensure that the APEI will not be affected by mining plumes from mining operations closer to these areas (ISBA/17/LTC/7, 2011).

Such areas have been proposed to be expanded and modified on improved scientific information and no mining is to take place within any of them. No APEIs are included in the central section of the overall CCZ, where there is high nodule concentration. This is because the APEIs were established at a later stage and mining contracts had already been issued (Jones et al., 2019). It is also important to mention that these 9 APEIs remain understudied and it is still not clear if their environmental conditions and faunas are similar to the mining license areas. It is therefore crucial to urgently study these areas, understand their functionality and spatial arrangement of the APEIs, in order to assess once more the EMP (Lledo et al., 2019), especially in the more eastern APEIs (APEI 8 and 9, per below map), which are almost unexplored (Lledo et al., 2020).

The EMP consists of a description for guiding principles, vision, targets and strategic regional objectives and goals for the Areas of Particular Environmental Interest. However, the targets are not definitive and impossible to recognize progress towards them. Vulnerable Marine Ecosystems, adaptive management and other tools are included, however the EMP lacks guidelines for realization (Tunnicliffe et al., 2018).

Below map identifies targeted Areas for Mining and Areas of Particular Environmental Interest (APEI) in the CCZ. The green areas present the ones that are reserved for future mining operations, which are not yet allocated. The orange areas refer to those that currently hold a contract for exploration purposes. The nine areas outlined in red, are the ones that are expected to shelter different habitats, in case a mining takes place (Smith et al., 2020):

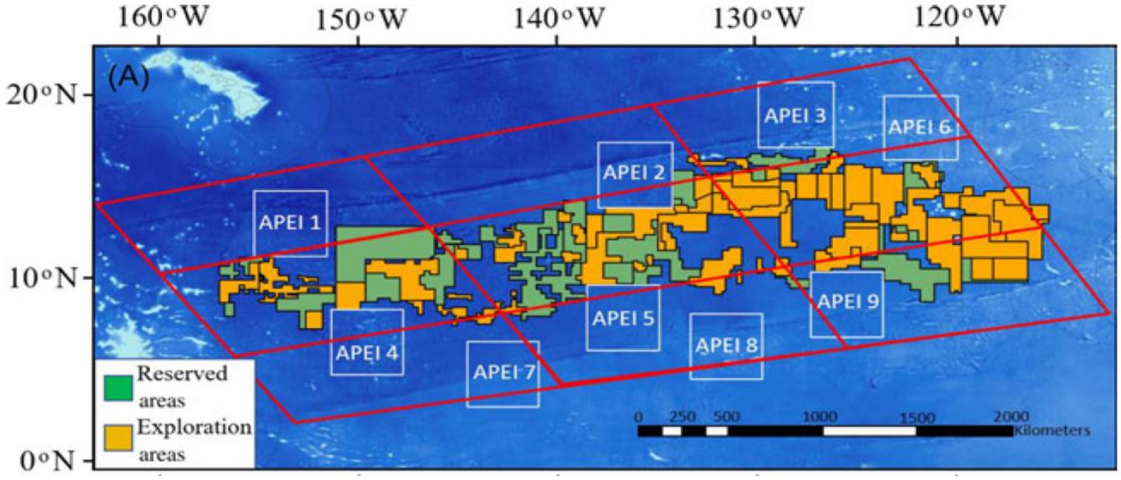


Figure 4.2. Reserved Areas and Exploration Areas in CCZ
Source: Smith et al., 2020

The following map represents the concentration of nodules, between the nine sub-areas as mentioned before. The dark red indicates high nodule concentration, cream color indicates limited existence of nodules and blue color indicates that no nodules are to be found (Smith et al., 2020).

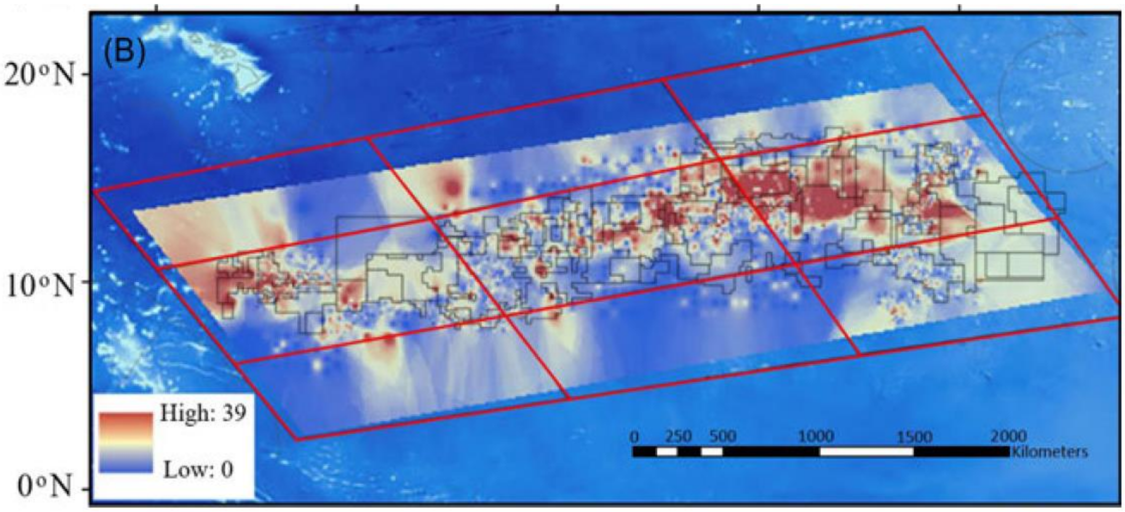


Figure 4.3. Areas targeted for mining, environmental management subregions, nodule rich Areas in CCZ

Source: Smith et al., 2020

In the above map, the nodules are mainly found in three of the nine subareas (on the center). In such areas the nodules cover the 10-30%, in the center of CCZ. However, each outlined area is expected to contain different communities. The disruption from a single mining operation can impact 2 to 4 times the mining footprint. Therefore, for a single 20-year mining operation, the affected area could be up to 8,000km^2 X 4 times the footprint impact= 32,000km^2 (Smith et al., 2020). It is therefore understandable that in the CCZ, where there are numerous contracts for exploration, there is a potential of cumulative results and a mosaic of effects, with impacts towards other marine users (Clark et al., 2019).

As mentioned in Chapter 3.3 and on a project scale, reference zones should be designated, containing Impact Reference Zones (IRZ) and Preservation Reference Zones (RPZ), as part of the project's EIA, which is mandatory. The IRZ are needed to assess the impacts of the exploitation operations to the marine environment, while the PRZ are areas that will not be impacted by the mining operations or the plumes that will be generated (Hao et al, 2020).

The ISA has also imposed a benthic biological baseline study to be conducted prior to the exploration contract and the exploitation operations (Lledo et al., 2020; Amon et al., 2016) along with environmental management plans, including specific measure to maximize the potential of biota impacted recovery of the area (Requirement no.3, ISBA/17/LTC/7, 2011).

The Contractors should also provide the below information, after conducting an activity in the CCZ, as per requirement no. 28 (Brager et al., 2018):

- Abundance and diversity of benthic communities and behavioral changes of key species, which will be smothered by sediments.
- Changes in the abundance and diversity of benthic communities of the mining area, and rates of recolonization.
- Potential changes in the benthic communities in nearby areas which not expected to be affected by the activity, including the disbursement of plumes and sediments.
- Changes in the characteristics of the water, in the layer of the discharge of plumes during the mining test, and
- Behavioral changes of the fauna at and below the discharge of plumes.

4.3. Physical and Chemical Characteristics

The CCZ has a depth between 3.600m to 5.500m (Hao et al., 2020), the average depth in the eastern CCZ is approximately 4.600m and in the western CCZ approximately 5.200m (Leitner et al., 2017). Nodules are located in flat-floor valleys, which can be divided with ridges that can be discontinuous (Hao et al., 2020, Agawal et al., 2012). It is dominated by the North Equatorial current, which has an average speed of approx. 10cm/sec. During the calm period the benthic current can be up to 3 cm/s, on tidal period until 6cm/s and benthic storms can last approx. 24hrs, with a current of 8 cm/s. There are also seasonal cycles in the waves of the area, having a peak during the winter (Agawal et al., 2012). However, there is variability between current speeds and directions (Morgan et al., 1999).

The sediment mostly consists of clays and siliceous biological casts (Agawal et al., 2012). However, different areas within the CCZ have substantial differences from each other with regards to the environmental characteristics. For instance, the APEI-3, which is located in the northern CCZ, has sediment with higher clay fraction and lower levels of pigments and Total Organic Carbon, than other areas (Hauquier et al., 2019).

The temperatures of the area vary depending the depth; in the mixed layer temperature is approx. 25°C, whereas in the deep layer at 1.000m depth, temperature is approx. 4.5°C (Agarwal et al., 2012). In some study sites, temperature can even reach below 2°C (Leitner et al., 2017). The density of the water is about 1.022 g/cm^3 and the primary productivity is affected by the solar energy input and the nutrient flux. There is an oxygen concentration at the mixed layer of about 400-500uM, which decreases to 350uM near the bottom. Respectively, the pH decreases with depth. Finally, there are traces of manganese found in the surface, and concentrations of copper and nickel increase with depth (Agawal et al., 2012).

The sedimentation of the CCZ is composed of radiolarians (30%), iron and manganese hydroxide. The CCZ is located in a volcanic crust which was formulated in the axis of the East Pacific Rise 30-40 million years ago. There are mountainous features with a height of 100 to 300m, spreading north to south. Due to the ridges and valleys existing on this area, a secondary displacement of sediment particles is enabled, along with gravity and current phenomena, resulting to locations with low sedimentation, where nodules are formed. This is also resulting to various distribution of formulation of the nodules (Fouquet et al., 2014).

With regards to benthic communities and in a broad scale within the CCZ across several kilometers, there were variations in megafaunal abundance and compositions found through adjacent areas in invertebrate and bait- attending surveys, in comparison to other areas in the north Atlantic. At a finer scale, across tens of meters, there are variations in faunal abundance as well as community structure that has been noticed between areas with different nodule availability, concerning megafauna, macrofauna and foraminifera. Such results are considered to be related to nodule-obligate taxa, which can represent the 60-70% of the total abundance of fauna (Lledo et al., 2020).

4.4. Characteristics of Benthic Communities

There is high diversity in species and high variation in fauna community composition and structure (Agarwal et al., 2012). The sediment of the CCZ is mostly composed of micro-organisms and small invertebrates (from tens of microns to a few millimeters). The communities are concentrated in the top few centimeters of the sediment and both their density and diversity are high. On the other hand, large organisms are few, as this is an oligotrophic environment.

However, their structure varies depending the zone due to the heterogeneity of the habitats, which is dependent on various factors, including the primary production gradients, the topography, and the coverage of the nodules (Fouquet et al., 2014). There are different communities from the western to the eastern of the CCZ, with the western region having decreased dominance of rattails and small shrimps, and increased dominants of ophidiids and large shrimps. This fact can be related to the increasing distance from the continental margin (Leitner et al., 2017). It is also noticed that there is higher taxa richness in the south-east CCZ than the north-east of the CCZ, which should be taken under consideration for the future conservation management strategies of the area (Lledo et al., 2020).

In surveys conducted in the Eastern CCZ, it has been concluded that almost half of the individuals of same species occurred onto the polymetallic nodules alone and that there is a positive correlation between megafauna and the nodule abundance. Furthermore, the habitat heterogeneity of the area partially drives the megafaunal diversity, which constitutes a significant component to the biodiversity in the abyssal deep sea and an important role in the deep-sea ecosystem function (Amon et al., 2016). Indeed, megafaunal taxa richness in the CCZ is one of the highest in the deep sea, having over 200 morphospecies, even when assessing locally (Andron et al., 2019).

The positive correlation between megafauna and nodule abundance, suggests that it may lead to increased prey abundance on and in proximity of the nodules. Since the greatest number of mobile predators in the deep sea are scavengers as well, the abundance and size of nodules may have a significant role in the structure of scavenger biodiversity and abundance (Harbour et al., 2020, Lledo et al., 2020). However, in a study conducted by Harbour et al., in the BGR area (The Federal Institute for Geosciences and Natural Resources, Germany), located in the eastern CCZ, there was not found a significant variation in scavenger biodiversity or abundance, in areas with nodules of different size. In any case, the same study, suggests that the community structure varies between different regions in the eastern CCZ and previous studies have shown that scavenging rates tend to increase with water depth. Therefore, it is important to have baseline information to asses with regards to scavenger diversity and behavior, before mining takes place, as such scavengers have an important role in the nutrient cycle and energy flow in the deep sea ecosystems by consuming and redirecting organic material. They depend on the transport of organic material from the pelagic zone, through the form of dead fishes, squids, jellyfish, and plant material (Harbour et al., 2020).

Furthermore, in the BGR license area, the scavenging community has appeared to be relatively species rich. However, there were differences in community composition, comparing to OMS and UK1 areas, which are in proximity, in the eastern CCZ. This shows that the scavenger community composition can have significant changes, even in relatively short distances of 20 kilometers or less. Therefore, it is important take such fact into account, when conducting baseline studies for the area (Harbour et al., 2020).

Below maps showing the location of BGR, OMS and UK1 areas in red, darker yellow and turquoise respectively (ISA, 2018):

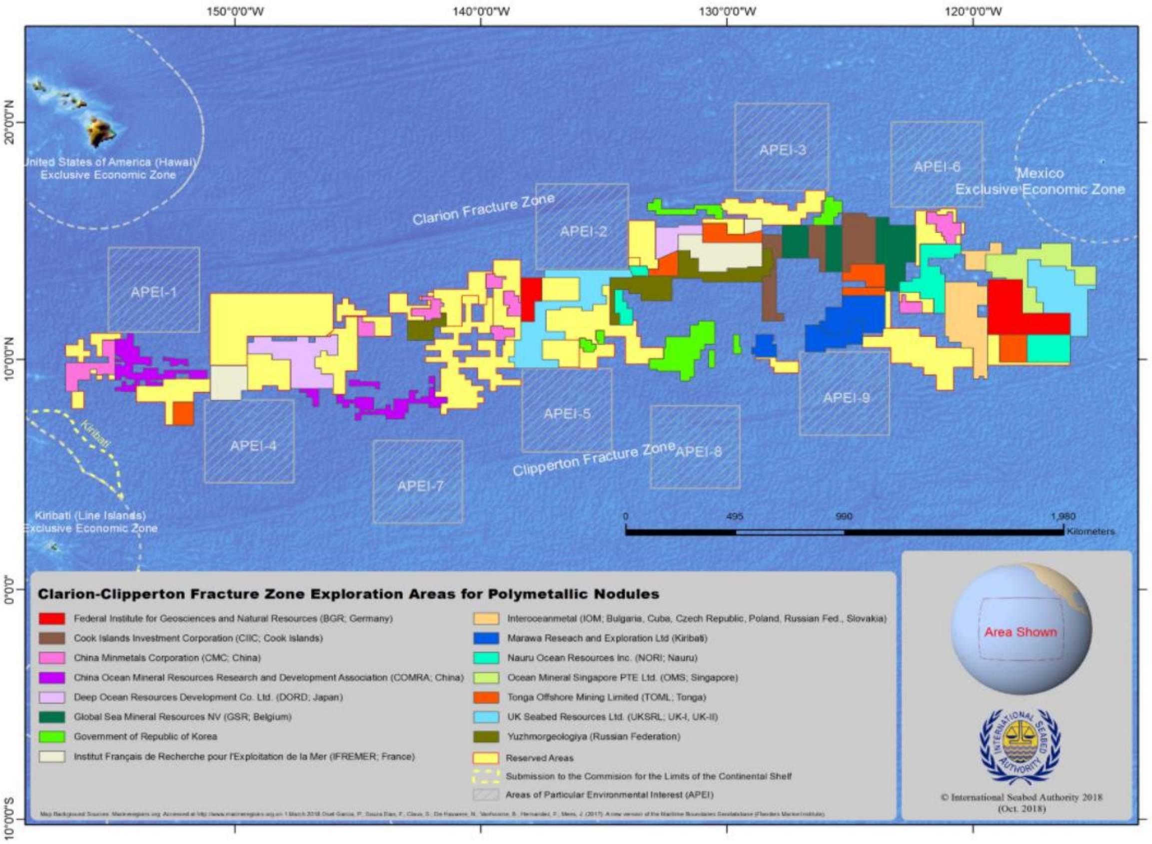


Figure 4.4. Exploration Areas in CCZ

Source: ISA, 2018

When habitat heterogeneity is increased, it enhances the community composition, density and distribution of megafauna, macrofauna and meiofauna in the CCZ. The abundance of nodules provides a hard substrate additionally to the sediments, which provide a soft substrate, contributing to the high habitat heterogeneity in the CCZ, in comparison to other areas where there are no nodules (hard substrate). Therefore, this heterogeneity enhances species richness and diversity (Amon et al., 2016) and habitat complexity (Lledo et al., 2020). Moreover, the type sediments can vary from one area to another, which is a characteristic that should be taken under consideration, as the size and distribution of substrate sediments will have impacts to the benthos food and distribution (Hao et al., 2020). This combination of hard and soft substrate is thought to promote the occurrence of one of the most biodiversity seafloor assemblages in the abyss (Lledo et al., 2020).

Manganese nodules are generally associated with suspension feeders (Andron et al., 2019). They are beneficial to such habitats; for example, most of the xenophyophores that are suspension feeders are colonizing to the nodules, to elevate, into the benthic boundary layer. Likewise, other hard substrate obligates such as corals, benefit from the presence of nodules, where they increase trophic and taxonomic diversity. However, such organisms can be at risk due the mining of the nodules, as they have adapted to very low concentration of suspended particles into the benthic boundary layers (Amon et al., 2016).

Another factor that plays an important role into the biological characteristics of benthic communities is the Particulate Organic Carbon (POC) flux (i.e food) of the seafloor, coming from the euphotic zone. The abyssal ecosystems are considered as “food limited”, because only a small part of the overlying export production reaches the seafloor. The abundance of abyssal megafaunal communities have a linear correlation with POC flux. In the CCZ, the eastern CCZ has the highest POC flux of the region (almost two times higher than in the western CCZ), however it still appears to be lower than in other regions. This fact may result to a community dominated by megafaunal but small (Amon et al., 2016). The limited food availability is impacting the megafaunal species densities which are low, despite the diversities being high. However, megafaunal living in areas with higher nodule coverage appear to have higher densities, as the suspension feeders live almost exclusively in the hard substrata of the nodules. On the other hand, such communities have lower densities in locations with lower nodule coverage (Andron et al., 2019).

Moreover, Dissolved Oxygen (DO) is linked to the distribution and abundance of organisms. There are previous mentions of seabed mining changing the chemical composition of the water column. So, a low level of oxygen will result to the escape, death or extinction of various communities (Hao et al., 2020).

A driver for shaping the biological characteristics of the CCZ is the small topographical changes. For instance, in the eastern CCZ, there are small changes (hills and valleys of the seafloor). Such changes are imperative for structuring a megafaunal community, as they can provide habitat structure that can be used by other habitats, that can provide an intermediate link in the trophic chain for bacteria and multicellular organisms, contributing to carbon cycling (Amon et al., 2016).

The depth of an area also plays an important role; for one, it impacts the mining operation, but it also impacts the sediment, the species and abundance of dominant organisms. This means that depending on the depth of an area, there is a relevant pressure and organisms should be adapted to such pressure. For instance, in deeper depths, more organisms that grow under greater hydrostatic pressure (barophilic organisms) can be found and distributed (Hao et al., 2020).

In the deep sea benthic ecosystems in general, it is understood that the deep sea ecosystem functioning, is exponentially related to the deep sea biodiversity. Also, the ecosystem efficiency is exponentially linked to functional biodiversity as well. Therefore, in the CCZ case, it is understood that only a small loss of benthic richness can result a greater loss of ecosystem efficiency and functionality (Andron et al., 2019).

4.5. Contracts in Clarion Clipperton Zone

To date, there are 11 exploration contracts with contractors and various sponsoring states involved for the CCZ. Below table presents such contractors, sponsoring states and dates entering the contract along with expiration dates (www.isa.org.jm):

Contractor	**Contract Date**	**Expiration Date**	**Sponsoring State**	**Location**
Interoceanmetal Joint Organization	29-Mar-01	28-Mar-21	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia	CCZ
JSC Yuzhmorgeologiya	29-Mar-01	28-Mar-21	Russian Federation	CCZ
Government of the Republic of Korea	27-Apr-01	26-Apr-21	-	CCZ
China Ocean Mineral Resources Research and Development Association	22-May-01	21-May-21	China	CCZ
Deep Ocean Resources Development Co. Ltd.	20-Jun-01	19-Jun-21	Japan	CCZ
Institut français de recherche pour l'exploitation de la mer	20-Jun-01	19-Jun-21	France	CCZ
Federal Institute for Geosciences and Natural Resources of Germany	19-Jul-06	18-Jul-21	Germany	CCZ
Nauru Ocean Resources Inc.	22-Jul-11	21-Jul-26	Nauru	CCZ
Tonga Offshore Mining Limited	11-Jan-12	10-Jan-27	Tonga	CCZ
Global Sea Mineral Resources NV	14-Jan-13	13-Jan-28	Belgium	CCZ
UK Seabed Resources Ltd.	08-Feb-13	07-Feb-28	United Kingdom of Great Britain and Northern Ireland	CCZ
Marawa Research and Exploration Ltd.	19-Jan-15	18-Jan-30	Kiribati	CCZ
Ocean Mineral Singapore Pte Ltd.	22-Jan-15	21-Jan-30	Singapore	CCZ
UK Seabed Resources Ltd	29-Mar-16	28-Mar-31	United Kingdom of Great Britain and Northern Ireland	CCZ
Cook Islands Investment Corporation	15-Jul-16	14-Jul-31	Cook Islands	CCZ
China Minmetals Corporation	12-May-17	11-May-32	China	CCZ

Table 4.1. Exploration contracts in the CCZ

Source: www.isa.org.jm

4.6. Environmental Impacts in Clarion Clipperton Zone

It is expected that the mining of the nodules will impact the megafauna within the mining area but over boarder scales as well. The removal of the nodules and burial by the sediments will remove hard-substrate habitats, destroy the nodule-obligate fauna, which will be unable to re-establish over ecological time scales (Amon et al., 2016). Therefore, the extraction of nodules will initially result that the nodule-obliged habitats will be destroyed, resulting to the local extinction of the related fauna (Fouquet et al., 2014).

Specifically, for the meiofauna, studies in the CCZ have shown that the recolonization or colonization can take up to several decades. Their recovery from a disturbance is found to be rather slow, despite being generally known to recover faster to their pre-disturbance conditions. Meiofauna such as nematodes are able to colonize and recolonize disturbed areas, however in the CCZ, due to different environmental settings in various areas, the outcomes could be very different, reducing the ability to predict responses at large- scale mining operations (Hauquier et al., 2019).

Furthermore, sedimentation with width over 5m and 5-20cm in depth would be removed along with the nodules but also, compacted, or re-suspended by machinery, which can result in great footprints, impacted further by the dispersed sediments across wider areas (Amon et al., 2016). Models have revealed that large sediment plumes will spread extensively and that plumes will cover at least twice the mined area (Jones et al., 2020). However, only few centimeters of sediments are the ones that provide a habitat to small animal communities to be developed, which are high in diversity and which are still poorly known (Fouquet et al., 2014). Studies in the CCZ have shown adverse impacts even from 1 cm of sediment disposition and that the most food-poor areas in the northwest CCZ, will most likely be more sensitive to sedimentation (Leitner et al., 2016).

Khripounoff et al., studied the current physical sediments characteristics of a track, when dredging was conducted 26 years ago in CCZ, in the French license area. It was noticed that the track in the bottom was still visible. Even though, the physical and chemical characteristics were not changed significantly, there was still not complete recovery from the disturbance caused. As per previous studies, even though recovery of fauna was mostly completed and there was recolonization, even after 2 to 7 years, however, there were differences in taxonomic composition, indicating disturbance effects remained, after several years. Furthermore, the nutrient and oxygen flux measurements showed no significant difference between the track and surrounding sediment. In any case, the authors recognize that in the area of study, the disturbance caused was weak, as the oxic layer of the sediment was not completely destroyed and the resuspended sediment was low (Khripounoff et al., 2006). Oxic sedimentation is presented in below scheme, showing that the depth of the oxic zone is deeper in the pelagic settings and sedimentation rates and organic carbon fluxes are lower (Tostevin et al., 2019).

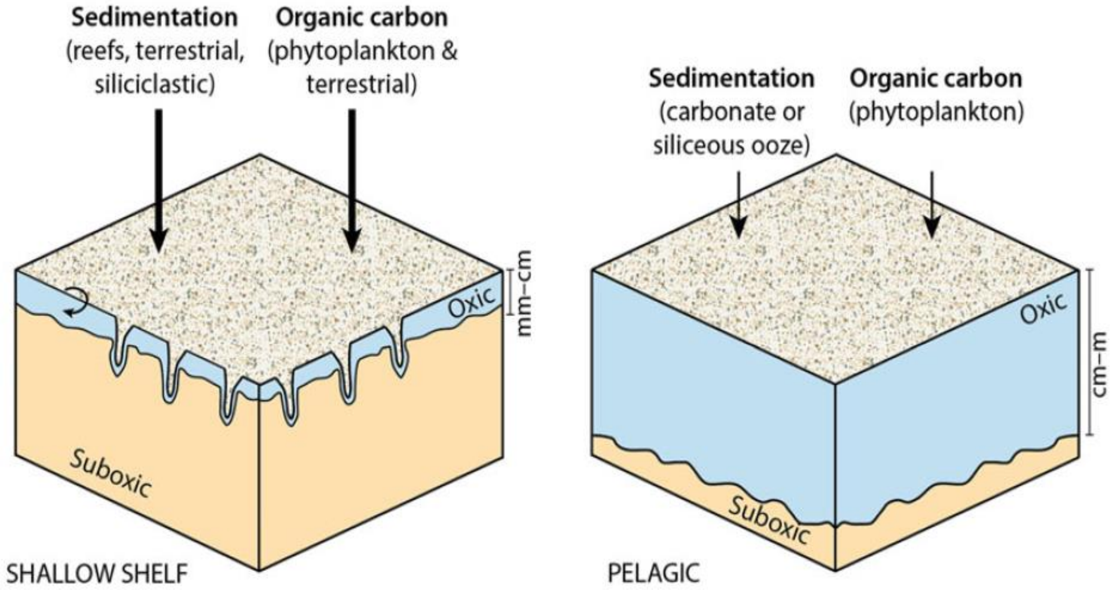


Figure 4.5. Oxic sedimentation in Shallow Shelf and Pelagic settings
Source: Tostevin et al., 2019

Other surveys conducted in the CCZ, on tracks from trawling and experimental mining simulations up to 37 years old indicate that epifauna is absent and recovery of the ecosystem is slow. The complete removal of nodules will cause significant adverse impacts, which will require long periods (millennia), for recovery of mining hundreds of km in extend (Leitner et al., 2016).

The mining operations in the CCZ are expected to also have effects in bacterioplankton communities, which are crucial in regulating energy and matter fluxes in marine ecosystems. The disturbances from the mining operation could alter the structure of upper ocean microbial assemblages with impacts to the deep- sea communities, which are still unknown. Even though bacterioplankton can respond quickly in metabolic activity and species composition in changes such as temperature, pH and variability in nutrient concentrations, potential changes in environmental conditions can cause shifts in the pathways, magnitude of ecosystem metabolisms and energy flow. Disturbances of sediments and plumes from mining activity can be disbursed into the water column and these waste materials could remain suspended for several years. Therefore, nutrients, attachment surfaces and potential energy resources could have effects in the pelagic food chain. If pushed outside normal range of conditions, the release of sediment plumes in the upper layer of the ocean and mesopelagic waters could alter the contemporary structure of the microbial community, with consequences for the microbial processing of carbon and other elements (Lindh et al., 2018).

As there are various licenses in the CCZ, once exploitation commences, there will be significant cumulative impacts, due to the multiple mining operations, but also the overlapping impacts from sectors irrelevant to mining operation (eg. Fisheries) (Leitner et al., 2016). The cumulative impacts of the mining operations are hypothesized to last for decades for sediment geochemistry and sediment community recovery and millennia in terms of nodule formulation and regrowth as well as recovery of nodule-obligate fauna (Amon et al., 2016). Studies conducted in the French license area, have shown that the recovery from dredging operation, to the location’s original characteristics necessitates almost 26years (Fouquet et al., 2014).

To sum up and as far as it can be predicted at this stage, the nodule recovery will impose a disturbance to all biota in a scale that can range from tens to hundreds square kilometers (Haquier et al., 2019). Other impacts will include light and noise pollution because of the machinery used, and other adverse impacts (Amon et al., 2016) as previously mentioned in Chapter 2.

4.7. Manganese Nodules Recovery Process

Below are presented the three basic components of the envisioned recovery process. Each component contains sub-systems, of which the bold ones are considered to be the most challenging ones (Agarwal et al., 2012):

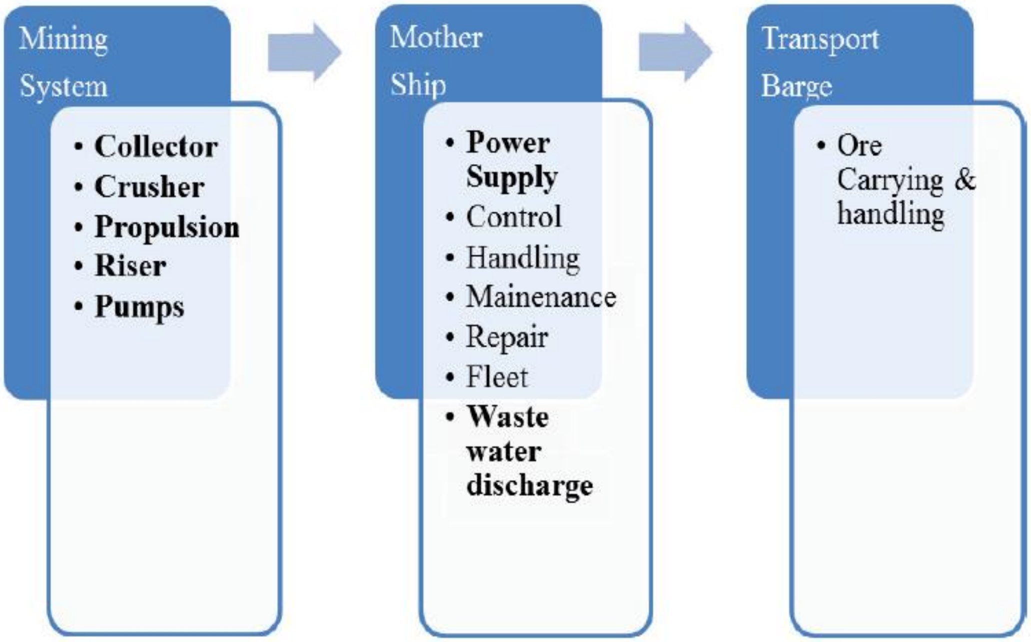


Figure 4.6. Basic components and sub-systems of envisioned recovery process
Source: Agarwal et al., 2012

The mining technique that has attracted more attention is the hydraulic mining system, consisting of a vertical riser pipe with a collector unit. The pipe would use either a centrifugal pump or an air lift system to transfer the collected nodules. There are three basic aspects on this proposed technique: the collector(s), the propulsion, and the vertical support (riser), as shown in the below scheme. Productivity will depend on the dynamics of their aspects and their efficiency in their combination (Agarwal et al., 2012):

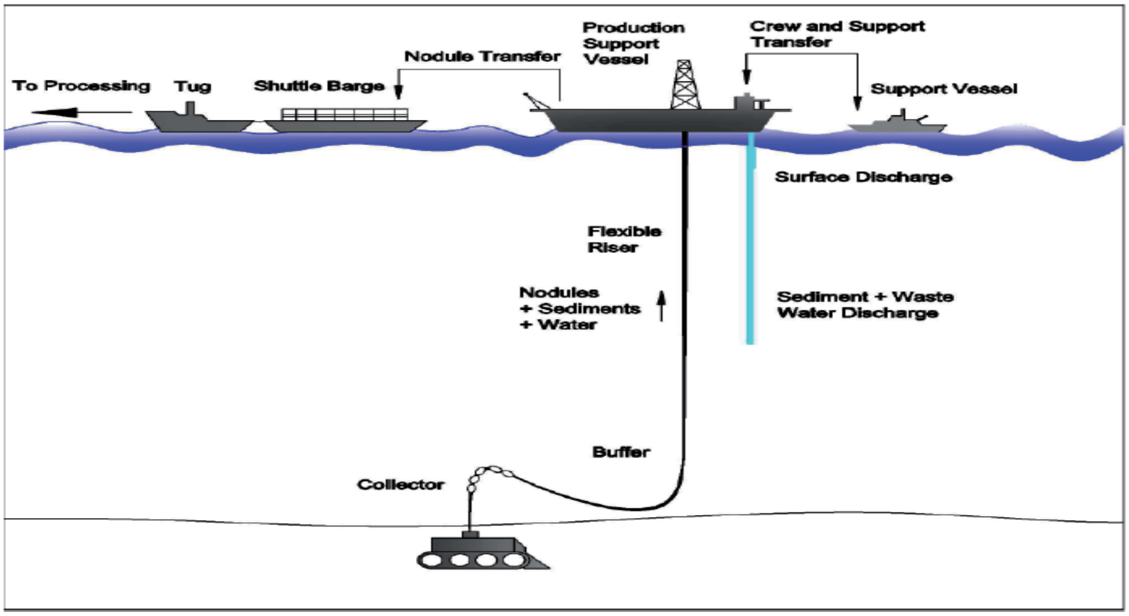


Figure 4.7. Hydraulic mining system
Source: Agarwal et al., 2012

Mining System: The Collectors would proceed into the seafloor and would collect the nodules, clean them from sediments, sending them to the support vessel through the riser pipe. A crusher can be incorporated to the collectors, to increase efficiency of the collecting process and the avoidance of oversized nodules being rejected. The collector would be considered effective, depending on the ratio of the collected nodules and the amount of sediments that have been released during collection, prior to sending them to the riser system. The propulsion of the collector could be either by being self-propelled or by being towed using means of the mother vessel. The Vertical transport process refers to the transportation of the nodules and the sediments, through the rising system. It is important to have a nodule pre-process to reduce the sediments transferred to the mother vessel reducing transfer weight, prevent any blockage to the rising system, and maintain the horizontal direction of the pipe. The sediments and water can be lifted through an air lifting system, which injects air into the collection line to have pressure and drive the flow towards the mother vessel. However, this technique requires more power than the hydraulic lift. On the other hand, if a hydraulic pump system is used, there should be pumps installed along the pipe, which should be designed to operate in high depths with increased pressure. The benefit of this system is that it simple to design, there is a high lifting efficiency and it is reliable. Below are presented two schemes for each system (Agarwal et al., 2012):

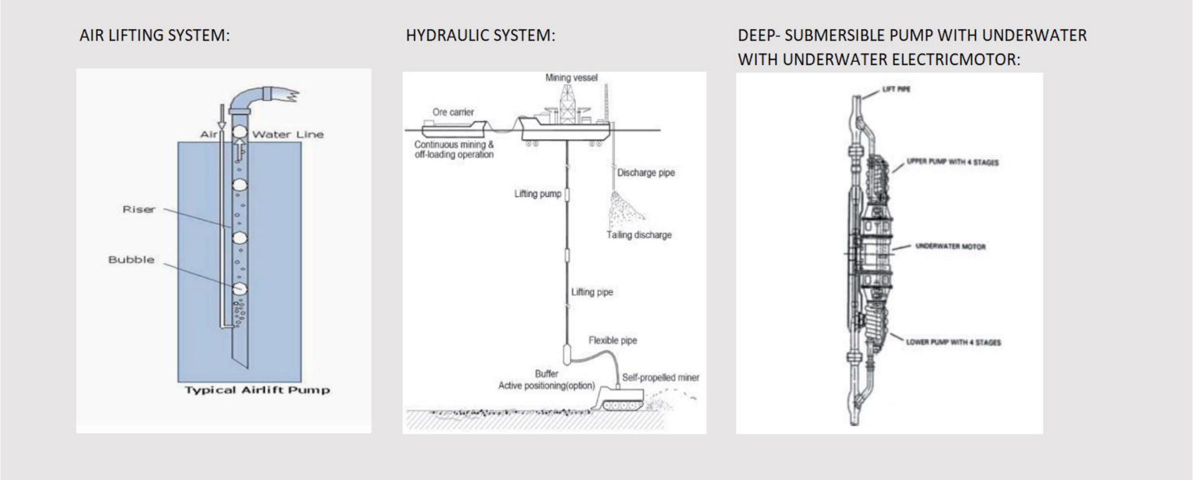


Figure 4.9. Air lifting system, Hydraulic System, Deep submersible pump
Source: Agarwal et al., 2012

Chapter 5. Discussion

The need to turn to deep-seabed mining has been developed due to various, mostly economic, factors related to the increase of the raw materials demand, due to the rising of the global population, urbanization, the prosperity of emerging and developing countries, along with the prompt development of technology and its innovations. The global needs in raw material are caused because of the development in electric mobility, the continuous enlargement of renewable energy in industrial counties and the evolution of infrastructure in developing countries. Therefore, deep-seabed mining has been considered by many countries and regions, to ensure their independence of importing minerals from other countries and safeguard that they will cover their demand. An example of the above is Europe, which currently imports almost 90% of the minerals used. Marine mining, could therefore secure the supply for its needs, especially since the trend of such minerals are increasing worldwide, due to high technologies, which require rare earth elements, cobalt, titanium and others (Watzel et al., 2020; Navarre et al., 2017).

5.1. Land - Based and Sea – Based Operations

It has become evident that to ensure the required metal resources, we will soon have to turn to the sea. However, such decision will come with great challenges and considerations, apart from being more costly comparing to the terrestrial mining. Deep-sea mining operations can have a lower ecological impact than traditional land-based mining. Nowadays large areas of rainforest must disappear on land due to the exploration procedures from mining companies. Deep sea minerals are lying on the seabed; so, there are not required any major infrastructure works to dig up the ground (Aoun I. and Vervoort E., 2018).

Below is a table presenting some of the mineral resources in demand along with their application and their current terrestrial mining countries (Mukhopadhyay et al., 2018):

Metal	Applications	Largest	Larger	Large
Cobalt (Co)	Wear- and heatresisting steels	Congo	Australia	China
Copper (Cu)	Electric cable,electric motors,building industry	Chile	Peru	USA
Gold (Au)	Investment, jewelry,electrical industry	China	Australia	USA
Iridium (Ir)	Displays, alloys,photovoltaics	China	Korea	Japan
Iron (Fe)	Steel, industrialmagnets	China	Brazil	Australia
Lithium (Li)	Accumulators,aviation and spacetechnology	Chile	Australia	China
Manganese (Mn)	Stainless steel, LEDs	China	Australia	South Africa
Molybdenum (Mo)	Steel	China	USA	Chile
Nickel (Ni)	Corrosionprotection, steel	Russia	Indonesia	Canada
Niobium (Nb)	Stainless steels,jewelry	Brazil	Canada	-
Palladium (Pd)	Catalysts (chemicalindustry), jewelry	Russia	South Africa	USA
Rare Earth Elements (REE)	Permanentmagnets,accumulators, LEDs	China	India	Brazil
Silver (Ag)	Investment, jewelry,chemical industry(catalysts)	Peru	China	Mexico
Zinc (Zn)	Corrosionprotection, batteries,constructionindustry	China	Peru	Australia

Table 5.1. Mineral Resources, Applications and Terrestrial sites

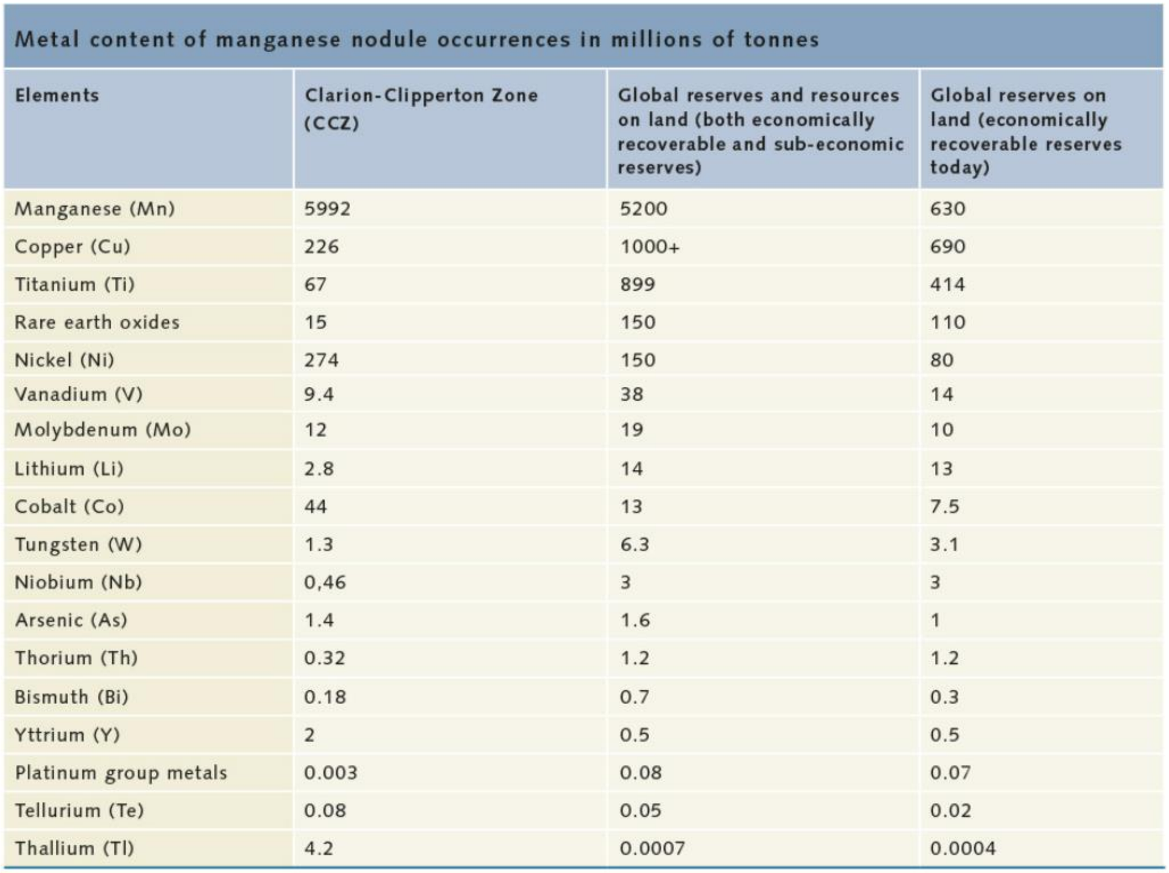
Source: Mukhopadhyay et al., 2018

Moreover, below is a short comparison between the sea and land - based operations:

1. Footprint: The footprint of mining at terrestrial sites is greater than the one in the sea, during and after the mining operations. This is because sites should be excavated, removing large overburden to find the required minerals. Such excavations completely change the landscape, even after mining operations are completed. On the other hand, in the deep sea, minerals are mostly lying on the seafloor, or buried under a few centimeters of sediments or clay.
2. Infrastructure: In terrestrial sites, permanent infrastructures such as roads or towers are required. During mining of the seabed, there is specific equipment used, connected with the mother vessel, and another vessel which would transfer the minerals to the shore is used, but, neither are permanent. Also, in terms of long-term capital cost, it seems that the deep-sea mining can be compatible or cheaper than land mining operations.
3. Ecosystem: The land-based mining can include deforestation and disturbance of the local ecosystem. Local species must find new habitat and might not be able to reoccupy their initial location, as the footprint left would be large. In deep sea mining, there would be impacts on the seafloor of a smaller populated ecosystem, where there is absence of light, and therefore photosynthesis. Surely, there will be

some impacts on such species, however, the overall effects will be significantly less than the ones in the terrestrial sites. In the deep seabed, such smaller footprint can allow the ecosystem to return to initial habitat.

4. Mineral diversity and concentration: In terrestrial sites, there is usually mining for a single mineral resource (for example nickel in Russia and cobalt in Congo). However, each deposit mined in the sea has multiple elements, such as manganese nodules, which can contain manganese, iron, nickel, cobalt, copper, and some rare earth elements, as previously mentioned, in Chapter 4 (Agarwal et al., 2012). Another factor is the concentration that can be found during mining operations (Mukhopadhyay et al., 2018). Below table presents the metal content of manganese nodule occurrences in million tones, in the CCZ, compared to terrestrial sites (World Ocean review, 2014):



Metal content of manganese nodule occurrences in millions of tonnes

Elements	Clarion-Clipperton Zone (CCZ)	Global reserves and resources on land (both economically recoverable and sub-economic reserves)	Global reserves on land (economically recoverable reserves today)
Manganese (Mn)	5992	5200	630
Copper (Cu)	226	1000+	690
Titanium (Ti)	67	899	414
Rare earth oxides	15	150	110
Nickel (Ni)	274	150	80
Vanadium (V)	9.4	38	14
Molybdenum (Mo)	12	19	10
Lithium (Li)	2.8	14	13
Cobalt (Co)	44	13	7.5
Tungsten (W)	1.3	6.3	3.1
Niobium (Nb)	0,46	3	3
Arsenic (As)	1.4	1.6	1
Thorium (Th)	0.32	1.2	1.2
Bismuth (Bi)	0.18	0.7	0.3
Yttrium (Y)	2	0.5	0.5
Platinum group metals	0.003	0.08	0.07
Tellurium (Te)	0.08	0.05	0.02
Thallium (Tl)	4.2	0.0007	0.0004

Figure 5.2. Metal content of manganese nodule occurrence in CCZ and terrestrial reserves

Source: Mukhopadhyay et al., 2018

5.2. DSM and Circular Economy

Deep seabed mining is a short-term solution for the coverage of demand in ores, with long-term and potentially irreversible environmental impacts. Deep seabed mining cannot occur in isolation, as disturbances can cross jurisdictional boundaries. Meanwhile, deep- sea ecosystems can take hundreds or thousands of years to recover. Negative effects on global fisheries would threaten the main protein source of billions of people and the livelihoods of millions of people, many in poor coastal communities. The global demand for mineral resources increases due to growing consumption patterns and therefore, an intense demand for valuable metals is expected to increase global prices over a longer term (Miller et al., 2018)

To date, deep-sea commercial mining procedure has not taken place, nor have there been pilot operations to enable accurate assessment of impacts. However, there have been proposed alternatives of exploiting stocks of ore from the seabed. Such approaches include replacing the use of metals in short supply (such as rare earths) for more abundant minerals with similar properties, landfill mining and collection of useful resources, and recycling of components from products at the end of their life-cycle (Seas At Risk, 2016). Increasing recycling and continuous research and development for alternative technologies that reduce or, in some cases, completely replace the use of metals is currently deemed critical for the transition to a renewable energy economy which is considered a vitally important complementary strategy. There are researches claiming that a transition towards a 100% renewable energy supply – often referred as the “energy revolution” – can take place without deep-sea mining (Seas At Risk, 2016).

The interest in alternative sources of minerals is growing among civil society, as scientists and companies, have undertaken working towards “urban mining”, shifting to a circular economy. There is already investment in urban mining, which is the process of “reclaiming compounds and elements from products, buildings and waste” (Lowrey N. & Rosenbaum H., 2019). Urban mining can contribute to a circular economy and reduce the need for material by recovering metals from electronic waste – one of the fastest global waste streams – helping to meet future global metals demand (DSCC, 2020). For instance, tons of gold and silver estimated to be worth $US21 billion, are used annually to make personal computers, mobile phones, tablets and other electronic products worldwide. Therefore, there is an abundance of gold, silver, rare earths, and copper in the waste generated by the disposal of these products. Urban mining could be extremely profitable, while dealing with an otherwise hard to solve waste problem, while at the same time capable of meeting future global mineral demand (Lowrey N. & Rosenbaum H., 2019). If turning to urban mining, products must be increasingly designed in ways that make repair and recycling more cost effective (DSCC, 2020).

Future demand for raw materials must also be assessed in the context of moving to a circular economy, aimed at enhancing design, repair, reuse, and recycling, as well as the development and use of alternative materials (Seas At Risk, 2016). A transition towards a sustainable, blue economy is required as it can provide social and economic benefits for current and future generations; restores, protects and maintains the diversity, productivity and resilience of marine ecosystems; and is based on clean technologies, renewable energy, and circular material flows. On the one hand there are the financial, social, and environmental risks of deep-sea mining. On the other, there is financial, social and environmental win-win of the future of metal resources which focuses on urban mining and the transition to a circular economy, in which mining plays only a minor role (Lowrey N. & Rosenbaum H., 2019).

A European Commission initiative, adopted in 2015, supports the transition toward a circular economy that promotes recycling and reuse of materials — from production to consumption. The raw materials are fed back into the economy though the strategy will depend on developing the necessary technology as well as changing consumer behavior (Miller et al., 2018). The European Commission has already introduced a circular economic framework (Lowrey N. & Rosenbaum H., 2019).

Circular economy is focusing on resource-efficient, energy-efficient and toxic-free products as well as waste prevention measures (Miller et al., 2018). It describes an economic system grounded in “cradle to cradle” product design, reconditioning, waste prevention and closed-loop production processes, while several companies have already put circular economy principles into practice (Lowrey N. & Rosenbaum H., 2019).

Circular economies aim to keep products, components and materials at their highest utility and value at all times: re-use what you can, recycle what cannot be re-use, repair what is broken and remanufacture what cannot be repaired. This contrasts with traditional linear economies where large quantities of materials are used in production and then thrown away. Supporters of deep-sea mining say it is necessary to ensure future supply of metals for use in renewable energy technologies. However, through deep-sea mining the continuous exploitation of the Earth’s resources is promoted, expanding humankind’s footprint, and potentially undermining efforts to transform economies by continuing unsustainable, single-use consumption. Metal demand associated with the dominant renewable technologies does not require deep-sea mining or other irresponsible forms of extraction. Indeed, within the next 10-15 years, it is likely that a different mix of metals and materials will be used in evolving technologies. Substantially, such mindset promotes the investments in public and private funding on technologies to extract metals from the deep ocean, instead of promoting and sharing circular economies’ knowledge and lifestyle change through innovations in technology and systems that could reduce the use of raw materials. For example, investing in increased public transit capacity, cycling and walking infrastructure will reduce the need for electric cars, the batteries that power them and the minerals required to produce them (DSCC, 2020).

Circular economy can only work if enough materials are in circulation. Metals can, in contrast to oil, be re-used repeatedly. But a large part of those metals is currently in windmills, solar panels, electric cars, mobile phones and infrastructure, and for that last application metals are stuck for a long time. The greatest demand comes from developing countries. Due to the growing world population, urbanization and higher living the demand for renewable energy and electric vehicles will continue to rise; ex. lithium and other battery minerals, copper in magnets in electric cars and other applications, wind turbine applications, rare earth minerals in computers, phones and photovoltaic panels and other renewable energy applications (Aoun I. and Vervoort E., 2018; Seas At Risk, 2016). By 2030, 40 million electric vehicles will be built per year. Primary mining is therefore not a competitor of recycling, redesign, and recuperation but an ally (Aoun I. and Vervoort E., 2018).

The legislation is developing upon sustainable product policies and eco-design, green public procurement, waste prevention targets, products and materials reuse all point in the right direction (Miller et al., 2018). While it is important to stimulate renewable energy implementation in order to combat climate change there will be choices that can be made between technologies, some of which may require less of the minerals found in the deep sea than others (Seas At Risk, 2016). Improving consumer access to recycling and streamlining manufacturing processes can be a more efficient and economically viable method of sourcing metals than mining virgin ore and could greatly reduce or even negate the need for exploitation of seabed mineral resources (Miller et al., 2018). Mining the seabed will degrade ocean health by affecting species, disturbing important areas for biodiversity and disrupting ecosystem functioning. There is a need to consider recycling existing materials, and being smarter about production and consumption (DSCC, 2020). Resource sovereignty would be better achieved by reducing the demand for minerals. Recycling, though crucial, is unlikely to provide sufficient quantities of metals to satisfy requirements in future years which has prompted suggestions that reducing use of metals in products will be a necessary part of product design (Miller et al., 2018).

Moreover, current trend towards responsibly recycling is the value of e-waste. The proper recycling of e-waste to recover technology metals such as cobalt provides a number of advantages over deep sea mining, ex. it reduces the number of created polluting e-waste dumps in poorer countries, there is no destruction of vulnerable marine ecosystems, and it reduces pressures on landfill sites and incinerators. In fact, it is a sustainable option, in concurrence with the circular economy that is needed in order to mitigate the climate change (Davenport B., 2019). Increasing the longevity of technological devices and promoting responsible e-waste recycling could be achieved through manufacturer take-back schemes, in which component materials can be safely and effectively recovered for reuse. Recycling metals carries its own challenges, which include potential release of toxic substances during processing and limitations during metals recovery that mean not all components can be isolated. A shift in focus to reducing consumption and, in addition, better products design (Miller et al., 2018).

5.3. Minimizing Environmental Impacts

Deep-sea mining has the potential to seriously harm the marine environment. Therefore, prior to proceeding to the exploitation phase, it should be understood that decisions may have to be invoked to mine a specific location, disapproval of a particular contract can incur, suspension or termination of mining operations may be needed, or requirements for adjustments could be needed to avoid serious harm. Also, in case of adverse impacts, compensation should be provided, as the mining operation can have impacts in adjacent locations. With such an understanding, there should also be indications of the type of impacts that should be avoided, along with other proactive regulations, ensuring effective protection. (Levin et al., 2016).

In order to minimize the uncertainty and the scale of impacts of seabed mining operations, sufficient environmental baseline information should be collected, which, as mentioned for the CCZ for instance, it is not the case. Such baseline studies will enable the assessment of the environmental impacts, including the impacts on the biodiversity of the area to be mined. Also, an evaluation of the project alternatives and ways to mitigate harm caused to the environment will require specific data from baseline studies, apart from test mining and surveys (Durden et al., 2018). Moreover, through baseline knowledge, the ecological thresholds[4] can be identified, however a long-term average baseline conditions and natural ecological variability will be required. By identifying the ecological thresholds, the decision makers can determine the impacts that are expected to exceed ecological thresholds, which should not be permitted, but also the impacts the that could indeed exceed ecological threshold, but require management, monitoring and to cease the mining operations, in case such thresholds are neared. Therefore, a well-designed baseline knowledge will contribute to the cautiousness or cessation of the impacts emerging from the deep seabed mining operations (Levin et al., 2016).

In the case of CCZ, there are previous mentions in Chapter 4, for the APEIs and their importance as part of a regional- scale management; they serve the purpose of capturing the full range of habitat biodiversity within each sub-region. As projects will move to exploitation and the Contractors hold approximately 75% of the area, which is currently in the exploration phase, it is of high importance to set the APEIs in a manner that will protect the environment. The size and space between contracts and protected areas should be set in a manner as to collect the minerals but at the same time maintain the environmental goals set, without them being compromised (Turner et al., 2018). As previously mentioned, there are no APEIs in the central zone of CCZ, where there is high concentration of nodules, due to contracts which were already established with Contractors. Also, APEIs are not part of the claim- scale monitoring scheme (Jones et al., 2019). Therefore, ISA also has to discuss, propose and decide the overlap between APEIs and current contracts in the CCZ, which holds many projects and cumulative effects are expected (Turner et al., 2018).

On the other hand, the Preservation Reference Zones (PRZ) and Impact Reference Zones (IRZ), as previously mentioned, should be designed by the Contractor, within their claim

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[4] Environmental threshold: “a point at which changes in an important ecosystem property or phenomenon have exceeded normal ranges of variability. Such thresholds may, but will not necessarily be, “tipping points” at which a small further change will abruptly produce a large ecosystem response resulting in a regime shift (change in the state).”, Levin et al., 2016

area. It is recommended that such areas should be suitably large and have sufficient separation between them, in order to permit repeated monitoring of representative effected and control areas. Such areas should also be monitored periodically and multiple times, having samples that will reflect the results and the state of the environmental conditions, should the mining had not taken place. Also, it should be considered that some impacts (for example from plumes), would not be reflected in samples immediately, as such impacts may not cause immediate changes. Therefore, by creating multiple zones, monitoring process could be facilitated, having representative samples from various zones. Also, PRZs should have sufficient high-quality resources and other habitats, as they should be representative of the mining area. As sediment plumes will not instantly reveal what the impacts in an area will be, there should be more than one IRZ as well, and by having IRZ outside the contract area can also facilitate in environmental monitoring and mitigation purposes. Also, since different contracts in the CCZ for instance could be close one to another, it could be of use and benefit for Contractors to share PRZ between claim areas. Last, monitoring should be conducted by the Contractor, but would also be beneficial to be verified by independent parties, enhancing public trust and gaining stakeholder support (Jones et al., 2020).

In below scheme presents the PRZ and IRZ, as per ISA’s mining code (purple text). As previously advised the APEI should have a buffer zone of 100km and a width and length of at least 200km. The blue texts are multiple PRZ and IRZ zones, as previously recommended (Jones et al., 2020):

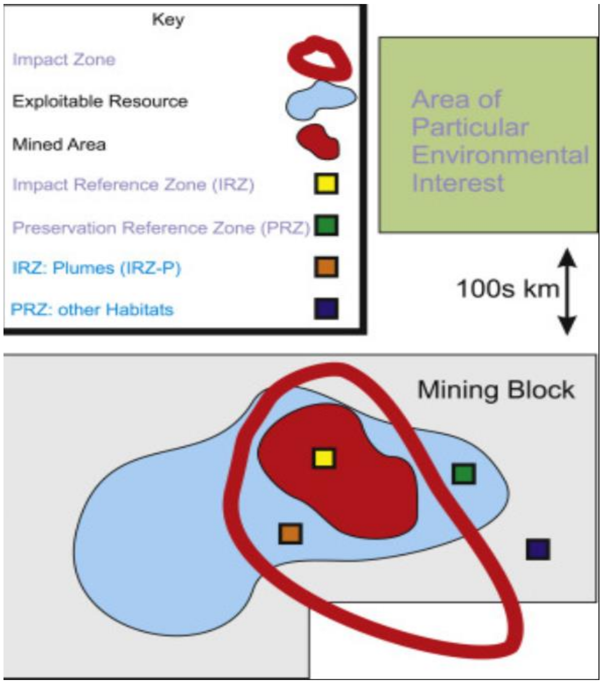

Figure 5.2. Graphical representation of PRZ and IRZ
Source: Jones et al., 2020

5.4. Accidental Risks and Social Impacts

In addition to the environmental impacts caused due to anthropogenic mining activities, the event of an accident or machinery failure should be considered in each EIA conducted for a specific project by the Contractor. For instance, an incidental disperse of ore may occur, during the transfer from the mother vessel to the barge or during its voyage to the shore. The latter can also include the loss of barge, which, apart from tones of minerals, has onboard other hazardous materials, such as its bunkers. Furthermore, there could be incidents related to natural phenomena and hazards, such as heavy, adverse weather conditions or volcanic activity, that should be included to environmental management plans. Also, as previously mentioned, the mining equipment should perform under demanding conditions, and therefore, its failure could lead to impacts in the entire water column. Such failure can include leaks of oil or hydraulic fluids (Navarre et al., 2017).

Additionally, quite recently, in April 2021, during trial mining and for research purposes, a prototype mining machine became detached from the lifting pipe linking it to the mother vessel, in the Pacific Ocean. Fortunately, the 25-tone robot machine was finally recovered (www.mining.com). Due to the great depth (thousands of meters), the recovery process could be quite challenging. Reportedly, there have been similar incidents, concerning the failure of the uplifting cable and another incident with a smaller prototype machinery, being hit by rocks, sand, and turbulence, during testing in shallower waters, close to the shore (www.bbc.com).

This Master thesis focuses on the environmental impacts occurring from deep sea mining. However, additional impacts related to social effects will be mentioned below in brief, for the sake of having a more complete picture of the impacts of mining activities. Even though some would argue that deep sea mining takes place far away from the land, there are some sites varying from 30km to 50km from the shore. Considering that the impacts and pollution in the sea are more difficult to be mitigated than in the land, coastal communities could be affected. First, barges containing the ore, would still need to go to coastal ports, which increases the risk of leaks, failures, or other incidents. Secondly, there could be impacts and disturbance to fishing, due to the presence of large vessels and toxic particles can intoxicate fish in distance, contaminating food, affecting humans as well. Thirdly, there are coastal communities, where their culture is directly linked to the ocean. For instance, in Papua New Guinea there are inhabitants believing that they will not meet their ancestors after death, as the location through where the spirits should pass is the granted license area of Nautilus, for the exploration of polymetallic sulfides. Other places in Papua New Guinea have specific fishing traditions related to sharks, as a ritual for young men's passage to the community, but also conduct a touristic festival related with their so-called tradition "shark calling". Many coastal communities depend on tourism and eco-tourism linked to the sea, which are highly important to the economy. In case of pollution, such communities will have severe effects in eco-tourism and future development opportunities (Navarre et al., 2017).

Chapter 6. Conclusion

In order to ensure the demand for minerals worldwide, it seems that sooner or later we will turn to deep sea, to cover our needs. The terrestrial sites still have some mineral resources to provide, which are not, however, unlimited and will soon expire. The reasons for not being able so far to turn to the deep-sea mining are various. The most important reason is that there is limited knowledge for the deep sea and limited baseline data information for the various locations of exploitation interest.

Minerals of interest are the cobalt rich crusts, the seafloor massive sulfites and the polymetallic nodules. All can be found in the Exclusive Economic Zone of some counties and in the deep sea, beyond national jurisdictions, for which the regulating authority is the International Seabed Authority. All three deposits can be extracted, however such process, indicates impacts and harm to the environment, unless there is a way to monitor the environmental thresholds, for which well-designed baseline knowledge of the area is imperative and mitigate environmental impacts.

In this thesis, we studied the case of Clarion – Clipperton Zone, which is one of the main locations of interest for the extraction of polymetallic nodules, holding up to 11 contracts to date for exploration purposes, by different States and third parties. Through our study, the limited scientific environmental knowledge is apparent, and the most severe concern is to avoid serious harm happening to the environment. As the nodules take millennia to be formed and developed and some of the fauna of the area has been proven to be nodule- dependent, it is projected that by removing the nodules, and taking under consideration the long-term to be created again, the environmental impacts seem irreversible. Irrespective of the local fauna, the impacts will also affect other organisms such as fish, mammals, due to the noise and light of the equipment, the dissolved substances released to the water column, the change of surface of the seafloor and others.

The International Seabed Authority has regulated some environmental regulations to take place, such as the establishment of the Areas of Particular Interest. However, as they were enforced after exploration contracts had been approved, they were positioned in areas where are doubtful to be fulfilling their purpose. It was noted that since the sole regulating authority is the ISA, it has to enforce strict regulations to the Contractors, enabling them to proceed to the mining phase, once there are sufficient environmental data, but without compromising the environmental health of the deep sea. The ISA's guidelines, regulation and overall mandate must be promoted and adjusted, along with further scientific discoveries. This is important for each site to be mined, but especially for the CCZ, where there are many contracts and projects for extraction and a mosaic of effects is already anticipated.

It is concluded, that turning into the marine environment for the extraction of mineral deposits will, at some point soon, be inevitable. However, finding a solution to cover our demands, should not lead in the creation of another (especially if irreversible) problem, of exceeding environmental threshold. Any attempt to proceed with extraction of minerals should be pursued cautiously (precautionary approach), conducting environmental risk management to foresee the outcomes (adaptive management), set environmental targets and biodiversity objectives related to mineral resources (local and regional assessment). The environmental measures taken for the ISA, such as the APEIs on regional level, the PRZ and IRZ should be ensured that are followed by the Contractors and that proper monitoring and mitigation measures are in effect.

Finally, due to the existing limited knowledge, is it important to gain as much time as possible prior to proceed with mining operations (exploitation phase). Through circular economy, some of that time could be gained; it is understandable that turning to circular economy would require enforcement of regulations and a turn of mindset of the various societies. However, the extra time is considered imperative considering what is at stake.

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Appendix: Supplementary material

Supplementary data associated with this dissertation can be found in the online version at:

https://www.isa.org.jm/mining-code

https://seas-at-risk.org/17-marine-litter/1041-new-eu-circular-economy-action-plan.html

https://wwf.panda.org/wwf_news/press_releases/?1416441/Deep-seabed-mining-is-an-avoidable-environmental-disaster