Study to investigate state of knowledge of deep sea mining

Final report Annex 6 Environmental Analysis

FWC MARE/2012/06 – SC E1/2013/04

Client: DG Maritime Affairs and Fisheries

Rotterdam/Brussels,

28 August 2014

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List of abbreviations

REEs	Rare Earth Elements
ABNJ	In Areas Beyond National Jurisdiction
APEI	Areas of Potential Environmental Interest
AUV	Autonomous underwater vehicles
CER	Chemosynthetic Ecological Reserves
CLB	Continuous line bucket system
CTD	Conductivity temperature and depth
EAM	Ecosystem approach to management
EBSAs	Ecologically and Biologically Significant Areas
EBV	Essential Biodiversity Variable
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EMSO	European Multi-disciplinary Seafloor and water column Observatory
ESONET	European Seas Observatory Network
ESP	Environmental Sample Processor
Eurometeaux	European Association of Metals
FISH	Fluorescent *In Situ* Hybridisation
GEO-BON	Biodiversity Observation Network
GES	Good Environmental Status
IMMS	International Marine Minerals Society
ISA	International Seabed Authority
ISIIS	In situ Ichthyoplankton Imaging System
MAR	the Mid Atlantic Ridge
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
OMZ	Oxygen Minimum Zones
OTEC	Ocean Thermal Energy Conversion
RALS	Riser and lifting system
ROV	Remotely Operated Vehicle
SAPS	Standalone pump system
SEA	Strategic Environmental Assessment
SMT	Seafloor Mining Tool
TEEB	The Economics of Ecosystems and Biodiversity
UNEP	United Nations Environment Program
USV	Unmanned surface vehicles
UVP	Underwater Vision Profiler
WEEE	Waste Electrical and Electronic Equipment

1 Summary

A considerable amount of scientific information has been generated on the physical attributes of sea-floor massive sulphides, manganese nodules, and cobalt-rich ferromanganese crusts. However the habitats, biodiversity, ecosystem structure, and resilience associated with these types of mineral deposits are less well-understood. If deep-sea mining is developed, environmental policies will need to be adjusted as new information, technologies and working practices emerge. This will require an on-going, collaborative approach involving industry representatives, policy makers, field scientists and subject matter experts, environmental managers, government authorities, international agencies, civil society and the general public. As deep-sea mining activities will, for the most part, be carried out in remote locations which may make independent observation difficult, transparency will need to be a key consideration in developing such approaches.

The major impacts from mining will be similar for the three types of mineral deposits considered here, namely:
1. loss of substrate,
2. effects of mining on the seabed, the operational plume and re-sedimentation and
3. discharge plume and its effects on pelagic and/or benthic fauna depending on the depth of discharge,

it is important to note that there are differences in impacts depending on the deposit type as well as the geomorphological setting, physical conditions, the scale of operations, and the technology used for extraction. The extraction processes that are expected to have strongest environmental impacts are the following:
- Disaggregation
- Lifting
- Dewatering.

The three mineral deposit types are expected to return different environmental results when it comes to the:
- duration of the impact;,
- size of the area impacted;
- nature of the impacts and the
- potential for recovery.

One of the most important drivers behind the impacts is the actual removal of the minerals which often hosts a number of species. Seafloor massive sulphides based in active hydrothermal vents are expected to recover relatively quickly (months to years) while inactive sites will take considerably longer ranging from tens to hundreds of years. Nodules will likely take the longest time when it comes to recovery after the removal of the elements and may take tens to hundreds of years or even longer in heavily mined areas (nodule faunas may take millions of years to recover). Similarly crusts are expected to recover slowly meaning tens to hundreds of years.

Another impact will be the spread of sediments which depending on the depth, technology, currents and the types of deposits mined can have varying levels of impacts. For all three elements the spread of sediment laden plumes near the seabed can go various kilometres beyond the mining site and can potentially smother seabed animals. Sediment in the water column can cause a reduction in light penetration and in temperature. These factors are likely to reduce plankton growth with knock-on impacts to the whole food chain. Additionally, ecosystems as a whole can be

impacted by the shift on sediment grain size (sediments may change towards sandier or finer composition).

Pollution from ships onto the surface water and noise pollution from the vessels as well as the underwater equipment can potentially have negative impacts; however as to date no extraction has taken place the extent of these impacts cannot be measured. With regard to noise pollution short-term masking effects on marine mammals are likely. As for all mining activities the disposal of tailings[1] on land or sea can also have long term impacts.

Finally, it is important to caution that although coastal marine mining in shallow waters (e.g. aggregates, diamond, placer gold) has a relatively long history, no actual commercial scale deep-sea mining operation (i.e. beyond 500m water depth) has ever been conducted. Only scientific mineral extraction and limited technological testing has taken place (as early as the 1970s). A cautious approach is thus a vital consideration when considering the topic of deep-sea mining, in order to avoid repeating destructive practices evident in the deep sea from, for instance, bottom trawling.

The social aspect

Embedded within the environmental and economic impacts there are important social implications that need to be considered. For the local population, the sea and the minerals it contains are often considered a property and the minerals under the sea can in some cases have cultural value associated with them. Therefore, it is important that stakeholders are sufficiently involved regarding the different aspects of the mining operations including safety and sharing of its benefits. Furthermore, transparency and continuous communication is necessary in order to ensure there is a common understanding on the principles of the operations and on the conduct of the mining company. Communication would preferably involve topics related to the entire value chain (from exploration through processing to decommissioning).

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[1] waste and refuse remaining after the ore has been processed

2 Approach to environmental analysis

2.1 Approach

The environmental analysis focuses on EU specific issues requiring particular policy considerations. The EU's Marine Strategy Framework Directive is one of several important approaches for regulating the environmental aspects in the deep sea, within EU waters. In Areas Beyond National Jurisdiction (ABNJ) regulatory regimes are developed by the International Seabed Authority (ISA) and aspects of the Marine Strategy Framework Directive (MSFD) may provide useful inputs, such as to the developing policy instruments for the exploitation of minerals from the seabed.

Additionally this report builds on the development of Regulations by the Southwest Pacific Islands Region lead by the Secretariat of the Pacific Commission[2]. Considering the vast ocean areas under their jurisdiction and limited land space, the Pacific Islands have a particular interest in ensuring the long-term health of the oceans and are have recently been granted an extension to continue the EU supported exercise to develop environmental and economic regulatory frameworks. Many aspects of the knowledge and experience gained with the Pacific are integrated in this summary.

Furthermore, with regard to international waters there are detailed Regulations for the exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich crusts[3]; as well as comprehensive guidance to contractors on the physical, chemical, geological and biological factors to be considered in baseline environmental surveys[4]. The Guidance to Contractors also includes activities, such as test mining, which require the submission of an Environmental Impact Assessment (EIA) and agreement with the ISA before operations can begin[5].

2.2 Overview of environmental concerns

This chapter presents an overview of the environmental impacts for the three types of minerals (sulphides, nodules and crusts) assessed in this study. A more detailed look at the deposit types follows the overview (from chapter 2.2.2 onwards) while a comprehensive analysis of impacts can be found under chapter 3.2.

While the major impacts from mining will be similar for the three types of mineral deposit considered here, namely:

4. loss of substrate,
5. effects of mining on the seabed, the operational plume and re-sedimentation and
6. discharge plume and its effects on pelagic and/or benthic fauna depending on the depth of discharge.

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[2] In December 2013, GRID-Arendal in support of the Secretariat of the Pacific Commission's Applied Geoscience and Technology Division (SPC/SOPAC) and in partnership with UNEP, an extensive group consisting of the top global experts in the field (including the ISA, academics, industry, governments, NGOs), delivered a broad assessment on the state of the knowledge on deep sea minerals and mining for the Pacific.

[3] International Seabed Authority, 2013a, International Seabed Authority, 2010, International Seabed Authority, 2012

[4] International Seabed Authority, 2013b

[5] Deep Seas Environmental Solutions Ltd, a member of the Ecorys consortium worked with the ISA Secretariat to produce the revised environmental guidelines adopted by the Authority

It is important to note that there are differences in impacts depending on the deposit type as well as the geomorphological setting, physical conditions, the scale of operations, and the technology used for extraction. The extraction processes that are expected to have environmental impacts are the following:

- disaggregation;
- lifting; and
- dewatering.

The three mineral deposit types are expected to return different results when it comes to the:

- length of the impact (in terms of time);
- size of the area impacted;
- nature of the impacts; and the
- potential for recovery.

One of the most important impacts is the actual removal of the minerals. Seafloor massive sulphides based in active hydrothermal vents are expected to recover relatively quickly (month to years) while inactive sites will take considerably longer ranging from tens to hundreds of years. Nodules will likely to take the longest time when it comes to recovery after the removal of the elements and may take tens to hundreds of years or even longer in heavily mined areas (nodule faunas may take millions of years to recover). Similarly crusts are expected to recover slowly meaning tens to hundreds of years.

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Pollution from ships onto the surface water and noise pollution from the vessels as well as the underwater equipment can potentially have negative impacts; however as to date no extraction has taken place the extent of these impacts cannot be measured. With regard to noise pollution short-term masking effects on marine mammals are likely. As for all mining activities the disposal of tailings[6] on land or sea can also have long term impacts.

2.2.1 Seafloor massive sulphides

Description

Seafloor massive sulphides are mineral deposits that form as a result of hydrothermal activity. They may be associated with “black smoker” chimneys, which can form where hydrothermal fluids (in excess of 350° C) are being emitted on the seafloor. Black smokers were first discovered in 1977 at the Galapagos Rift. Since then hydrothermal venting and seafloor massive sulphides deposits have been found in all the world’s oceans associated with oceanic plate boundaries – mid ocean ridge spreading centres, volcanic arcs and back arc basins. Copper, lead, zinc, and gold are among the valuable metals found in seafloor massive sulphides deposits. Seafloor massive sulphides deposits are the modern analogue of terrestrial massive sulphide deposits found globally in a variety of geological settings.

[6] waste and refuse remaining after the ore has been processed

Sulphide deposits are precipitated as reduced compounds in a wide area around the hydrothermal vent. During mining activities the deposit will be ground into finer particles and during initial dewatering, carried out on board ship at the sea surface, it will be oxygenated. These activities may lead to phase changes in critical elements, some of which may be toxic in low concentrations. The pH of the water may also be changed, and the discharge plume may have a higher temperature than the surrounding water. The exact processes and environmental consequences of these changes require further investigation.

Habitat and biodiversity

The physical and ecological characteristics of hydrothermal vent systems are unlike that of other ecosystems or biomes that use light as a source of energy. In an environment of elevated temperatures and the complete absence of light, hydrothermal vents support food webs based on chemoautotrophic primary production. The distribution of the hydrothermal vents is sporadic[7] (the spacing between vent sites can be up to hundreds of kilometres), and their existence can be ephemeral. The life cycle of a vent system can range from thousands to tens of thousands of years depending on the rate of spreading (for deposits on spreading ridges) and the ease with which fluids can circulate the subsurface (efficiency of plumbing system).

However, at slow spreading ridges, such as the Mid Atlantic Ridge, and ultra-slow spreading ridges, such as the Gakkel Ridge in the Arctic Ocean, where seafloor massive sulphides are more likely to occur, vent systems may persist for extended periods. It is important to appreciate that vent fauna at fast spreading ridges in the Pacific Ocean with high disturbance regimes, may have different life history characteristics to vent fauna on other ridge systems[8].

Changes in vent fauna may occur in relation to fluid flow (temperature, volumes, and location) and substrate (chimney collapse, eruptive magma events, etc.). These dynamics influence the point sources of hydrothermal emissions and also the lifespan of the individual “chimneys” and associated ecosystems[9].

Based on current deep-sea exploration technologies (which use “plume sniffing” to locate seafloor massive sulphides sites), only active seafloor hydrothermal systems (and/or inactive ones found in proximity to active sites) have been the targets of possible deep-sea mining efforts. Therefore the following information is focused on impacts related to these sites.

The mining of seafloor massive sulphides will create permanently (in terms of human timescale) disturbed areas at the mine site. As seafloor massive sulphides mining targets highly spatially concentrated deposits (as opposed to manganese nodule mining), the geographical extent of the physical disturbance from an individual mine is likely to be less than for comparable land operations. For example the Solwara 1 site in Papua New Guinea has a surface area of only 0.112 km^2 and when mining is completed is expected to leave a hole that is approximately 30 m deep[10]. Compare this to terrestrial massive sulphide mines, which are generally orders of magnitude larger e.g. the Broken Hill mine in Australia is 2km^2 and 1600 m deep, the Canadian Kidd Creek mine covers an area of more than 8 km^2 and by 2017 is expected to reach a depth of more than 3000 m.

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[7] Ferrini et al 2008 and Baker 2009

[8] Boschen et al. 2013

[9] Baker and Beaudoin, 2013; Johnson et al 2000

[10] Coffey 2008

Hydrothermal vent ecosystems are important places of biodiversity where the vent-endemic species have adapted to tolerate such challenging conditions. The list of endemic species numbers over 600 and new species are being identified regularly[11].
The communities of vent-endemic animals vary regionally throughout the global oceans. For example, the eastern Pacific vents are dominated by giant tubeworms, but they do not occur in the Atlantic or Indian Oceans, where varieties of shrimp, anemones, and snails dominate[12]. The current research on the variability of vent communities shows that there may be at least five "biogeographic provinces" for vent-endemic animals, although studies have yet to produce specific boundaries for these areas[13].

While localised hydrothermal active vent ecosystems[14] are the focus of some commercial activities, such as Nautilus Minerals Inc. within the Exclusive Economic Zone (EEZ) of Papua New Guinea, the largest seafloor massive sulphides are likely to occur at inactive sites on mid ocean ridges. Some contractors to the International Seabed Authority, for instance, have indicated their exploration for seafloor massive sulphides is focussed on inactive sites[15].

The organisms associated with these areas are more typical of mid ocean ridge rocky fauna, the actual nature of which will depend on depth and the geomorphological / physical oceanographic setting[16]. Areas in which massive sulphide deposits will occur may also be a mosaic of rocky surfaces and sedimented areas[17].

Environmental issues of relevance to seafloor massive sulphides will relate not only to vent fauna, but also to fauna on rocks, such as corals and sponges, and sediment communities. Benthic communities will include micro-organisms, meiofauna, macrofauna, megafauna, necrophages and fish. Areas of sulphide deposits that are not hydrothermally active may provide a inactive surface. The existence of a specialised fauna associated with weathered sulphide deposits is at present unknown[18]. In addition, impacts may occur on pelagic ecosystems, including specialised bentho-pelagic organisms, such as swimming sea cucumbers[19].

Mining activities at one depth may impact deeper living communities through downslope transmission of sediment-laden plumes or the initiation of turbidity currents. Deep-sea fauna are highly specific in their depth ranges owing to the effects of temperature and pressure on their cell wall structure and enzyme systems[20]. Direct impacts by mining at one depth may therefore have also have a significant effect on very different assemblages of species at greater depths.

Environmental impacts on seafloor massive sulphides

The technology currently proposed for extraction of seafloor massive sulphides involves digging and grinding of the mineralised rock. The mining processes will remove the surface habitat and the mineralised subsurface part of the deposit – at Solwara 1 this is estimated to be down to a depth of 30 m. There is some indication that following the removal of active chimneys at some sites, some

[11] Desbruyères et al 2006a, Van Dover 2011
[12] Baker et al. 2010; Boschen et al. 2013
[13] Van Dover et al 2002; Bachraty et al 2009; Moalic et al 2011; and Rogers et al 2012; Boschen et al. 2013
[14] Vent ecosystems are highly localized as they are entirely dependent on venting hot fluids. Even going just a few meters away from a source of hot fluids, biodiversity and biomass levels drop very significantly.
[15] International Seabed Authority, 2011, 2012
[16] Boschen et al. 2013
[17] e.g. Priede et al. 2013
[18] Van Dover 2007
[19] Billett et al. 1985
[20] e.g. Billett, 1991; Howell et al. 2002; Carney, 2005; Menot et al. 2010

regeneration may take place. For example at a Solwara 1 mining test site, active chimneys have been observed to “grow back” on a scale of weeks[21].

Organisms living at active vent sites[22] may have adapted to withstand relatively frequent loss of habitat related to volcanic and seismic activity[23] and the intermittent nature of the vent fluid discharge. Thus, they may be able to recover from mining-induced disturbance. Studies have shown how larvae from other vent sites can be transported from tens or even hundreds of km away[24]. Other studies have shown how sites can have strong indications of recovery within a few years[25]. However, this may be dependent on whether the sulphide resource is associated with fast-spreading, slow-spreading or ultra-slow spreading ridges (see above). In non-vent areas the deep-sea fauna typically have long generation times and may take decades to hundreds of years to recover. It is important to note that the number of such examples is trivial compared to the diversity of fauna found at such sites.

Apart from the physical destruction of habitat the mining process will also generate increased turbidity related to the extraction/operational plume on the seafloor and from the release of waste-water and fine particulate material (< 8 um) in a discharge plume following initial on-board dewatering of the ore[26]. The plumes released by the mining process will travel across the seabed potentially impacting areas adjacent to, and downslope from, the mine site. Particles settling from this plume may smother organisms and/or be toxic to some organisms (due to the presence of sulphides and heavy metals). The plume released into the water column during the transfer of ore to the sea surface and during any pre-processing on board the vessel could have similar effects and may include changes in pH and temperature. These plumes may have different properties to the naturally occurring hydrothermal plumes and may impact different areas. This is especially the case for any plumes released in mid-water that could potentially affect large areas.

The impact of the discharge plume will depend on the depth at which the plume is released. If the plume is released at the sea surface it could have a major impact on plankton by possibly reducing light penetration, or by stimulating greater growth by the introduction of nitrate, phosphate silicate and other nutrients, and through possible toxic chemical content.

Acknowledging that naturally occurring plumes are common at active sites, human activity-caused discharge plumes released at the sea surface at lower than ambient temperature may affect local weather (Ocean Thermal Energy Conversion – OTEC - environmental effects). If released at midwater plumes may have an impact due to particle load and possibly toxicity. Many gelatinous zooplankton in the mesopelagic and bathypelagic zones filter feed and may be harmed by the increased particle content. Changes in oxygen concentrations may occur if the discharge occurs in and around a mesopelagic oxygen minimum zone. In addition, if waste water is released at depth but has a higher temperature than the ambient water it may rise towards the sea surface where it will have a larger impact.

Ultimately the optimal conservation zone size (to protect species diversity, habitat diversity and genetic diversity) may differ in relation to the type of venting (rift valley, crest etc.), vent flow rates,

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[21] S. Smith personal communication

[22] Active vents are home to complex ecosystems with high biodiversity and relatively high biomass. Inactive vents located amongst active ones will be part of that complex ecosystem. Inactive vents isolated from active ones will have simple ecosystems with limited biodiversity and biomass.

[23] Van Dover 2011a

[24] e.g. Millineaux et al. 2010

[25] Tunnicliffe et al. 1997, Shank et al. 1998

[26] Coffey 2008

surrounding currents and connectivity to other populations[27]. Consideration must also be given to near-vent fauna or background fauna. It has long been hypothesised that background fauna among vents benefit from the chemosynthetically produced organic matter, but the scale of this is only beginning to be constrained. A recent study[28] illustrated that non-vent fauna had considerable portions of their dietary requirements met by chemosynthetic organic carbon sources at locations hundreds of m from active vent sites in the Manus Basin.

2.2.2 *Ferromanganese nodules*

Description

Manganese nodules are concretions of iron and manganese hydroxides and occur in a variety of sizes (most are in the range of 5-10 cm in diameter). They are most abundant in the abyssal areas of the ocean (4000 – 6500 m water depth). Manganese, or more accurately polymetallic, nodules contain significant concentrations of nickel, copper, cobalt, manganese and trace metals, such as molybdenum, rare-earth elements, and lithium. The trace metals have industrial importance in many high- and green-technology applications. The abundance of nodules and the concentrations of metals within nodules vary with location. Nodules of commercial interest have been found in parts of the Clarion-Clipperton Zone (CCZ) of the equatorial eastern Pacific, around the Cook Islands in the SW Pacific, and in an area of the Central Indian Ocean Basin.

The occurrence of polymetallic nodules has been well known for more than a century, but it was during the 1970s that interest was formed in mining the nodules. This interest did not translate to commercial operations, but in recent times polymetallic nodules have been put back on the agenda as a potential source of minerals. The ISA presented a model for deposit locations within the CCZ and the equatorial north Pacific region, which helped to build momentum for exploration in the area[29].

Habitat and biodiversity

Manganese nodules are found in highly stable environments where the flux of particles to the seabed is low – they typically occur under low productivity areas within the tropical Pacific and Indian Oceans. In the open ocean, far from land influences, sediment arriving at the seabed generally falls as a particulate rain of biological origin from the sunlit surface waters above. Organisms that exist on the deep-seafloor rely on this gradual downward flux of organic matter from the surface waters above for their survival[30]. However, even in the equatorial Pacific Ocean there is spatial, seasonal and inter-annual variation in the dynamics of surface water productivity and the subsequent flux of organic matter to the seafloor[31] and this is likely to have a significant effect on the fauna that occur across the vast expanse of the CCZ[32].

Research into biodiversity on abyssal plains has revealed high species diversity, with organisms living in the fine sediment on the seafloor, on the surface of the sediment, attached and within nodules, and in the overlying water column[33].The sediment community includes many new species including meiofauna (such as nematode worms and protozoan foraminiferans)[34], macrofauna (such as polychaete worms and isopod crustaceans)[35], and larger animals (megafauna) such as

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[27] Van Dover 2011
[28] Erickson et al. (2009)
[29] International Seabed Authority, 2010
[30] Smith and Demopoulos 2003; Smith et al. 2008a
[31] Wedding et al. 2013
[32] International Seabed Authority, 2008a,b; 2009
[33] Snelgrove and Smith 2002
[34] Nozawa et al 2006; Smith et al 2008b, and Miltjutina et al 2010
[35] Glover et al 2002; Brandt et al 2005; and Ebbe et al 2010

seastars, and sea cucumbers[36] and 'giant' protozoan such as komokiaceans and xenophyophores[37].

Most of the research into biology assemblages associated with polymetallic nodules to date has been done in the CCZ (a vast area across the Pacific Ocean floor similar in breadth to the United States of America). Significant faunal change in sediment communities is evident across the CCZ[38]. Similar assemblages are found in the Indian Ocean, although there will be some differences in terms of specific species[39]. There is a significant problem in achieving a consistent taxonomy of species within an ocean basin, let alone across oceans and this is a significant obstacle to determining the geographic distributions of species that may be impacted by mining.

The fact that diverse life on the deep ocean floor covers such large areas has led some researchers to suggest that deep-sea assemblages play significant roles in the ocean processes. For example, the great abundance of foraminiferans just by their combined biomass may be important in global carbon cycling, and thus the climate system[40]. Likewise the huge abundance of bacterial microfauna is likely to exert significant control on ecosystem dynamics of the seafloor, such as the remineralisation of organic matter[41].

Environmental impacts

Mining polymetallic nodules is expected to occur over very large areas of the abyssal sea floor because the ores are present in a very thin layer about 30 cm thick on the seabed. This is in contrast to seafloor massive sulphides deposits that are three-dimensional ore bodies extending some metres or tens of metres into the seabed. The CCZ covers approximately 4.5 million km^2 with an estimated 300 billion tonnes of nodules. A single polymetallic nodule mine site may disturb about 300 km2 of seabed area each year and there may be multiple operators mining at the same time at different sites. The mining process is likely to rake the nodules from the sediment surface. It is expected that many organisms living on the sea floor within the top 50cm of the sediment will be destroyed. However, portions of the microbial fauna and meiofauna (e.g. nematode worms, foraminiferans) may survive.

The systems used will also compact the sediment surface. Jets of water may be used to wash the nodules creating a plume of very fine sediment which will cover surrounding areas of the abyssal plain. This turbid plume may adversely impact the surrounding fauna, including on surrounding seamounts and abyssal hills deep-sea fauna are likely to be poorly adapted to cope with disturbance, as the deep sea is one of the most stable environments on the planet. It may also have a significant effect on gelatinous zooplankton and micronekton in the benthic boundary layer and perhaps even higher up in the water column depending on the buoyancy character of the water used and produced.

Mining the nodules will also permanently remove them as a habitat for attached species, such as sponges, sea anemones, komokiaceans and xenophyophores, as they will not regenerate (nodules take millions of years to form). It is expected that there may be many other species using nodules as a preferred habitat.

[36] Billett, 1991
[37] Gooday, 1991
[38] International Seabed Authority, 2008
[39] Rodrigues et al. 2001
[40] Lambshead et al 2002; Miljutina et al 2010
[41] Smith and Demopoulos 2003

A numerical simulation study using a 3-dimensional time-resolved particle tracing tool estimated that the finer fractions of re-suspended material from mining activity could remain in the water column for 3-14 years depending on factors such as inter-annual variation in environmental conditions[42]. Two key aspects of this will be the increase in physical presences of fine particles in the water as well as the gradual redistribution of finer particles from the mining area to surrounding areas. These processes will result in altered sediment fabric and habitat structure that would vary depending on the intensity, method, and duration of mining. The use of particle tracking models is likely to play an important role in estimating the possible trajectories and lifetimes of particle suspension across various size classes including the importance of time of year or climatic condition (e.g. El Niño vs. La Niña).

The discharge from nodule mining is unlikely to have any toxic effects as the mined material is generally inert. If the discharge plume is released at the sea surface, ecosystem effects can be expected by introducing cold, nutrient rich and particle-laden water into tropical surface waters. Strict control of water brought to the surface will have to be maintained and the integrity of riser pipes and discharge pipes will require continuous monitoring. In nodule areas the depth of the ocean will be great (4000 to 6000m) increasing options for where a discharge plume might be released. Oxygen Minimum Zones (OMZ) between c. 100 and 1000m are often associated with polymetallic nodule areas, such as the CCZ. While these areas are generally lower in biomass than in more productive parts of the ocean, they may contain many species with very poorly known levels of endemism. Metals in a discharge plume in OMZs may go through phase changes. Deeper discharge in the mesopelagic zone (at depths down to c. 1500m) may affect some species that undertake diurnal vertical migrations into surface waters. Pelagic biomass typically decreases with increasing depth before increasing in the benthic boundary layer. Options for discharge in the bathypelagic and abyssopelagic zones may need to be considered, although these zones also have characteristic fauna. However, the pelagic species are likely to have wider geographic distributions, at least on the regional scale. There may be a requirement for efficient heat exchangers within the discharge pipeline in order to cool the discharge water to the exceptionally low ambient temperatures (1 to 2 °C) found in the deep sea. Deep-sea organisms are sensitive to small changes in temperature.

Abyssal plain communities like those found in the CCZ have been shown to respond to increases in available food supplies within days to weeks in a range of data spanning increases in sediment community oxygen consumption to changes in macro and megafauna densities[43]. Such changes in food supply have also been linked to changes in the size distribution of fauna, or in the energy consumption distribution among animals in various size classes illustrating so called compensatory dynamics[44]. However, these changes did not take into account the kind of changes in sediment structure and grain size that would result from mining activity. Indeed some fauna may be adversely affected in relation to such structural habitat changes. Studies of recovery from experimental mining over periods of up to 7 years suggest that larger fauna such as crustaceans may recover more quickly in areas of simulated or test mining than nematodes.[45] However, it should be noted that the larger fauna are exceptionally difficult to study at abyssal depths owing to their low abundance. A much longer-term study covering 26 years revealed that nematode communities still have reduced density and diversity and differing composition inside experimental mining areas when compared to areas nearby[46].

[42] Rolinski et al. 2001
[43] e.g Ruhl et al. 2008
[44] Ruhl et al. 2014
[45] Bassau et al. 1995; Radziejewska, 2002
[46] Miljutin et al. 2011

2.2.3 Cobalt rich ferromanganese crusts

Description

Similarly to polymetallic nodules, cobalt-rich ferromanganese crusts are formed by the precipitation of manganese and iron from cold seawater. Both nodules and crusts form very slowly growing only a few millimetres every one million years. However, unlike polymetallic nodules, which occur on sediments at depths > 4000m, crusts coat the rocky slopes and summits of seamounts (undersea mountains) at depths as shallow as 600m.

Valuable crusts occur on the flat tops of guyots in the western Pacific. There are about 1,200 seamounts and guyots which may be of commercial interest in the western Pacific Ocean[47]. Crusts of commercial interest are found principally at water depths between 800 – 2500 m[48]. The crusts can be up to 25 cm thick. The crusts have commercially important metals such as cobalt, nickel, tellurium, and rare earth elements[49].

Mining crusts might be inherently difficult in some cases, given that they are attached to the underlying hard substrate and occur in areas of irregular geomorphology. Mining operators will face a challenge to develop technology, which can remove crusts from steep rocky surfaces with minimal waste rock and its attendant environmental effects[50]. There may be problems in removing sediment overburden[51], and operations near the summits of seamounts have the potential to impact deeper depths through the creation of downslope sediment plumes.

Habitat and biodiversity

Ferro-manganese crusts form on bare rock surfaces that are swept clean of sediment by strong currents. The seamounts and guyots with thick crusts are widely distributed, and as such have differing physical conditions – e.g. depth of summit, total depth range, steepness of slopes, current speed, substrate, nutrient concentration[52]. Very few seamounts are alike and all possess considerable heterogeneity. The physical heterogeneity leads to great biological variety[53]. Surveys carried out at crust sites in the Pacific regions have identified foraminiferans, sponges, corals, squids, echinoderms (sea stars, sea cucumbers, feather stars), crabs, and sea squirts[54]. Of these large organisms, foraminiferans have been found to be conspicuously abundant and diverse[55].

The isolated nature of many seamounts, although often occurring in groups or chains, led to various hypotheses that seamounts were hotspots of diversity, abundance, biomass and endemism. In many ways these views were built on what was known about island biogeography[56]. Subsequent sampling, however, has challenged these initial thoughts, and today the 'distinctness' of assemblages on seamounts is unproven[57]. Other sources claim that while many species are shared with other deep-sea habitats such as continental slopes and banks, seamount assemblages may have a different community structure[58]. However, seamounts are very poorly sampled and genetic studies of connectivity show a variety of patterns depending on the taxon studied[59].

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[47] Clark et al. 2012
[48] Hein et al. 2000, 2009
[49] Hein, 2010
[50] International Seabed Authority, 2002
[51] sediment covering the ores
[52] Clark et al. 2010
[53] Pitcher et al. 2007; Consalvey et al. 2010
[54] Rogers, 1994; Fukushima 2007; International Seabed Authority, 2011; Schlacher et al. 2013
[55] Mullineaux 1987
[56] McClain, 2007
[57] McClain, 2007; Rowden et al. 2010
[58] Clark et al. 2012
[59] Shank, 2010; Baco & Cairns, 2012; Bors et al. 2012; O'Hara et al. 2014

The lack of comprehensive data has led to generalisations about seamounts as a whole which probably apply only to a subset, depending also on the bio-geographical province in which they occur[60]. A major step forward has been made, however, in compiling a relational database of geomorphological, physical oceanographic and biological characteristics of seamounts, with strict quality control and a measure of confidence in the data[61]. These data have highlighted that the degree of knowledge decreases very markedly with increasing depth. The level of knowledge of seamount ecosystems at depths at which cobalt crusts may be mined is extremely limited.

Cobalt crusts may also occur on large ridge like features on the seafloor, such as the Rio Grande Rise off Brazil[62]. As for seamounts, recent research on non-hydrothermal vent fauna on the Mid Atlantic Ridge (MAR) in the North Atlantic has shown large-scale affinity of fauna at bathyal depths (c. 200 to 3000m) on the MAR to fauna found on the European and North American continental margins at similar depths[63]. It is likely therefore that benthic fauna are widely distributed within any one particular ocean basin, although there may be differences between ocean basins.

Environmental impacts

Mining crusts involves removing the relatively thin layer of ore from the underlying rocky surface. While the technology to undertake this has not been established, it is generally considered that it will involve grinding or scraping the crust off. This is a difficult process due to the lack of uniformity in the thickness of the crust and physical conditions likely at the mine sites: fast currents, steep inclines and rugged geomorphology. However, initial cobalt crust mines are likely just to mine the tops of guyots or the upper flanks of a seamount where slopes are reduced. Removing the crust will destroy all the sessile organisms. It is thought that the marine life on the rocky surfaces may recolonize, but this may occur over very long timescales[64].

Corals on seamounts at depths where mining may occur may be as old as 2300 years[65]. A study of habitat recovery from bottom trawling on seamounts found that there was little recovery over periods of 5 – 10 years with statistically significant recovery found in only a few taxa[66]. As with seafloor massive sulphides mining, the sediment plume generated during the extraction process, may also impact surrounding and downslope fauna. Waste water extracted from the ore slurry will also be returned to the water column as described above for polymetallic sulphides. Should there be fast currents present, these are likely to quickly disperse this material but it may still impact surrounding fauna.

2.3 ATLANTIS II Red Sea

Building from the geological description of the Atlantis II DEEP deposit provided in Task 4: Geological Analysis, we describe some basic environmental considerations for this occurrence separately owing to its unique status. At an estimated 90 million tonnes in size, Atlantis II DEEP is the biggest known metal-rich sea-floor deposit discovered to date, and it is the only example of a large-scale metalliferous-sediment type deposit. In the 1970s, a pre-pilot test mining study was conducted by a German company (Preussag A. G.). Using what was described as “conventional floatation” means, they recovered 15,000 m^3 of seafloor sediments and brines from four test sites in

[60] McClain, 2007; Clark et al. 2012
[61] Kvile et al. 2013
[62] Perez et al. 2012
[63] Priede et al. 2013
[64] Meaning beyond human timescale sourced from Rowden et al. 2010
[65] Carreiro-Silva et al. 2013
[66] Williams et al. 2010

the Atlantis II basin. They also proceeded to concentrate the recovered material at sea.

Environmental and biological assessments were made as part of the MESEDA Programme in 1981 but were not released publicly at the time. The work was conducted by scientists from the University of Hamburg and Imperial College of Science and Technology, London School of Mines. In 2010, following the announcement of the joint venture between the mining companies Diamond Fields and Manafa, permission was given to release the report on the Internet.[67]

In its conclusions, the report raises a series of environmental considerations including:

- Sub-surface, deep-water discharge of tailings[68]: The report stresses the importance of good management and monitoring of tailings discharge in the context of the conservation and protection of marine life in the central Red Sea, adjacent coasts, and adjacent areas that are home to coral reefs. (It should be noted that if mining were to proceed today there may not be any discharge of tailings into the water column. This is due to improved technology and potentially stricter regulation regarding discharge.)
- The report highlights how planktonic organisms in the vicinity of the possible tailings plumes are the most vulnerable life forms that would be affected by heavy metals and chemical processing agents that could be discharged. In addition, subsequent leaching of any tailings (release of zinc, copper, cadmium, mercury, and other toxic elements) would produce an important ecological stress.
- The report also describes the high level of uncertainty with respect to the in-situ effects of tailings on oceanic plankton. There are noted concerns as to the fate of plankton that may transport certain levels of toxic elements from the area near the mining activity to other biological communities further afield. It was also noted that the addition of volumes of inorganic material into the “detritus-seston” flow could affect the food supply of deep-water benthic organisms.
- The report notes how plankton recruitment from areas to the South of the mining site would be vital for the recovery of Central Red Sea deep-water ecosystems. A better understanding of population dynamics is therefore needed as so many unknowns persist that limit the ability to properly manage the conditions for recovery.
- The study noted that the impact of tailings discharge on the benthic environment would include both physical and toxicological effects. They calculated a 1,500 km^2 area of tailings spread within which areas of intense sedimentation would lead to the creation of an azoic[69] zone. Beyond the area of most intense impact, reduced levels of sedimentation could permit some organisms to survive.
- The study examined the longevity of tailings in the water column and how the residence time might influence the effects of toxicological hazards on benthic organisms. Some leaching trials showed notable removal of heavy metals within a period of two-to-three weeks. Such leaching processes would likely reduce the toxicological risk of tailings that might deposit in the overall impacted area and could thus favour survival of benthic organisms and enable better conditions for post-mining recovery.
- The study warned of possible long-term risks associated with bio-accumulation of toxic heavy metals within the trophic levels of the epipelagic and mesopelagic zones. The more wide-spread the distribution of tailings materials the higher the risk of unforeseen, long-term environmental issues.
- The report also highlighted how the potential release of natural high salinity brines into the bottom waters of the Red Sea could be enough to cause localised mortality of organisms if not

[67] http://www.senckenberg.de/root/index.php?page_id=15250
[68] waste and refuse remaining after the ore has been processed
[69] without any life

properly mitigated.

Finally, the study team outlined a series of key recommendations should mining of the deposit be considered:

- Pilot mining operations and environmental assessment should take place for at least a 2 year period in order to identify and measure the full-scale of environmental and social impacts of the specific operations.
- In order to be realistically comparable to actual full scale mining (with respect to relevant environmental monitoring strategies), pilot mining operations should be conducted in a manner well representative of full scale mining.
- For any mining activity, tailings discharge must be restricted to depths greater than 1,100m. It should however be kept in mind that further research may modify this minimum depth level.
- Monitoring plans must include observations of particulate plume development and sedimentation, observation of 'liquid' plume development and its possible extended distribution and observations on potentially toxic substances in relation to ambient concentrations.

A solid baseline understanding of the fate of tailings during full scale mining operations needs to be established in advance in order to plan contingencies and set up emergency response plans. Focused research must be directed to address the needs of a proper environmental monitoring programme that would be implemented during mining. This research needs to include:

- An examination of whether plankton replenishment by species from the Gulf of Aden is a viable process to aid in the recovery of habitats destroyed by mining.
- An examination of the nutrient exchange pathways between the Open Ocean and coastal regions.
- Studies to distinguish between impacts caused by the mining activity and similar impacts caused by other land-driven natural and man-made sources.

2.4 Key knowledge gaps

The following table provides an overview of the main knowledge gaps in relation to understanding the environments where deep sea minerals occur. Some of these questions have been answered at some mineralisation sites (e.g. extensive studies have been undertaken at the Solwara 1 site in PNG) however at other potential mining sites there are still significant knowledge gaps.

Table 2.1 Key knowledge gaps by deposit type

	Sea floor massive sulphides	Key references
Physical and chemical	• controls on sub-seabed fluid flows supporting hydrothermal vent regimes[70] • recovery rates due to loss of habitat of vent systems if mined directly • chemical composition and particulate content of waste water released in a discharge plume following initial dewatering/processing of minerals at the sea surface • particle concentration, settling behaviour and dispersal of the operational plume caused by mining.	Coffey 2008
Biological	• extent of endemism amongst vent organisms and	Van Dover 2011

[70] This refers to the "plumbing system" that controls the flow of fluids underneath the seafloor. There is limited scientific understanding of how that system evolves over time and what influences it. When fluid flux rate, chemistry, temperature etc. changes, this has an immediate effect on organisms dependent on the fluids.

	methods of dispersal • extent of connectivity, genetic diversity and distributions of non-vent benthic fauna, such as, but not exclusively, corals and sponges • effects of operational and discharge plumes on pelagic ecosystems • toxicity of operational and discharge mining plumes on benthic and pelagic biota • critical tolerance threshold of benthic fauna to concentration of particulates • downslope ecosystem effects from mining operations • recolonisation rates and recruitment processes at active and non-active vent sites • spatial dynamics of fauna and understanding the drivers governing faunal zonation and micro-distribution patterns at active and non-active vent sites. • modelling of vent and non-vent population dynamics	Boschen et al. 2013 Marsh et al 2012 Erickson et al. 2007 Gollner et al. 2013 Beedessee et al. 2013 Teixeira et al. 2013
	Ferro-manganese nodules	
Physical and chemical	• amount and extent of turbidity that will result from the extraction process • particle concentration, settling behaviour and dispersal of the operational plume caused by mining • chemical composition and particulate content of waste water released in a discharge plume following initial processing of minerals at the sea surface • compaction of sediment surface • effect of temperature difference of discharge plume relative to ambient seawater • release of nutrient-rich water from deep into surface waters stimulating primary production and ecosystem change • release of cold deep water into warm surface waters or the mesopelagic zone	
Biological	• loss of nodules as a hard substrate for seafloor life • recolonisation rates at disturbed areas • affects of increased turbidity on communities and individual species • genetic diversity of biota • effects of operational and discharge plumes on pelagic ecosystems • effects of mining and plumes on fish and necrophage assemblages • effects of plumes on seamount and abyssal hill fauna if in the vicinity of operations • smothering effect of resedimentation from operational and discharge plumes • connectivity at the regional scale and whether it is taxon specific • population size and area for protection to maintain reproducing populations	Tully & Heidelberg 2013 Wu et al 2013 Thiel, H. (2003).

	• changes in ecosystem functioning and relation to changes in diversity and species composition • modelling of abyssal sediment population dynamics • effect of noise from exploration and mining systems on cetaceans, fish and other organisms	
	Cobalt rich crusts	
Physical	• better understanding of seamount characteristics and interaction of geomorphology, physical oceanography, depth and biogeographic setting in creating habitat heterogeneity and complexity • chemical composition, particle concentration, settling behaviour and dispersal of the operational plume caused by mining • chemical composition and particulate content of waste water released in a discharge plume following initial processing of minerals at the sea surface • creation and nature of downslope turbidity currents and sediment transport of overburden	Kvile et al. 2013 Clark et al. 2012
Biological	• relationship between crustal composition and community composition • effects on biological assemblages and distributions caused by the interaction of geomorphology, physical oceanography, depth and biogeographic setting • effects of downslope sediment transport on deeper benthic assemblages • effects of mining activities on demersal fish populations • toxicity of operational and discharge plumes on biota • effects of operational and discharge plumes on pelagic ecosystems • connectivity between seamounts and at the regional scale and whether connectivity is taxon or life-history specific • better understanding of connectivity between seamounts and other deep-sea habitats such as continental slopes and banks • joint genetic and physical oceanographic modelling studies • population size and area for protection to maintain reproducing populations • changes in ecosystem functioning and relation to changes in diversity and species composition • recolonisation rates and recruitment processes on seamounts effect of noise from exploration and mining systems on cetaceans, fish and other organisms • biodiversity inventory of seamount fauna with good standardised taxonomy and genetic information • combined databases of geological, physical, chemical and biological characteristics of seamounts with data quality control • predictive modelling of seamount population dynamics • understanding of possible cumulative impacts (e.g.	Clark et al. 2011b Probert et al. 2007 Pitcher et al. 2007 (several chapters in in Pitcher et al. book) Consalvey et al. 2010 Rowden et al. 2010 Schlacher et al. 2013 Clark et al. 2012 Kvile et al. 2013

	fishing and mining in the same region) • critical evaluation of environmental proxies for biological communities • valuation of ecosystem services provided by seamount ecosystems • predictive modelling of ecological risks and mitigation strategies	

2.5 Spill-over impacts affecting ecosystem services

The ecosystem services which exist in these potential deep-sea mining sites may include habitats that are important for local and/or commercial fisheries, scientific research opportunities (especially apparent in the case of hydrothermal systems which offer the chance to study the evolution and adaptation of life under extreme conditions and possibly even the origins of life on Earth) and potentially valuable genetic resources and yet to be discovered chemical compounds. It is important that nations fully consider both the economic benefits and potential environmental costs of deep-sea mineral extraction and opportunity costs such as those arising from the displacement of other potential uses of the ocean. Notably, some of the external costs might involve the loss of non-market values, such as the existence of a unique ecosystem or species.

According to a recent UNEP report[71] in principle, destruction of ecosystems associated with deep-sea minerals might involve the loss of ‘existence values’, or ‘bequest values’, or there may be future-use values of which we are currently unaware (also known as ‘option values’). Conversely, passive and option values (existence and bequest values) are likely to increase for three reasons:

1) people will become more aware of these habitats, especially the specific habitats where mining is proposed; deep-sea mining exploration would lead to increased societal awareness of deep sea sites which may result in the non-use value people ascribe to these ecosystems to increase, making it more difficult to justify approval to go from exploration to mining.
2) any future mining activity will decrease the number of available mining sites; as intact sites become more scarce, use and non-use values will inherently increase - and
3) potential non-extractive uses of deep sea habitats including medicinal applications, bio-engineering, or even tourism may become relevant. Deep-sea mining exploration will add to other forms of exploration (e.g. targeted science) in increasing the potential for discovery of new uses that can be derived from these ecosystems, thus affecting their perceived or their concrete value to society.

Given that current passive and option values for these habitats are exceedingly small, as exploration efforts linked to deep-sea mining expands, the value ascribed by society to these ecosystems is only likely to grow as we learn more about these habitats. Consequently, in addition to prudent management there needs to be a programme of scientific research, dissemination of results, and on-going public consultation.

Disturbing large areas of seabed may also have impacts on regulating ecosystem services. At present there is very little knowledge of ecosystem services in the deep sea. A global economic valuation of ocean ecosystem services is currently in the planning phase under the auspices of UNEP’s TEEB (The Economics of Ecosystems and Biodiversity) effort. This valuation approach applied to deep ocean systems could help provide a better understanding of the importance and

[71] UNEP et al., 2012

value of such ecosystems even if distant from human habitation and/or direct use.

Currently there is limited understanding of TEEB issues in the deep ocean from basic scientific knowledge through to scalable estimates of ecosystem function and service. There is also very little work done to understand valuations of existence[72] and related values. The confluence of these unknowns suggests that a precautionary principle is needed and that valuations are revisited as more information comes from various levels and awareness changes[73].

2.6 Recycling

In line with the EU's strong commitment to waste reduction and recycling, it is important to assess whether a significant share of the metal demand driving Europe`s interest in deep-sea mining could be met by increased recycling (taking into consideration both pre- and post-consumer recycling) activity. In such an assessment, it would be important to consider a number of European policy documents including the forthcoming review of key waste legislation which aims to significantly increase recycling rates, and shift towards a fully 'circular' economy, whereby valuable materials are extracted from old products, to serve as secondary raw materials for new ones.

Additionally, it is important to assess the EU strategy for secure and sustainable raw materials supply of which both recycling and sea bed mining are components. The Raw Materials Initiative (COM (2008) and COM(2011)025) of the European Commission is based on 3 pillars. The first pillar “access to raw materials on world markets at undistorted conditions” sets guidelines for European raw materials diplomacy with particular attention to development policy. The second pillar “fostering sustainable supply of raw materials from European sources” is to improve framework conditions and raw materials supply from EU sources (including seabed) and the third pillar “reduction of the EU’s consumption of primary raw materials” is to boost resource efficiency and recycling. Another relevant initiative is the Strategic Implementation Plan of the European Innovation Partnership on Raw Materials which includes actions to facilitate access to primary raw materials (including deep sea) and to improve framework conditions and technologies for recycling[74]. Finally, Horizon 2020, Societal Challenge 5: Climate Action, Environment, Resource Efficiency and Raw Materials also include support for research to recycling and deep sea mining.

In order to understand whether increasing European recycling potential could cover the increasing metal demand three key areas need to be assessed; these are:

- global metal demand;
- European metal demand; and
- European recycling potential.

In order to assess global metal demand, it is worth noting that an increasing number of applications – including environmental[75] and commercial technologies – are being developed using types of metals that can also be sourced from the seabed. The demand for such applications and products particularly from emerging economies on the medium to long term could prove to be a driver for increasing extraction. However, it is not all clear what share of these metals would or could potentially come from seabed sources taking into consideration:

[72] existence values are the non-use (intrinsic) value of ecosystem services, they represent the maximum willingness to pay for a natural resource for preserving its state without actually using it

[73] Science 16 May 2014: Vol. 344 no. 6185 pp. 696-698 DOI: 10.1126/science.1251458v

[74] EC (2014) : European Innovation Partnership on Raw Materials https://ec.europa.eu/eip/raw-materials/en/content/about-sip

[75] Including metal components In cell phones, wind mill turbines, hydrogen fuel cells, hybrid and electric car batteries etc.

- reserves available from current and soon-to-be-opened land-based mines;
- prices of commodities;
- global demand for metals; and
- quantity of cost-efficiently extractable high concentration ores from seabed reserves.

Once minerals sourced from the seabed enter the global market it is expected that they would - to a smaller or larger extent depending on the quantity of minerals in question, geo-political environment as well as the abundance of land-based resources – influence the prices of metals. An additional consideration at this point would be the share of these metals that would be imported to Europe. The particular points to analyse here can include European demand and global prices of these commodities. As no commercial scale deep-sea mining has taken place yet at this stage assumptions would have to be made regarding the quantity of metals sourced from the seabed that would be imported to Europe, with particular focus on key industrial areas. This means that the European markets of the key applications – e.g. hybrid cars, wind mills, batteries and electronic devices etc. - that are expected to drive the demand for these metals in the future should be analysed in light of:

- expected changes in European metal demand for commodities that can also be sourced from the seabed; and
- price implications of metals sourced from seabed minerals.

Once an analysis on the European demand for these metals[76] has been carried out, taking into consideration different price scenarios, it would be important to assess the extent to which the European recycling industry would be able to cover this demand. For this, a number of variables would need to be analysed, including:

- changes in the quantity of metals entering the recycling chain;
- current recycling potential for metals in Europe;
- foreseeable increase in recycling capacity in Europe;
- distortions in practices and recycling potential between Member States;
- trends in other disposal and recovery activities for metals;
- innovations in recycling technologies for metals;
- current quantity of waste shipments (old and new scrap[77]) to non-OECD countries.

Underpinning this assessment should be an analysis of the regulatory and policy environment, including the forthcoming "Circular economy" package of proposed revisions, as well as the wider EU waste acquis, including, *inter alia:*

- The Waste Framework Directive;
- The Landfill Directive;
- Mining Waste Directive;
- Waste Shipments Regulation;
- The Waste Electrical and Electronic Equipment (WEEE) Directive;
- The Batteries Directive;
- End of Life Vehicles Directive; and
- Ship Recycling Regulation.

The above described assessment of seabed mining sourced minerals and recycling potential within Europe could help to identify the particular challenges the European recycling sector could face in

[76] Including copper, nickel, gold, silver, manganese, zinc and cobalt

[77] New scrap is generated during the manufacturing processes and has a known composition and origin. Old scrap is end-of-life scrap

the future in light of a projected increased demand. A recent study[78] from the European Association of Metals (Eurometaux) has identified some of the current challenges for metals recycling in the European Union, which include the following:

- recyclability of finished products;
- suboptimal end-of-life collection schemes:
- landfilling of post-consumer goods:
- shortage of secondary raw material due to exports to non-European countries partly due to illegal or dubious shipments of waste;
- lack of level playing field worldwide and quality recycling;
- technological and economic hurdles to recycle increasingly complex products; and
- transparency across the value chain and better enforcement of legislation.

The cumulative impacts of such a focused exercise could lead Europe closer to a circular economy by closing the loop on the recycling systems and at the same time could facilitate research into innovative technologies for recycling.

[78] Eurometaux (2013): Boosting Recycling to support access to raw material and resource efficiency, http://www.eurometaux.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=6603&PortalId=0&TabId=57

3 Desk-based research

3.1 Findings

Like any mining activity, deep-sea mining will directly impact habitats, resulting in the removal of fauna and seabed rock and sediments. Because this is a known outcome, environmental management plans that guide seabed mineral extraction should aim to strike a balance between economic opportunity associated with resource revenue, conservation objectives, and the environmental impacts described herein. Consideration of the lessons learned from terrestrial mining, particularly those that address conservation and minimum impact objectives (e.g. case studies collected by the International Council on Metals and Mining and IUCN, Mining and Biodiversity[79]) may aid in developing sound policy.

3.1.1 Overview of findings

As outlined by Clark and Smith[80] environmental impacts from deep-sea mining can generally be divided into four categories:

- *impact from dislodging minerals* which includes the physical removal of organisms, rock and sediment;
- *impact from a sediment plume* that generally accompanies mining activities and can potentially have a spatial extent larger than the mining footprint itself (depending on ocean currents, the amount of sediment removed and the technology used);
- *impact from the dewatering process* which delivers contaminated and potentially highly turbid seawater into the water column; and
- *impact from the operation of the mining equipment.* This includes noise and light (although very little is known about their effects on deep sea organisms the negative impacts of noise on marine mammals living closer to the surface are well documented), oil spills and leaks from hydraulic equipment, sewage and other contaminants from the ore carriers and support vessels.

Combined, these impacts can reach organisms at the mine site and beyond. Although there is some understanding about their individual effect, very little is known about the cumulative effect that these impacts have on the marine environment.

In addition to potential impacts from normal operations, natural hazards, such as extreme weather events, volcanic activity, etc. will also need to be considered in the management plans. These impacts may include those that are more generally associated with the presence of marine vessels and primarily occur at the surface. They may be the introduction of noise and air pollution generated by ships and equipment, fluid leaks and discharges from vessels and equipment, and vibrations. More specific to mining is the introduction of light into seabed environments that are normally light-deprived. Light is known to be either a source of attraction or a deterrent to some fish species, which may or may not alter their normal behaviours for feeding and reproduction, although due to deep sea setting of currently targeted deep-sea mining deposits of interest, is not likely to affect fish stocks linked to fisheries

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[79] Good Practice for Mining and Biodiversity, ICMM website access August 7, 2014: http://www.icmm.com/page/1182/good-practice-guidance-for-mining-and-biodiversity

[80] Clark and Smith (2013 a, b)

From a non-ecosystem perspective, there are other impacts to consider. The presence of mining vessels will necessitate site closures before, during, and potentially after mining activities. Such restrictions may extend beyond the mining site to the shipping routes. This may displace or disrupt fisheries and have an effect on revenue. Anthropogenic noise, is an important factor and with the involvement of the mining vessels both on the surface and below it is expected to increase the already significant levels of noise pollution that exist in particular areas. The exact impact on the mining areas would have to be determined taking into consideration the population of marine mammals present in the area as well as the level of noise pollution present in the mining area as a result of other industries. It is important that when it comes to biodiversity the population of animals living in shallow waters are also given as much attention as those of the deep-seas.

There are also impacts on the water column that merit consideration. Impacts on the water column are generally caused when the mined material is lifted from the sea-bed to the mining vessel at surface level, when there are routine discharges and also spills from the vessel, and during the release that takes place when the ore is dewatered[81]. When the mined material is lifted, the amount of material that escapes back into the water column will be dependent on the lifting system itself and whether or not it is a fully- or partially-enclosed mechanism. There is also likely to be a physical impact to any fish or other organisms present in the water column at the time when equipment is in use. This may result in direct, perhaps fatal, strikes with the organisms or displace them. These impacts however are not likely to affect a full population, but rather the local population found at that mining site. A sound management plan for site selection will include criteria for looking at the nursery and spawning grounds of fish in the vicinity and for avoiding mining activities during ecologically important times. Dewatering in the water column (versus as near to the seabed as possible) may have a clouding effect, or an impact that restricts the normal amount of light penetration through the water column. This may result in localized impacts to primary productivity and potentially reduce oxygen levels – again however, these impacts while not insignificant are not thought to impair a full animal population.

An additional consideration for the impact of dewatering and the water column is that the released seawater will be different in composition from when it was collected with the ore. It is now likely to contain trace amounts of toxic metals or chemicals that will be emitted into water where those materials (which may be naturally found in vent plumes) were not previously present, and this may have an impact on biodiversity. Additionally, when dewatering is done at the surface, the released seawater may have different characteristics than the surrounding seawater into which it is discharged, such as different levels of salinity or temperature. Again, this may have impacts to localized biodiversity. In this instance, modelling may be used to estimate the impact of discharge water.

3.1.2 *Steps of the Mining Process that Impact the Environment*

Extracting the ore involves basic processes that are common to all three mineral types. As described by Clark and Smith[82] they are:

Figure 3.1 Basic mining processes

Process	Description
Disaggregation	Crushing and grinding techniques will generally be used for removing both seafloor massive

[81] removal of excess water that has been absorbed within the ore
[82] Clark and Smith (2013 a, b)

Process	Description
	sulphides deposits and crusts. Manganese nodules will be "vacuumed" up from the sea floor.
Lifting	The ore is pumped up to the collection vessel in a seawater-slurry via a lifting system. At present it is generally considered that this will be done using a closed system – the riser and lifting system (RALS). However the continuous line bucket system (CLB) has also been proposed for nodule collection. The CLB operates like a conveyor belt transporting the nodules in buckets from the seafloor to the surface.
Dewatering	Once on-board the excess water is removed from the slurry and returned to the water column at a predetermined depth.

A cautionary approach will need to be taken when designing controls for the technology, equipment, and techniques for deep sea mining[83]. The technology used in these processes can significantly influence the extent of the environmental impact. Currently technology and tools are not fully adapted to deep sea conditions and require further development, however some of the technologies such as hydraulics, and cutting, crushing, and drilling are being adapted from the offshore petroleum and tunnelling industries. Pumping and riser systems as well as the vessels and watering systems specifically developed for deep sea environment are being patented[84].

3.2 Environmental Impacts Unique to Mineral Type

The impacts that are unique to sea-floor massive sulphides, manganese nodules, or ferromanganese crusts are considered here. Risks and impacts to biodiversity and physical habitat will need to be evaluated according to the extent to which they will occur, both in duration and distance from the mine site. Tables 3.1, 3.2 and 3.3 below summarize the potential impacts of mining activities relevant to each deposit type.

Not included in the table below are accidents or exploration activities. Accidents could include the deposition of mining equipment onto the seafloor, the breakage of riser pipes and the unexpected release of produced water or toxins. Some accidents might also result from geologic instability and collapses of sloped seafloor during or after mining. While some of these may not be of trivial scale, others might be more localised than accidents that result in long-term uncontrolled release of toxins (e.g. oil leaks/spills or well blowouts). Exploration activities will likely be similar to mining activities, but at a much reduced scale, excepting the possible addition of extra acoustic noise from seismic surveys done for resource assessment. Frameworks for such noise impact assessment could be adopted from the oil and gas industry.

[83] Hoagland et al., 2010
[84] www.google.com/patents/CA2735901C?cl=en

Table 3.1 Nodule mining impacts: Area licensed to each operator - 75,000 sq. km

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Removal of nodules, complete disturbance of seabed and its compaction	Long term. Probably tens to hundreds of years for a non-compacted surface layer to reform; millions of years for nodules to reform	Between 120 (Petersen) and 600 (Sharma) km^2 per year per operator. ISA consider 3-10 operators at any one time. Therefore 360-6000 km^2 per year	Destruction of habitat and associated organisms	Likely to be extremely slow. For the substrate - may take tens to hundreds of years or even longer in heavily mined areas. For the nodule faunas will take millions of years.	1. Biodiversity is maintained 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded
Sediment laden plumes near seabed containing particle load	During mining activity	Spread will depend on mining process and local currents. Could be tens of kilometres beyond licensed area boundaries	Smothering of seabed animals. Will affect suspension feeders on other nodules in the licensed area and on any seamounts in the vicinity of mining operations	Likely to be slow especially in areas heavily impacted by plume fallout. Elsewhere may take tens of years	1.Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. The depth at which the plume is	If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-	Recovery will be rapid once activity ceases	1.Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 6. Sea floor integrity ensures the

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
		released may also determine its spread. Potential areas affected could be very large – thousands of square kilometres	on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area.		structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition.	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low.	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity
Noise	During mining activity	The sound characteristics of deep sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.	11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem
Potential loss of ship	During mining activity		Pollution of surface waters		8. Concentrations of contaminants

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
or pollution from ships					have no pollution effects 10. Marine litter does not cause harm to the marine and coastal environment
Tailing disposal on land/sea	Long term	Potentially hundreds of km^2			1. Biodiversity is maintained 4 Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects;

Table 3.2 Impacts of SMS mining - Are of each mine site – $0.1km^2$ for Solwara 1 but could be larger

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Mining of seabed, with removal of habitat	On active vent sites may be some years beyond the mining phase. On off-axis vent sites may be	Area of mining maybe c300 m diameter (based on proposed Solwara 1 mine, Papua New Guinea). However several	Destruction of habitat and associated organisms by initial mining and pollution of the environment by chemical toxins.	On active vent sites maybe relatively short term (months to years). On off-axis vent sites likely to be of longer term - probably tens	1.Biodiversity is maintained 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
	hundreds of years to due deposition of toxic chemicals	adjacent locations may be mined sequentially giving rise to a mined area of some km^2	This will have a greater impact in off-axis sites	to hundreds of years	
Sediment laden plumes near seabed containing particle load and potentially chemical toxins	During mining activity and for many years beyond due to the chemical toxins	Spread will depend on mining process and local currents. Could be kilometres beyond mined area boundaries. Plumes will flow downslope	Smothering of seabed animals by the particulates especially proximal to the mined area and downslope. Potential poisoning of animals in all areas affected by the plume due to the chemical toxins	Recovery from the particulates will probably take a few years. In the off-axis vents recovery from chemical pollution may take tens to hundreds of years	1.Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8.Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Sediment laden plumes in water column containing particle load and chemical toxins	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres.	If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters	Recovery will be rapid once activity ceases	1.Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
			introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area. Toxins in the plumes could cause loss of organisms at all levels in the food chain and could impact commercial fish stocks		adversely affect the ecosystem 8. Concentrations of contaminants have no effects 9 Contaminants in seafood do not exceed agreed standards
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution. May also include changes in fine scale (biologically relevant) bathymetry	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition. Shifts at seafloor massive sulphides sites likely larger than nodule mining sites	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low.	1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity
Potential loss of ship or pollution from ships	During mining activity		Pollution of surface waters		8. Concentrations of contaminants have no pollution effects 10. Marine litter does not cause harm to the marine and coastal environment
Noise	During mining activity	The sound characteristics of deep sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short term masking can occur for individuals within the area affected, the long-term consequences and effects at the	11.Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
		(generally low frequency, but with some high frequency components). The amplitude is unknown. The area impacted is generally a product of frequency and amplitude, so cannot be determined at present.		population level from masking are unknown.	
Tailing disposal on land/sea	Long term				1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised; 6. Sea floor integrity ensures the functioning of the ecosystem; 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem; 8. Concentrations of contaminants have no effects;

Table 3.3: Impacts of cobalt-crust mining

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Removal of crusts	Long term. Probably hundreds to thousands of years		Destruction of habitat of attached epifauna	Likely to be very slow (tens to hundreds of years).	1.Biodiversity is maintained 6. Sea floor integrity ensures the functioning of the ecosystem
Sediment laden	During mining activity	Spread will depend on mining	Smothering of seabed animals	Likely to be very slow (tens to	1.Biodiversity is maintained

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
plumes near seabed containing particle load		process and local currents. Could be tens of kilometres beyond licensed area boundaries. Plumes are likely to flow down the seamount flanks		hundreds of years) if epifaunal organisms are impacted on bare rock surfaces	4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not exceed agreed standards
Sediment laden plumes in water column	During mining activity	Spread will depend on local currents, grain size of material and volume of material released plus length of time of release. Potential areas affected could be very large – thousands of square kilometres	If plumes are released in the photic zone (c200 metres) they will cause a reduction in light penetration and in temperature. These are likely to reduce plankton growth with knock-on impacts to whole food chain. Sediment load likely to affect feeding of gelatinous zooplankton. High nutrient load from deep waters introduced into oligotrophic waters may stimulate primary production and of different species than those normally occurring in the area.	Recovery will be rapid once activity ceases	1.Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 6. Seafloor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects 9. Contaminants in seafood do not

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
					exceed agreed standards
Size and ecosystem function fractionated impact on life	Shifts in sediment grain size distribution. May also include changes in fine scale (biologically relevant) bathymetry	Depending on position relative to mining and/or sediment plume impacts, sediments may change in their grain size towards sandier or finer composition. Shifts at crust sites likely larger than nodule mining sites	This changes the habitat in terms of the sizes of life that will either be benefited or be impacted negatively	These effects may be long lasting as background sedimentation rates are low.	1.Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity
Potential loss of ship or pollution from ships	During mining activity		Pollution of surface waters		8. Concentrations of contaminants have no pollution effects 10. Marine litter does not cause harm to the marine and coastal environment
Noise	During mining activity	The sound characteristics of deep sea mining have yet to be established. It is likely to be similar to shallow water dredging in terms of frequencies emitted (generally low frequency, but with some high frequency components). The amplitude is unknown. The area impacted is generally a product of frequency and amplitude, so cannot be determined at present.	Probable masking effects on marine mammals that use the main frequencies emitted.	Impacts on species are not known. While short term masking can occur for individuals within the area affected, the long-term consequences and effects at the population level from masking are unknown.	11.Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Impact	Length of impact	Potential impacted area	Nature of impact	Potential for recovery	Relevance for GES descriptor
Tailing disposal on land/sea	Long term				1. Biodiversity is maintained 4. Elements of food webs ensure long-term abundance and reproductive capacity 5. Eutrophication is minimised; 6. Sea floor integrity ensures the structure and functions of ecosystems are safeguarded 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem 8. Concentrations of contaminants have no pollution effects

3.3 Comparison with land-based mining

Introduction

Generally, it is becoming harder to find new, high-quality land-based mineral deposits[85] yet the demand continues to increase. This has pushed miners towards mining lesser-grade deposits, which return lesser yields and increase production costs due to having to mine more rock for the same metal product. A decreasing supply of high-quality ores also drives mining operators towards more "remote and challenging environments" such as the seabed which is likely to have certain environmental and social impacts (particularly on the rights, uses and values of the sea of indigenous people).

Additionally, for some countries including many in the EU that have limited land-based resources or have difficulties accessing them, deep-sea mining could present a new opportunity to diversify resource streams and ensure provided it is a financially viable alternative. However, in addition to financial feasibility of such projects environmental, social, and economic factors would also need to be considered.

Deep-sea mining is a new industry with many unknowns, but there are lessons that can be learned from onshore mining and offshore oil and gas extraction. These industries share the need to manage physical habitat destruction, the potential loss of biodiversity and the dispersal of toxic waste. The technology required for deep-sea mining is still being developed and must be able to operate at the great pressures associated with deep water. These difficult conditions will require expert management and maintenance of equipment to ensure that accidents do not occur.

At present, there is **insufficient information** to determine whether the environmental impact of deep-sea mining is greater or less than land-based mining. For seafloor massive sulphides, in particular, it is conceivable that a smaller volume of waste rock and overburden would be displaced than for land-based operations, in order to access the ore. However, some sediment overburden will be removed in seafloor massive sulphides mining and the resulting plume will have effects over a much larger area, and deeper, than the mine site.

As we have described earlier, many aspects of the proposed deep-sea mining involve the same steps used in conventional mining. Countries and regions with already limited biocapacity would simply be adding to their overall "ecological debt" if some trade-offs are not at least considered. Deciding on such trade-offs is by no means straightforward. It is unknown whether a deep sea mine can replace a new land-based mine, or if the resource streams for specific metals may be diverted from ecologically (and socially) costly land-based operations to deep-sea efforts that may potentially be less ecologically costly. In all cases countries would need to evaluate independently - taking into consideration the market and environmental conditions of the individual minerals - whether the economic and environmental footprint of deep-sea mining would be smaller or larger than that of land-based mining.

Embedded within the environmental and economic impacts there are serious social implications that need to be considered. The sea and the minerals it contains are often considered a property of the indigenous people of the land, the minerals under the sea can have strong cultural value associated with them. Therefore it is essential that a consensus is reached between the stakeholders regarding the safety and benefits of the operations. Furthermore, continuous

[85] Paterson 2003; SNL Metals and Mining 2013

communication is a necessary local stakeholders in order to ensure there is a common understanding on the principles of the operations and on the conduct of the mining company. This communication would preferably involve areas relatable to the complete value chain (from exploration through processing to decommissioning).

However if policy is designed in a holistic, cross-sectoral manner based on resource frugality (i.e. reduced total consumption), replacement of ecologically high cost activities for lower ones, and the integration of economic progress within a framework of nature-based performance, it may indeed be possible for mineral extraction activities to be a corner stone of an ecologically sustainable and socially inclusive “blue economy”.

Table 3.4 contrasts the environmental impact of land-based mining with potential impacts from marine mining. Please note that the actual impacts for both land-based and seabed mining will need to be evaluated on a case-by-case basis s they depend on a variety of factors including the type of activity, the ore etc. Additionally until commercial extractions begin impacts of seabed mining activities are hypothetical.

Table 3.4 **Comparison of land based and deep sea mine sites**[86]

Parameters	Land based mines	Marine mines
	Volcanogenic Massive Sulphides	Seafloor Massive Sulphides
Land disturbance	Large area of disturbance (due to buried nature of the deposit type) both at the mine (open cut and underground). Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades. Potentially require relocation of communities.	Limited spatial extent of physical disturbance because individual mines are of small scale, but destruction of site-specific habitats possible, limited and reusable infrastructure. Short mine life. Effects of operational and discharge plumes will affect a much larger area than on land. No relocation of communities.
Waste generation	Large amounts of waste including waste rock, tailings, effluent (potential for acid mine drainage), air pollution, potential oil/chemical spills.	Little or no overburden, limited (if any) tailings (in comparison to land based deposits) due to lack of overburden and also because the ores will be shipped intact. Waste-water plumes may transport toxic substances over large distances, limited air pollution from vessels, potential oil/chemical spills.
Biodiversity	Total biodiversity loss over a large spatial scale at open cut mines. Recovery possible over centuries time scale to a state of functional ecosystem; millennia scale for return to state closer to pre-mining.	Total biodiversity loss at sites of extraction and adjacent areas affected by plumes. Recovery possible within a decade for active sites; can expect similar ecosystem to pre-mining state.
Rehabilitation potential	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over decades to centuries.	Major changes to seafloor topography but on limited spatial scale due to near surface nature of deposit type and lack of overburden. Rehabilitation rates variable, potentially fast for active hydrothermal vents (months to years) but otherwise very slow (decades to centuries)
Energy use and GHG emissions	GHG emission via transport and cement production, air pollution, high energy use (depending on the extraction technique energy costs can account for 10-12% of all costs)	Off-shore processing of the minerals and transportation by air or water while undoubtedly contributing to GHG emissions could reduce the environmental and social impacts caused by the infrastructural developments linked to road transportations and building of on-shore processing plants.
	Manganese	Manganese nodules

[86] The actual combined environmental impacts of the operations including processing and transportation would have to be compared and evaluated on a case-by-case basis

Parameters	Land based mines	Marine mines
Land disturbance	Large area of disturbance both at the mine (open cut and underground). Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades.	Very large areas of disturbance of benthic layer at mined areas and potentially areas adjacent. Potentially short mine life.
Waste generation	Large amounts of waste including waste rock, tailings, effluent, air pollution, potential oil/chemical spills.	No overburden, limited tailings (in comparison to land based deposits) due to near seabed surface nature of the deposit type and also because the ores will be shipped intact, some waste-water discharged as a plume which may disperse considerable distance, limited air pollution, potential oil/chemical spills.
Biodiversity loss	Total biodiversity loss over a large spatial scale at open cut mines.	Total biodiversity loss at sites of extraction and potentially adjacent areas due to plume spread and smothering. Loss of nodules substrate for attached fauna.
Rehabilitation potential	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over decades to centuries.	Although changes to the seafloor morphology may be limited, current scientific evidence indicates that there is likely to be very poor rehabilitation potential within human time scales.
Energy use and GHG emissions	GHG emission via transport and cement production, air pollution	Off-shore processing of the minerals and transportation by air or water while undoubtedly contributing to GHG emissions could reduce the environmental and social impacts caused by the infrastructural developments linked to road transportations and building of on-shore processing plants.
	Nickel mines	Cobalt rich crusts
Land disturbance	Moderate area of disturbance both at the mine. Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades.	Spatial area of a commercial mine is currently undefined, but could be significant and on a larger spatial scale than for land mining. Top of individual guyot (seamount) may be 200 km^2. Several guyots may be mined within the same area
Waste generation	Large amounts of waste including waste rock, tailings, effluent, air pollution, potential oil/chemical spills.	No overburden, limited tailings (in comparison to land based deposits) due to near seabed surface nature of the deposit type and also because the ores will be shipped intact, some waste-water discharged as a plume which may disperse considerable distance, limited air pollution, potential oil/chemical spills.
Biodiversity loss	Total biodiversity loss over a large spatial scale at open cut mines.	Total biodiversity loss at sites of extraction and potentially areas immediately adjacent.
Rehabilitation potential	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over years to decades.	Major changes to substrate, slow recovery over tens to hundreds of years. May never fully recover in some areas of altered substrate.
Energy use and GHG emissions	GHG emission via transport and cement production, air pollution	Off-shore processing of the minerals and transportation by air or water while undoubtedly contributing to GHG emissions could reduce the environmental and social impacts caused by the infrastructural developments linked to road transportations and building of on-shore processing plants.

3.4 Comparison with recycling

While the recycling process itself can contribute to a reduction of consumption of primary resources as well as in some cases to the conservation of energy[87] (compared to primary metals production), there might also be some negative environmental impacts associated with the activities, which can include additional resource use, GHG emissions, release of toxic materials etc. The following table compares the environmental impacts of recycling and land-based mining. Please note that the following table does not aim to present recycling and land-based mining as interchangeable alternatives to one-another (based on the findings of the economic analysis it is evident that recycling cannot replace land-based mining as an adequate source of metals supplying European consumers and industries), rather it seeks to identify the amalgamated environmental consequences of different sourcing techniques.

Table 3.5 Comparison of recycling and land based mining

Parameters	Recycling	Land based mines
Land disturbance	The infrastructural development related to establishing a recycling facility and connecting it via road infrastructure does entail a certain amount of land disturbance. However, recycling facilities require permitting which ensures none or limited ecosystem impact.	Large area of disturbance both at the mine (open cut and underground). Some disturbance associated with infrastructure such as roads, concentrator, smelter. Mine life can be measured in decades. Potentially require relocation of communities.
Waste generation	Toxins in metal can be released into the environment during processing e.g. lead from circuit boards released as dust. Paper recycling can require the use of chemicals to remove ink. Wastewater can contain dioxins and other carcinogens. Waste sent to landfills may contain heavy metals.	Large amounts of waste including waste rock, tailings, effluent (potential for acid mine drainage), air pollution, potential oil/chemical spills.
Rehabilitation potential	Recycling infrastructure does not cause significant changes to the landscape and the site can be re- used shortly after the infrastructure has been	Major changes to landscape and hydrological regime, but good potential for general rehabilitation over decades to centuries.
GHG emission	Transportation of recycled materials through collection as well as to and from the recycling facilities can cause significant emission	GHG emission via transport and cement production
Energy use	Energy use is particularly significant in the sorting and processing of scrap metal (but varied for alloys). Energy requirement for the production of virgin paper is also significant	High energy use (depending on the extraction technique energy costs can account for 10-12% of all costs)

It is worth noting that meanwhile there might be common practices (sorting, shearing, melting), metals recycling is a diverse practice. Some recycles specialise in handling particular types of metals or alloys while others might accept all types of scrap metal. As products in increasing numbers contain metal mixed to form alloys, the recycling practices for retrieving particular metals may also differ. In the case of nickel for example there are thousands of different alloys each with

[87] The extent of energy use in recycling depends largely on the materials and the process in question. Therefore overall energy consumption will have to evaluated on a case-by-case basis

their particular combination of technical properties (corrosion resistance, mechanical properties and service life)[88]. In order to optimise the retained value of the scrap metal, the industry develops specific technologies which may differ per metal or per alloy type. Further details on the practices and the economic impacts of recycling can be found within the economic analysis chapter of this study.

With regard to environmental impacts metals recycling in general transportation and the related GHG emissions are one key concern. Transportation of recycled material through collection and processing as well as the transportation of recycled material to the manufacturing facility are all stages where GHG emissions occur. Appropriate planning during the design stage can help identify the most suitable locations for the recycling facilities hence avoid any disturbance to land-use and allow for short haul connections between the value chain partners.

Energy use is also a factor in sorting and processing scrap metal however this energy use is much less in comparison to primary production or extraction of ores. In the case of copper for example extraction of the ore requires around 95 million Btu/tonne whereas recycling copper uses much less energy, about 10 million Btu/tonne[89]. It is worth pointing out that in the case of highly mixed metal alloys figures on energy use for recycling can be higher. In light of the fact that up to date no extraction had taken place we have no information on how this data would compare to the energy use of deep-sea mining operations.

The above overview illustrates that even though recycling – as any other industrial activity – does have an environmental footprint, it constitutes to a significant added value when it comes to resource and energy efficiency, however these benefits depend on the efficiency of the recycling technology applied.

[88] Nickel Institute: Recycling of Nickel-Containing Alloys, http://www.nickelinstitute.org/en/Sustainability/LifeCycleManagement/RecyclingofNickel/HowNickelIsRecycled/RecyclingofNickelcontainingalloys.aspx

[89] Bureau of International Recycling http://www.bir.org/industry/non-ferrous-metals/

4 Roadmap to identify operational targets for Good Environmental Practices

4.1 General environmental management approaches and principles

Responsible environmental management involves balancing resource use with maintaining deep-ocean ecosystem processes and biodiversity. Management should therefore include functional linkages between elements of the seabed ecosystems with the subsurface biosphere, the water column, the atmosphere, shelf seas and coastal areas, as well as preserving the full range of goods and services that deep-sea ecosystems provide[90].

Management approaches often focus on a single sector (such as a particular area or human activity) or a single species. However, there is increasing recognition of the importance of an ecosystem approach to management (EAM). The 1992 United Nations Convention on Biological Diversity defined the ecosystem approach as: “Ecosystem and natural habitats management….to meet human requirements to use natural resources, whilst maintaining the biological richness and ecological processes necessary to sustain the composition, structure and function of the habitats or ecosystems concerned.” Inherent in EAM is the application of ecological, economic, and social information, and the underlying acceptance that humans are an integral part of many ecosystems. The approach requires integration of information from a wide range of disciplines, across different levels of ecological and socio-economic organization, and on a range of temporal and spatial scales.

A second important concept in the exploitation of any resource is the *precautionary approach*. One of the primary foundations of the precautionary approach results from the work of the Rio Conference, or Earth Summit, in 1992. Principle 15 of the Rio Declaration states: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[91] The precautionary approach is also a fundamental principle of the European Union’s environmental policy detailed in Article 191 of the Treaty on the Functioning of the European Union.

Continuous learning and updating precaution as new evidence comes to light can be an essential part of active adaptive management practices. Adaptive management acknowledges the fact that scientific understanding of an ecosystem will likely always be incomplete at the same time it recognises that as scientific knowledge improves as will the accuracy and reliability of decision makers’ ability to predict outcomes.[92]

The International Marine Minerals Society (IMMS) has compiled a code of conduct for marine mining[93] in 2001 and amended this in 2011. The Code is meant to serve all stakeholders active and engaged in seabed mining operations. It requires companies, amongst others, to respect the

[90] Armstrong et al 2010

[91] UNCED 1992; see also DSM Project Information Brochure 13 available at www.sopac.org/dsm, for discussion on the Precautionary Approach as it relates to DSM

[92] Benidickson et al 2005

[93] IMMS (2011): Code for Environmental Management of Marine Mining, http://www.interridge.org/files/interridge/IMMS_Code.pdf

regulations of sovereign states as well as the applicable policies of relevant international bodies as well as to facilitate community partnerships on environmental matters throughout the project's life cycle. The Code also sets a number of operating guidelines which include a commitment from stakeholders on sustainability and environmentally responsible behaviour. Many elements of the Code do reoccur within the findings of this chapter including data collection, performance reviews, and reporting.

In the context of deep-sea mining the precautionary approach can also be applied through Marine Spatial Planning (MSP), which is a tool used increasingly by countries to manage multiple uses of marine space. MSP determines what activities can be undertaken where, manages conflicts among competing marine activities, and reduces environmental impact by analysing current and anticipated uses of the ocean. It is a practical way to balance demands for development with conservation goals. The principal output of MSP is a comprehensive spatial management plan for a marine area or ecosystem.

4.1.1 Example for Marine Spatial Planning from Solwara I

The draft Environmental Management plan developed by Nautilus Minerals for the Solwara 1 mine includes a representative no-mine reserve area approximately two km upstream from the mine site. Research has shown that the active sites at the mine site and the reserve area share the same biomass-dominant species and generally similar indices of diversity and community structures. This makes the reserve area a suitable control site that can be a source of recruitment of organisms to mined areas[94].

In the CCZ where impacts will occur over much greater areas, the International Seabed Authority has introduced a network of Areas of Potential Environmental Interest (APEI) as part of a regional environmental management plan[95]. More recently MacMillan-Lawler et al[96] utilised the new global seafloor geomorphology map[97] to examine the geomorphic feature representativeness of global MPAs as a proxy for biodiversity – a technique that may be useful in assessing and developing APEIs.

4.1.2 Dinard workshop[98]

In response to potential pressures on hydrothermal vent ecosystems from the initiation of deep-sea mining (and other activities such as fishing, biotechnology exploration, tourism etc.) a group of experts met in Dinard to formulate general guidelines for the conservation of vent ecosystems (as well as cold water seeps). They developed a set of design principles for the comprehensive management of active vent environments that could be used in systematic marine spatial planning.

The Dinard Guidelines are provided to policy makers, environmental managers, and other relevant parties and stakeholders with the aim of guiding the sustainable use of chemosynthetic resources. They state:
Spatial Design of Chemosynthetic Ecological Reserves (CERs)[99]

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[94] Coffey 2008

[95] Smith et al. 2008; International Seabed Authority 2008b; 2009; 2012c and http://www.globaloceancommission.org/policies/deep-seabed-mining/

[96] unpublished conference proceedings, 2013

[97] Harris et al 2014

[98] The workshop took place in 2010 in Dinard, France. The aim of the workshop was to formulate general guidelines for the conservation of vent and seep ecosystems at regional and global scales and to establish a research agenda aimed at improving existing plans for the spatial management of vent and seep ecosystems http://www.isa.org.jm/files/documents/EN/Pubs/TS9/index.html#/1/

[99] Source: Van Dover, et al., 2011b

- Identify chemosynthetic sites that meet the Convention on Biodiversity criteria for Ecologically and Biologically Significant Areas (EBSAs) or are otherwise of particular scientific, historical, or cultural importance for priority consideration for protection.
- Define the regional framework for protection of biodiversity. Natural management units (biogeographic provinces and bioregions within these) form the ecological framework within which CERs should be established for the protection of chemosynthetic ecosystems.
- Establish the expected distribution patterns of chemosynthetic habitats to provide a spatial framework for capturing representativity.
- Establish CERs and design replicated networks of CERs within bioregions, using guidelines for size and spacing that ensure connectivity and that take into account the pattern of distribution of chemosynthetic habitats, which may vary from semi-continuous to widely dispersed.
- Define human uses and the levels of protection for each CER to achieve the conservation goal.

Management Strategies for Chemosynthetic Ecological Reserves

- Use a two-level approach for establishing CERs: (1) select CER sites of extraordinary stand-alone value; 2) fill in the “gaps” to establish networks of CERs that, combined, will contribute to the network-level conservation goals while taking into account the spatial demands of human activities.
- Use adaptive management strategies to account for uncertainty and new knowledge.
- Establish CERs in a manner that is consultative and transparent.
- Governance of CERs should be within existing governance regimes wherever possible.
- Where CERs include activities with the potential to cause significant adverse impacts, EIAs should be required for these activities and should follow best practices.
- Establish monitoring strategies to assess the impacts of cumulative activities in space and time relative to the conservation goal and objectives.
- Use a set of prescriptive criteria, established before multi-use activities begin, to trigger closer monitoring or cessation of activities that jeopardize the conservation goal within a bioregion.

The above examples illustrate that there is interest from stakeholders to develop an integrated approach to manage the use of marine areas and open discussions with regard to the identification of marine protected areas and the externalities that might arise as a consequence for the countries. However, there is no international initiative that would facilitate a comprehensive approach and set guidelines for the selected areas with regards to marine spatial planning.

4.2 Marine Strategy Framework Directive (MSFD)

If commercial seabed mining activities are to develop sustainably, internationally agreed definitions need to be developed and adhered to by all stakeholders. The EU's Marine Strategy Framework Directive establishes a comprehensive, ecosystem-based approach to the management of the marine environment and requires Member States to apply these principles in their marine strategies, with a view to achieving of maintaining 'Good Environmental Status' (GES) by 2020 This approach could serve as an illustrative example for the framing of possible future management of deep-sea mining activities.

A few key points of context need to be considered in examining the MSFD as a potential approach to apply to seabed mining. As an EU instrument, it only applies to EU Member States' waters. In addition, while the MSFD broadly addresses the existing pressures and their impacts on the marine environment, with a view to their minimization and management, it does not set requirements for specific industries.

The first round of implementation of the Directive has recently been completed, with Member States having reported on the initial assessment of their marine waters (under Article 8), their determination of GES for their marine regions (Article 9), and their establishment of environmental targets (Article 10). In February 2014, the Commission published its assessment of this reporting exercise, highlighting the need for a greater level of precision, and cross-comparability of the data generated, in order to assess progress towards GES in a meaningful way.

Box 4.1 **GES descriptors**

The European Union adopted the Marine Strategy Framework Directive in 2008 with the aim of achieving a GES for Europe's marine waters by 2020. Eleven descriptors are identified to determine GES. These are summarized as[100]:

1. Biodiversity is maintained;
2. Non-indigenous species do not adversely alter the ecosystem;
3. Populations of commercial fish species are within safe biological limits;
4. Elements of food webs ensure long-term abundance and reproductive capacity;
5. Eutrophication is minimised;
6. Seafloor integrity ensures the structure and functions of ecosystems are safeguarded;
7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem;
8. Concentrations of contaminants have no pollution effects;
9. Contaminants in seafood do not exceed agreed standards;
10. Marine litter does not cause harm to the marine and coastal environment;
11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

These descriptors are further developed, with corresponding criteria and indicators, in Commission Decision 2010/477/EU[101]. The Commission has recently launched a review process for this decision, which will deliver results in 2015.

The elements of the MSFD were established for Member State authorities to determine the boundary conditions within which their waters achieve Good Environmental Status. Nevertheless, all EU operators - throughout their economic activities globally – could draw inspiration from them when establishing their sustainable development principles and environmental imperatives.

As detailed in the previous chapters there are gaps in knowledge with regard to the physical and bio-chemical properties of the seabed ecosystems. In order to define descriptors for international waters similar to that of the MSFD, extensive sets of data and information on the current state of seabed ecosystems would need to be collected. This would allow for the identification of threshold figures (or ranges) that could – using continuous monitoring – alert to any changes resulting from the commercial activities of deep sea mining that could be considered damaging. Most, but not all, of the 11 descriptors listed are either directly or indirectly relevant when considering such monitoring of the deep sea environment. The table below provides an overview of the descriptors that could be used to monitor changes in deep sea ecosystems.

Table 4.1 **Relevance of MSFD descriptors for the deep-sea environment**

MSFD descriptors	Deep-sea relevance	Possible spill over impacts on other industries
Biodiversity is maintained	Maintaining biodiversity is a key	

[100] For the formal definitions, see Annex I, MSFD, 2008/56/EC

[101] Commission decision 2010/477/EU of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters

MSFD descriptors	Deep-sea relevance	Possible spill over impacts on other industries
	concerns in connection with deep-sea mining and can range from the complete eradication of species` habitat to a more limited impact allowing for the re-colonisation of sites	
Non-indigenous species do not adversely alter the ecosystem	Non-indigenous species are unlikely to be introduced as a result of deep sea mining activities.	
Populations of commercial fish species are within safe biological limits;	While deep-sea mining is not expected to have a direct impact on commercial fish species some spill over impacts could be monitored.	Monitoring of economic impacts of the fishing industries and socio-economic impact on coastal areas
Elements of food webs ensure long-term abundance and reproductive capacity	Depending on the extent of impact on biodiversity, food webs might be affected	
Eutrophication is minimised	The lifting of ore and deep water rich in nutrients can lead to eutrophication especially in oligotrophic tropical ocean which is particularly sensitive to nutrient inputs.[102]	
Seafloor integrity ensures the structure and functions of ecosystems are safeguarded	Monitoring seafloor integrity and ensuring that the physical and bio-chemical properties of the benthic environment are protected is an essential criteria for creating a sustainable marine environment alongside deep-sea mining	
Permanent alteration of hydrographical conditions does not adversely affect the ecosystem	Monitoring of hydrographic conditions especially in connection with the mining of manganese nodules - and the stirring and resettling of sediments - is an important element for ensuring sustainability and for using the most appropriate, site specific technology.	
Concentrations of contaminants have no pollution effects	Measuring the level of contaminants at mining sites (e.g. from vent communities via drifting particles) can indicate long-term environmental impacts	
Contaminants in seafood do not exceed agreed standards	Contaminants in seafood may occur if mining for polymetallic sulphides is undertaken nearshore at depths where diurnal vertical migration of micronekton occurs.	
Marine litter does not cause harm to the marine and	Littering from off-shore processing and other activities linked to deep sea mining	

[102] Mineral Policy Institute (nd): Management of DSM http://www.mpi.org.au/issues/deep-sea-mining/precationary-management-of-deep-sea-mining/

MSFD descriptors	Deep-sea relevance	Possible spill over impacts on other industries
coastal environment	as well as monitoring of waste management processes are integral to sustainability	
Introduction of energy (including underwater noise) does not adversely affect the ecosystem	Impact of low frequency noise on marine mammals and migration routes of cetacean.	

Once appropriate descriptors monitoring marine areas affected by deep-sea mining have been identified and data has been collected on the current state of the environment, boundary conditions should be established within which the activities of deep-sea mining should take place if they are to avoid threatening sustainability.

The previous chapter on desk-based research contains a detailed analysis of the environmental impact of deep sea mining and includes a column highlighting the relevance of GES descriptors for the specific impacts.

4.3 Operational targets and good environmental practices

Operational targets or operational objectives define the necessary steps that would need to be taken in order to fulfil the goals of an organisation. Within the context of this project, operational targets include those **practices** that would be required from policymakers or contractors to ensure the integrity of the marine environment of those areas where seabed mining operations take place is preserved and that the **sustainable use of these marine waters are guaranteed.** Where such activities take place within EU Member States' waters, the targets could also inform the implementation of the Marine Strategy Framework Directive. It is essential that the sequence of activities leading to the operational objectives reinforce one another and provide added value individually as well as collectively. Furthermore, engagement with stakeholders including industry, NGOs, the research community, policymakers and others is vital to ensure that policies defining **good environmental seabed mining practices** are constructed in such a way that they do not facilitate circumvention via international consortiums or other means. Moreover, facilitation of an international industry-wide commitment on adhering to good environmental practices and sustainable use of marine waters could contribute to the transparency of operations and to the mitigation of environmental impacts.

Based on the key environmental impacts identified earlier in the project there are aims to propose a sequence of activities (roadmap) that could result in establishing operational targets for good environmental practices for marine waters where seabed mining activities take place. In the case of activities taking place within EU Member States' waters, such targets could shape Member States' approach in achieving GES under the MSFD. In order to identify viable elements for operational targets it is important to be aware of the operations involved with seabed mining as well as their environmental impacts and the status of the environment at various geographical locations.

The roadmap builds upon current limitations in knowledge specifically with regard to biodiversity in benthic environments and consequently includes activities such as data gathering and transparency in reporting as well as the establishment of conservation areas where mining activity should be prohibited.

The purpose of this roadmap is to steer commercial mining practices in such a way as to meet the ecological objectives and achieve good environmental practices within the relevant marine areas. Additionally the roadmap can facilitate discussion and research into sustainable seabed mining practices as well as the coordination of activities of the different stakeholders.

In addition to the development of GES in the MSFD framework, there are also a number of other indicator variables that are becoming accepted for issues related to climate change these include the Essential Climate Variables which in the case of the sub-surface of the ocean can include temperature, salinity, nutrients, carbon dioxide partial pressure etc.[103]. The Group on Earth Observation has several communities of practices which are examining such variables and how to implement them globally. The Biodiversity Observation Network (GEO – BON) has developed a set of Essential Biodiversity Variables (EBVs) that are widely accepted as being valuable for tracking change (Pereira et al. 2013). These include genetic diversity indicators, the abundance and distribution of various taxa, habitat and the timing of change. Data from such variables can feed directly into GES indicators and would form the foundation that would underpin provision of information on environmental and ecological change.

4.4 Methodology

A preliminary draft for the roadmap was presented to the European Commission at the beginning of this study. This draft (seen in the below figure) includes the identification of the individual steps necessary for setting operational targets, a brief analysis of costs and benefits, and recommendations for their implementation e.g. types of policy measures.

Table 6: Proposed template for preliminary roadmap on operational targets for Good Environmental Practice

Step 1: Gathering raw data on deposits and ecology
Description:
Cost and benefit estimation:
Recommendations for implementation:
Step 2: Transparency of information exchange
Description:
Cost and benefit estimation:
Recommendations for implementation:
Step 3: Common indicators for technology assessment
Description:
Cost and benefit estimation:
Recommendations for implementation:

In order to establish the validity of the steps proposed for the roadmap, stakeholders have been contacted and literary sources consulted so as to develop an understanding of the different

[103] Global Climate Observing System , 2013, http://www.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables

practices that would be expected to take place once commercial deep-sea mining is operational. Information on the supply chain, deep sea mining processes, and applicable international legislations is crucial for the operational objectives to be effective and relevant. Once activities associated with significant environmental impact are identified policies, objectives, and operational targets can be developed to ensure that these operations are carried out under specified conditions assuring that the desired environmental objectives are achieved.

Consequently the sequence of activities proposed below are a translation of the relevant environmental, social values, high level policy objectives, and standing legislation into a form of practical steps that have a direct impact on the management of deep-sea mining operations. The activities are:
- outcome-focused and describe the expected response from sea-bed mining operators;
- measurable by qualitative or quantitative indicators; and
- timescaled, providing a sequence.

4.4.1 Workflow
Indicators can take several forms from the interpretation of limited variables such as the level of toxins in a given environment and potential responses in a model organism to complex multi-metrics such as those for fishes or primary productivity. In the case of marine primary productivity this can include data on the amount of pigments and composition of phytoplankton. For fish, this could include variables such as species composition, relative abundance, density or biomass, indicator or model species. GES indices process generally takes the form as illustrated below.

Figure 4.1 Basic workflow

Classification takes into account prior knowledge about variation in the indicator setting and translates the information to a policy relevant context such as ‘undisturbed conditions’ to ‘evidence for severe changes’. The roadmap to creating a set of indicators thus necessarily involves consideration of each of these steps.

4.5 Roadmap to establish operational targets

The following steps are foreseen as elements to establish valid and adaptable operational targets for good environmental practices for marine environment where deep-sea mining activities take place.

The term adaptable is viewed as an essential quality for the below steps as new information, data, and experiences linked to first time commercial operations are expected to feed invaluable information on the actual environmental impacts. Consequently the below proposed sequence of activities remain “dynamic “and subject to change.

Step 1: Gathering raw data on deposits and ecology

Step 1: Gathering raw data on deposits and ecology
Description: A comprehensive benthic survey would need to be carried out over extensive areas prior to awarding extraction licenses for deep-sea mining. These benthic surveys would include mapping of: • habitats, • water quality, • composition of the minerals to be mined, and • embedded geological structure. Benthic habitat maps can be derived from seafloor bathymetry, underwater photos, acoustic surveys, and data gathered from sediment samples. The resulting digital map could be viewed using geographic information system tools. Information on the mineral deposits and the benthic ecosystems impacted would be one of the most dynamic elements of the roadmap. It is the one area where the extent of unknowns is unclear. This would require the use of advanced technology that maps and records migration.
Cost and benefit estimation: Depending on the method of implementation it is likely that a significant portion of the costs would be borne by the companies carrying out deep-sea mining. **Costs:** To be developed (information from survey companies for specific areas). **Technology:** • Survey management • Analysis of acoustic data • High definition video and stills photography • Remotely Operated Vehicle (ROV) surveys • Seabed sampling (grab sampling, box coring, trawling) • Single beam echo sounder capabilities (dredge monitoring, beach profiling, monitoring of disposal sites etc.) • Identification of seabed biotopes • Physio-chemical analysis • Taxonomic identification
Recommendations for implementation: In order to ensure consistency in data collection a regulative measure would need to be applied which requires companies operating within Member State continental shelf areas to carry out benthic surveys and share the information in a public domain. In the case of ABNJ it is likely that an international initiative would need to the launched with a similar mechanism whereby the ISA could host the information in a domain accessible for the public. Potential risks might arise if activities take place in the continental shelf areas of countries which do not impose the requirement for preliminary benthic survey and information exchange. A highly desirable outcome would be an international agreement on compulsory benthic surveying for deep-sea mining operators. Such an international agreement could also contribute to ensuring harmonisation with regard to the methodology of information collection.

Step 2: Streamlining data management
Description: Access to data and information are a fundamental element not only for establishing good environmental practice but also for managing large scale mining operations. It is expected that individual stakeholders – mining companies as well as national authorities - would collect data on the benthic environment as well as associated impacts of the operations; however it is essential that a broad overview of data including statistics and forecasts is gathered and regularly updated on the European as well as the international level. Streamlining data management would allow the creation of a single data repository with online access. Such a database would allow exporting and importing of maps and aerial views for the different sites and could be customised and configured in such a way that information marked as confidential would not be displayed for all viewers. Further consolidation of data with the ISA would create a transparent system that includes information on stakeholder involvement (details of the mining companies), sites of the operation, and exploration and extraction licenses. **Types of information**:

Step 2: Streamlining data management
• benthic survey • stakeholder involvement per operation • sites of operation • size and access to deposits • exploration and extraction licences • future extraction potential etc .
Cost and benefit estimation: costs of streamlining data management would be mostly incurred at the host site which can be maintained by an international organisation (e.g. ISA, EU) or contracted to third parties.
Recommendations for implementation: Depending on the level of data consolidation, maintaining and updating such a site could fall into the competences of the European Commission. With regard to the data collection, in order to have a complete overview stakeholders would be required to report and can be obliged by regulatory measures or can be encouraged by voluntary intra-industry schemes such as certification or quality control initiatives. It is important to note that issues related to confidentiality stemming from exploration permits and/or exploitation licenses would need to be ensured.

Step 3: identifying common indicators for technology assessment
Description: A critical element of the roadmap will be to establish indicators in order to assess the sustainability of the deep-sea mining operations. Taking into account the impacts of the technology used and the status of the benthic environment, these indicators will be essential for defining good environmental practices, and in the case of activities with EU Member States' waters, could also inform management of such activities in the context of achieving Good Environmental Status under the MSFD. Sustainable technology has the characteristics of minimising negative environmental impacts and can include methods and processes as well as physical infrastructure. Two main types of indicators could be used: • technology indicators; and • environmental impact indicators. Technology indicators would comprise of an assessment on the following criteria: • performance of the system (state and types of tools and machines used in deep-sea mining operations); • adaptability of technology to the changing benthic and pelagic conditions; • safety of the system (safety score); • reliability of the system (mean time between failures); and • social impacts of technology. Environmental impact indicators would comprise of an assessment on the following criteria: • resource usage for building and operation; • waste management (waste water, solid waste etc.); • pollution (air, water, land); and • impact on density and species composition at benthic and pelagic zones; • impact on sediment composition • presence of alien or non-indigenous species The indicators developed from the above criteria can build on benthic and pelagic indicator models already adopted (e.g. ECASA toolbox) taking into consideration that none of the existing indicators have been ‘tried and tested’ yet.
Cost and benefit estimation: The development and regular update of a comprehensive list of indicators could fall into the competences of the European Commission and the relevant international organisations (ISA).

Step 3: identifying common indicators for technology assessment
Recommendations for implementation: Determining and evaluating indicators would require a joint effort of national and international regulatory bodies, research centres, NGOs, and other stakeholders. Based on these indicators, strategic objectives can be derived with regard to the long-term environmental status of the marine waters to prevent adverse effects of deep sea mining and to safeguard human health and ecosystems (see step 4). In the EU context, the development of such indicators could take place in context of on-going work in relation to developing indicators for Good Environmental Status under the MSFD, and build on work carried out for the regulation of other offshore activities (e.g. offshore oil and gas). In the case of ABNJ and for marine waters belonging to the continental shelves of third countries a wider international agreement would need to be reached in order to establish a common set of indicators for operational activities.

Step 4: establishing qualitative descriptors
Description: Taking into account the indicators developed in Step 3 and the current state of the relevant marine areas, and drawing on existing frameworks, such as the MSFD as outlined in section 4.2, a set of key targets for sustainability could be established, accompanied, if appropriate, by regulatory measures to achieve them. Prevention would be a vital element, since it can be extremely difficult to take measures to remove or reduce the impact on the natural system once it has taken place. Therefore, an early warning system adapted to the specific maritime area should be developed including detection, diagnosis, quick screening, risk assessment, identification of proper response, reporting to the competent authority and an authority response[104] .
Cost and benefit estimation: The establishment of targets and in particular any regulatory measures in an EU context should be subject to an impact assessment to assess the environmental, economic and social costs involved.
Recommendations for implementation: Following the selection of the indicators, in the EU context, a European level regulatory requirement could be examined in order to establish minimum standards. Such a requirement would need to take into account relevant existing legislation in relation to the marine environmental protection (e.g. MSFD) as well as instruments currently in place which regulate other offshore activities (e.g. oil and gas installations).

Step 5: reporting
Description: Reporting requirements would be twofold; on the one hand reporting would be required from stakeholders engaged in deep-sea mining operations. On the other hand national authorities and international bodies would be also be required to share consolidated as well as disaggregated information on environmental impacts, and protective and preventive measures taken. Environmental impact reporting or environmental statements from individual stakeholders would include: • The identification of the state of the specific marine environment prior to deep sea mining operations (based on surveys as described under step 1); • The description of the technological tools and practices; • An assessment of the operations based on the technology and environmental indicators (as described under step 3)

[104] Van Hoey et al., 2010.

Step 5: reporting
• As assessment of the marine environment during the operations of deep-sea mining, including measures taken to comply with targets and any regulatory requirements (as described under step 4) Environmental impact reporting or environmental statements from national and international regulatory bodies would include: • Consolidated information on the state of the marine environments prior to deep sea mining operations of all relevant stakeholders under licence from the ISA (based on surveys as described under steps 1 and 2); • An assessment of the operations based on the technology and environmental indicators (as described under step 3) • As assessment of the marine environment during the operations of deep sea mining (as described under step 4) • Updated independent audit reports on the technological tools, practices and environmental impacts of the deep-sea mining operations (as described under step 6).
Cost and benefit estimation: Reporting requirements would entail costs for the exploration or extraction contractors. Furthermore in case of national reporting obligations administrative costs could incur on the level of national authorities required to report to international bodies.
Recommendations for implementation: The content and frequency of reporting requirements can be set by European regulatory provisions making it obligatory for Member States or individual companies. Alternatively individual stakeholders can be encouraged to report on the impacts of their activities via voluntary measures such as quality control or certification schemes. In the case of ABNJ and for marine waters belonging to the continental shelves of third countries a wider international agreement would need to be reached in order to establish reporting requirements.

Step 6: ensuring independent assessment of practices/measuring environmental impact
Description: Independent assessment of the operational practices serves the purpose of verifying the compliance of completed or on-going deep-sea mining activities with the relevant provisions of legislative elements, environmental policies, indicators and qualitative descriptors. Third party environmental audit reports reinforce transparency, reliability and social accountability of the stakeholders. Moreover, target setting and external reporting facilitate environmental improvement through public disclosure of targets and results. It can also contribute to the reduction of corporate risks and broaden the range of investors. Furthermore it can improve the list of preferred suppliers for buyers with green procurement policies. [105] In order to achieve comparability and transparency of operations a generally accepted standard for environmental reporting (whether third party or self-evaluation) would need to be developed.
Cost and benefit estimation: Third party audit schemes would be developed by certification bodies and relevant costs would be levied onto the individual stakeholders carrying out the operations.
Recommendations for implementation: Regulative measures can be imposed to make third party audit schemes compulsory once extraction licenses have been granted. Alternatively environmental reporting and third party auditing can also be prerequisites of obtaining extraction licenses. In the latter case implementation of provisions would fall into the competences

[105] Association of Chartered Certified Accountants (nd)

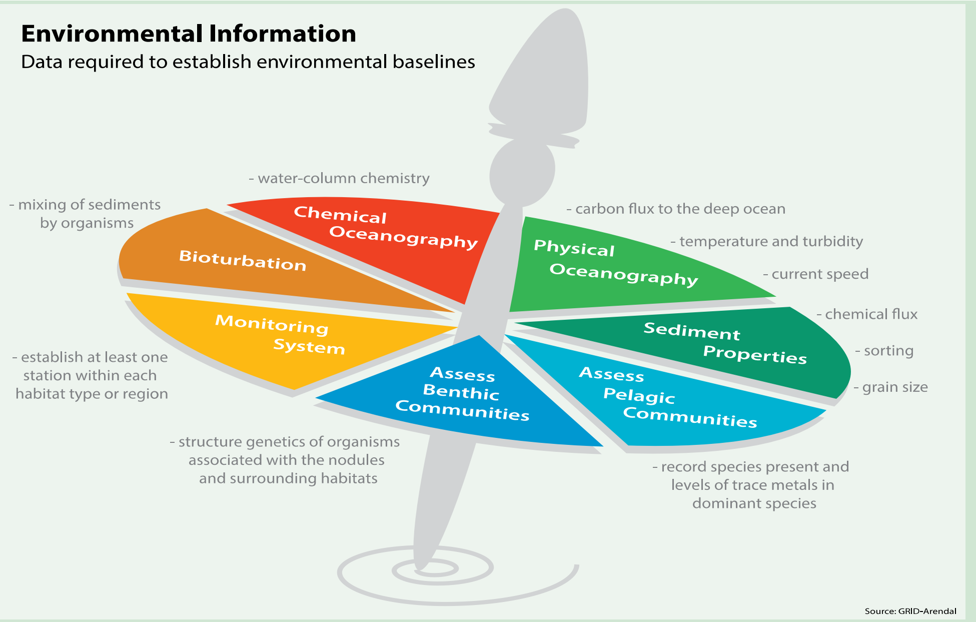
Step 6: ensuring independent assessment of practices/measuring environmental impact
of the ISA and national authorities responsible for granting licences of operation.

Once basic environmental impacts are identified and a roadmap prepared to measure operational targets, the next step will be to monitor the operations. In order to establish monitoring criteria tools will be assessed that are currently available for the review and monitoring of the environmental impacts.

5 Review and inventory of monitoring techniques

Seabed mapping and monitoring techniques are a cost-effective way to carry out wide-scale surveys and can be used to identify seabed (or sub-seabed) features of conservation, resource, or scientific interest[106]. Seabed mining operators in international waters are obliged to satisfy best environmental practices and to provide the regulatory authority with reporting/monitoring information confirming that best practices are being applied[107]. Within jurisdictional areas of particular countries relevant national provisions also apply.

Relevant regulatory authorities are responsible for the verification of the monitoring measures and that the mining operator is adhering to the best environmental practices. In order to achieve this baseline surveys will be needed prior to mining activities. Additionally, mapping of pre-mining conditions such as seabed sediments, habitats, and water column features are necessary in order to identify any physical impacts. Once measurements have been carried out on the physical properties of the specific areas a minimum threshold needs to be set with regard to the environmental impacts, such as impacts on the sediment, species, pollution, waste generation practices etc. within which activities can be considered to fulfil best environmental practices.



Example of environmental baseline data required under the ISA Mining Code's regulations on prospecting and exploration within the Area. GRID Arendal 2013 in Lodge et al 2013).

5.1 Inventory of monitoring techniques

Oceanographic tools have evolved over the last century to include a wide array of platforms and sensors that can now measure a range of marine variables in manual, semi-autonomous or autonomous ways. These can range from making measurements by shipboard sampling systems

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[106] Boyd et al. 2006
[107] International Seabed Authority 2011a

to releasing robotic equipment which then reports back to shore via satellite for its full service lifetime, several years in some cases. Platforms can range from satellites, to ships to specialised deep-sea vehicles. Likewise oceanographic tools range from thermometers to sensors capable of conducting molecular genetic analyses *in situ* and reporting data back to shore, fully autonomous and in real time. Sampling for the complete range of known body size is now possible through various sampling and processing approaches including varied sieve and water filter sizes.

Satellites can see the ‘skin’ of the ocean and have proved very valuable insights into the spatial variation in temperature, salinity, sea surface height, and even bathymetric features through their gravimetric influence on sea surface height. In a seafloor mining context such imaging could provide useful indications of the distribution of potentially sediment laden plumes at the sea surface. Although there have been great advances in autonomous systems, ships remain a vital platform for oceanography and marine survey work. The greatest recent change in the way ships are used is that a greater portion of sea time is now going into deploying and servicing a wide range of systems that are able to collect data autonomously in one way or another. Additionally the use of remotely operated vehicles (ROVs) and hybrid systems has also increased. Thus the capability of any single research cruise has greatly increased, with much more being possible in a given number of days on station. Ship dependant equipment includes ROVs, which are tethered to a ship, as well as conductivity temperature and depth (CTDs) recording systems, which also have a suite of biogeochemical sensors and sample bottles. These CTD rosettes can take samples at discrete depths in the water column, and can also come specially fitted for examining trace metals such as iron. Another wire-deployed tool is a standalone pump system (SAPS) for filtering water *in situ*. There are also multiple tools for sediment sampling including box cores, multiple coring systems such as the Bowers and Connely megacore system, which are widely regarded as being able to return the least disturbed sediment samples possible without an ROV or specialised lander.

Capabilities for buoys, moorings and lander systems have improved in recent years with a vast array of sensors now deployable to deep ocean depths, many of which can operate for a year or more without service[108]. These can operate as standalone or delayed mode systems where data is returned whenever the systems are serviced. However, there have been important advances in telecommunication methods such that there are now many examples of systems that can telemeter data acoustically from the deep seafloor to near surface, and then by wire to a surface buoy that can send and receive satellite messages.

Seafloor cable systems have also increased in their use and reliability and have much greater capability in terms of power available for sensors and telecommunication bandwidth, as well as real time data feed. The added capacity of bandwidth can allow for images and other large format data to be readily relayed. And some sensors such as video and active acoustics can use relatively larger amounts of power depending on how frequently those are running[109]. These systems can operate either from bespoke cables which connect to a junction box, which either can go to shore via another cable or connect to an acoustic to satellite relay system as mentioned above. Cabled systems are also required for applications were time synchronisation and real-time alerting are needed, such as for monitoring of geophysical motion in relation to geo-hazards. Junction boxes and sensors can also be added to existing and even disused seafloor telecommunication cables as has been done with the H20 and ALOHA cabled system projects in the northeast Pacific Ocean.

Tools such as buoys and moorings do not require constant monitoring and can be serviced once a year. Data recording devices can also be recovered and serviced by divers. Some of the sensors

[108] see Ruhl et al. 2010 and 2011 for more detail including examples and vendor details
[109] Priede et al. 2003, Barnes et al. 2008, Favali et al. 2009

allow for the electronic transmission of data while others store information in which case divers need to download the data.

Box 5.1 Monitoring tools proposed by Nautilus Minerals[110]

In its Environmental Impact Statement for the Solwara I project, Nautilus Minerals has listed some of the monitoring tools it aims to deploy in order to ensure sustainable operations. The following list is a selection of the proposed tools and methodology:

- Place time-lapse cameras on the seafloor to observe selected vents
- Repeat temperature mapping of mine area at appropriate intervals, at least annually
- Video and map active chimneys in areas after Seafloor Mining Tool (SMT) (i.e., mining) activity.
- Obtain long-term temperature monitoring in selected vents using thermistors.
- Complete a centre-line transect imaging survey at Solwara 1 and South Su after three to six months, and thereafter six-monthly or at an appropriate frequency to be determined.
- Photo mosaic/video pass (frequency as above).
- Visual analysis of species, density and abundance from video transects.
- Use settlement collectors to obtain settling animals
- Using ROV and scoops (opportunistically and/or during routine monitoring), transport samples of densest clumps of snails in path of mining and relocate to adjacent areas (initially).
- Video observation of plumes generated by SMT activities (including mining, sediment removal and competent waste material side casting) during operation.
- Establish sedimentation traps at the selected/control sites to monitor natural/mine-induced settlement.
- Particle size analysis annually.
- Video redeposition of sediments on mine areas and changes to topography of mined areas.
- Core samples for grain size analysis (annually).
- Hydrophone monitoring of sound characteristics of MSV, Riser and Lift System and SMT operations.
- Record any observations of marine mammals in the vicinity of operations during life of mine.
- Deploy a current meter (ADCP) for continuous recording at a fixed site for ocean currents and plume predictions.

According to the information on the website of Nautilus Minerals, further details of the proposed monitoring programs, including descriptions of the methods, locations and frequency of monitoring, will be included in the detailed Environmental Management Plan ("EMP") which will be submitted to the government of PNG for approval prior to project commissioning.

Several research projects have conducted research and development activities around ocean observatory science and technology including the European Seas Observatory Network (ESONET), EuroSITES, European Multi-disciplinary Seafloor and water column Observatory (EMSO) project, and the Fixed Point Open Ocean Observatory (FixO^3) project. The EMSO project has also sought to form a European Research Infrastructure Consortium, which is a legal instrument created by the EC to facilitate more effective operation of research infrastructures. It is expected that the EMSO-ERIC will be operational by 2015. Moreover, this organisation can act as a clearing house for knowledge on ocean observatories for European industrial interests.

Ocean data buoys now have a track record for recording and relaying data from open ocean sites globally (see OceanSITES). These can carry a large payload of sensors and power systems. Power can come from batteries, solar, wind and even on-board diesel generators or wave energy. One of the key advantages to buoy systems is that it allows for the direct measurement of atmospheric conditions and how the relate to sea surface conditions over time including the transfer of heat, wind and wave energy, and primary production which drive marine food webs, even for most deep-

[110] Coffey (2008): Environmental Impact Statement, Nautilus Minerals, Solwara I. http://www.cares.nautilusminerals.com/assets/documents/main%20document%20text.pdf

sea life[111]. Measurements at this interface can, importantly, help when trying to differentiate potential human impacts from naturally occurring seasonal or inter-annual variation[112].

Telecommunications can come via two-way links to satellites for relaying data and taking software upgrades and new instructions to instruments, as well as links to systems down mooring lines or acoustically.

Moorings can have a surface expression (buoy), but deep water moors often avoid surface waters as this reduces risk due to weather damage and vandalism. Moorings can be recalled by acoustic release, timed release, corrosive release, or some combination depending on the application and acceptable levels of risk. They can serve to fix instruments or packages of instruments at certain depths in the water column over time at fixed points. Thus they are very useful in creating time series data for various water column features like profiles of water mass structure, biogeochemical fluxes including the transfer of energy primary production to deeper depths as a particulate rain of 'marine snow'. They can also easily hold sensors for the measurement of suspended particle load and current profiles. Here too, these data allow for understanding of not only impact related variables such as particulates and their fluxes, but also provide information on the natural variation in particular organic carbon fluxes, for example.

Seafloor landers are another long-used platform for marine research and survey work. They can carry a wide range of payloads including current meters, seismometers and other geophysical devices, cameras which can measure animal activity and diversity[113] and sedimentation dynamics[114], animal and seafloor community respiration measurement equipment[115], and complex experimental systems[116]. Lander systems can also carry baited cameras and current meter systems that can calculate the densities and biodiversity of fishes and invertebrates.

The last decade has seen the maturation of several advanced platforms including unmanned surface vehicles (USVs), wave gliders, buoyancy gliders, autonomous underwater vehicles (AUVs) with long range and/or endurance, AUV docking stations, and benthic rovers. All of these systems can now be deployed for months at a time and collected data over a pre-programmed range of depths or spatial settings. USVs have which can station keep or survey an area cyclically. Because theses can carry relatively large payloads as well as solar and/or wind harvesting equipment, they can have long endurance for a wide range of variables. Examples of USVs from commercial vendors are now available. Wave gliders gather wave energy and have limited navigation capability that includes station keeping capability. One wave glider has done a trans-Pacific crossing providing an important demonstration of endurance. Buoyancy gliders now have broad uptake in the oceanography community and can hold a limited number of compact sensors including examples for optical backscatter (turbidity), fluorescence, nutrients and oxygen.

A wide range of AUVs are now available from several commercial vendors. These often have a modular payload. AUVs that can dive to abyssal depths remain relatively rare, though, with only a few commercial and research organisations designing, building and using these globally[117]. Multiple research and development laboratories have now developed AUVs with long range and high

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111 e.g. Smith et al. 2009, Hartman et al. 2010, Billett et al. 2010
112 e.g. Vardaro et al. 2013
113 e.g. Vardaro et al. 2009
114 e.g. Smith et al. 2014
115 Bailey et al., Smith et al. 1999
116 Sweetman et al
117 Wynn et al. 2014

endurance[118]. The Autosub LR, for example, has expected range of 6000 km or endurance of up to 6 months[119]. This long range capability stands to provide a step change in monitoring capability and cost effectiveness. It can reduce the dependency on costly ship time and improve spatiotemporal sampling. These systems can act as virtual mooring infrastructures providing repeat profiles of the entire water column over time, or they can conduct ocean data sections over ocean basin scales. Moreover, because of the endurance and ability for satellite telecommunication, they can do so without the need for additional complexity added by docking stations for data and power exchange.

Benthic rovers have also become more common with multiple research labs now working on next generation rovers. These have capability to make measurements of seafloor oxygen consumption and similar variables on timescales of days[120]. These can also carry a range of cameras and other sensors and in many ways these can operate as mobile lander systems, where the rover can move to new locations in time series.

There are a broad range of sensors now available, with miniaturisation and improvements in reliability and cost effectiveness changing rapidly. This is driven, in part, by requirements to get sensors on to gliders and AUVs where space and power are at a premium and there are rarely chances to fix failed sensors. Conductivity, temperature and fluorescence sensors have been available in compact systems for many years. Chemical electrode based sensors have also long been used in oceanography and include oxygen sensors. These electrode systems are now often surpassed in performance by optode systems, where foils exposed to seawater are illuminated and a subsequent response by the foil is then quantified. These optodes have now been adapted for a variety of purposes. Similarly infrared light-based methods have also improved, with systems now able to detect nutrients and CO_2 now commercially available. There are now also sensors in development which use microfluidics or 'lab-on-chip' systems. These allow for reagent based techniques to be deployed *in situ* with better efficacy including those for nutrients.

A major advance in acoustic and optical imaging is currently happening. Acoustic current meter technology is also mature with several variants of 2D or 3D acoustic current meters now available. There are now several efforts to better process such data to get more value added data such as those values that can be inferred from backscatter. The rendering of detailed 3D surfaces from acoustic data is also improving with vertical faces now imaged for habitat composition.

With the maturation of digital cameras, platforms and semantic image processing, the use optical images is set to make a step change in the coming years. Photographs and photogrammetric methods have long been useful in oceanography, marine survey and ecological research. These systems can image life and habitats across a wide range of scales. In the water column, the challenge of scale measures has been overcome through the use of structured light cameras, where the imaged volume is known. Examples include the *In situ* Ichthyoplankton Imaging System (*IS*IIS[121]) and Underwater Vision Profiler (UVP), or via 3D systems were the size and location of objects can be determined. Holographic imaging systems have been developed and commercialised that can image marine algae cells and smaller zooplankton (e.g. LISST-Holo). Macro and mega plankton imaging systems have also been developed and commercialised, including the UVP. HD video has also been used successful to map plankton[122].

[118] e.g. the TETHYS vehicle at the Monterey Bay Aquarium Research Institute [MBARI], and the Autosub Long Range [LR] at the National Oceanography Centre, UK
[119] Wynn et al. 2014
[120] e.g. Sherman et al. 2009
[121] Cowen and Guigand, 2008
[122] Robison et al. 2005

Benthic imaging has benefited from HD video and digital camera development. The pair of digital still cameras with advanced AUV technology as brought a step change in capability for mapping large areas of the seafloor photographically. For example, an area with sides of about 10 km^2 was mapped with the Autosub6000 AUV at the Porcupine Abyssal Plain[123]. The system was able to photograph 160 km of track line with mm scale pixel resolution in a lattice layout. This has allowed for research at a more landscape scale than has been possible in the marine sector previously, where continuous surveys are generally limited to a few km. Newly commercialised 4k cameras (a.k.a Super-Hi Vision, 7680×4320 pixels) have also been adapted for deep sea use, such as those used in the HADES project[124]. Importantly, there are detailed and well accepted best practices for analysing data from images that are embodied in point transect and line transect theories[125].

Molecular sensors have been maturing with at least one system having been commercialised, the Environmental Sample Processor (ESP), developed at MBARI. The ESP is capable of taking water samples to 4000 m depth, decompressing the sample in its housing, and running a complex set of molecular probe analyses via real time DNA, RNA, molecular marker reactions including q-PCR. The results are then imaged using Fluorescent *In Situ* Hybridisation (FISH), and phytotoxin quantification. These images can then be sent back to shore in real time via ocean observatory telecommunication systems such as seafloor cables or cable-buoy-satellite relay.

Given the range of available platforms and sensors, it is now possible to mount much more comprehensive monitoring programmes that can help eliminate doubt as to the sources of variation, be they human or natural. Best practices should include the appropriate sensor or sampler for the target variable, size class or fauna character as well as stratified random sampling with sufficient replication for observed variation. These strata can be made up of factors such as habitat type, time of year or other known features and if adequate samples are taken across each strata, then each can be systematically examined in EIA and other analyses including statistical methods.

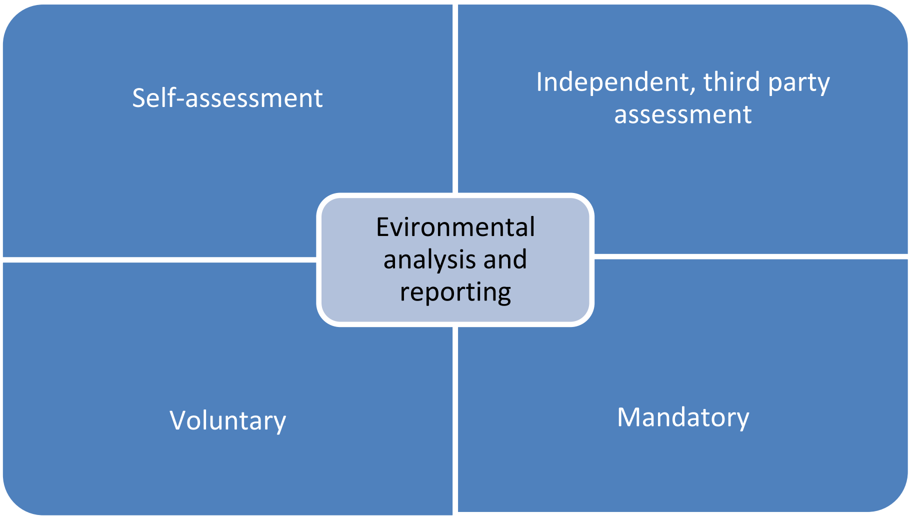
The curation of data and samples for areas of seabed mining by any researchers or contractors is especially important considering the rarity of such samples globally and the need to cross reference specimens which may not be taxonomically described, but occur at sites being examined by more than one contractor. Thus, the curation of samples should include entry of sample collection details into taxonomic database systems. In the oil and gas sector this is often handled at a national level. However, given that many areas are outside of national jurisdiction, a coherent data-basing and voucher specimen system is advisable. Likewise, because there is relatively little data available (with suitable metadata) for deep-sea systems generally, the more data that can be made openly available, the better able scientists and surveyors will be at understanding potential and real impact. While there are no doubt commercially sensitive data in industrial applications, much if it can be released without economic detriment to industrial interests.

5.2 Analysis and reporting

Once an on-site survey has been carried out findings can be further analysed and reported. There are again multiple ways to evaluate the findings ranging from a basic assessment against criteria and environmental performance to more in-depth analysis of the conditions taking into consideration social and economic spill-over impacts.

[123] Wynn et al. 2014
[124] http://www.whoi.edu/hades
[125] Buckland et al. 1993

Environmental impacts can be assessed and reported by the operators (self-assessment) or independent third parties. Moreover, the analysis and reporting activities can be mandatory or voluntary.



The following are some of the methods for analysis and Reporting on environmental performance:

- Strategic Environmental Assessment (SEA);
- Environmental Impact Assessments (EIA);
- Self-reporting or third party assessment based on National and international legislative framework;
- Setting environmental performance targets; and
- Voluntary or mandatory quality control or certification scheme (ecological-technological).

In the case of both SEA and EIA the analysis takes into consideration a wider set of impacts and looks at a longer time frame than a general, annually audited environmental performance or certification would do. Assessment tools based on a set targets – either defined by legislation or independent environmental performance targets – can be rather restrictive and focus on impacts recorded at a given time without providing an on-going review of impacts along the value chain.

A key point to note here is that transparency should remain focal and SEAs and EIAs should be accessible and discoverable within the public domain not only for relevant authorities such as the ISA, but for the general public as well.

The following figure illustrates the differences that could exist between EIAs and SEAs.

Figure 5.1 Differences between EIA and SEA

Difference between EIA and SEA

Environmental Impact Assessment of projects	Strategic Environmental Assessment of strategic initiatives
A Technical instrument related to activities with geographic and technical specifications	A Political instrument related to concepts
A Reactive approach - at the end of the decision-making process	A Proactive approach - at earlier stages of the decision-making process
Identifies specific impacts in the environment	Addresses issues of sustainable development
Limited review of cumulative effects	Gives early warning of cumulative effects
Emphasis on mitigating and minimizing impacts	Prevention in terms of identified environmental objectives

Least strategic → Most strategic

Most detailed ← Least detailed

GRID-Arendal

Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) as part of the decision making process (GRID Arendal 2013 in Pendleton et al 2013).

Quality control schemes, which can be linked to certification, look at a broad range of activities through the supply chain and in addition to identifying harmful activities they also provide assistance in improving the environmental performance of companies. Certification schemes can be further divided according to their target. Some certification schemes set a baseline standard against which they measure the performance of companies. In other cases certification schemes can set more stringent requirements to identify top performers or premium standard.

6 Environmental Workshop

6.1 Overview

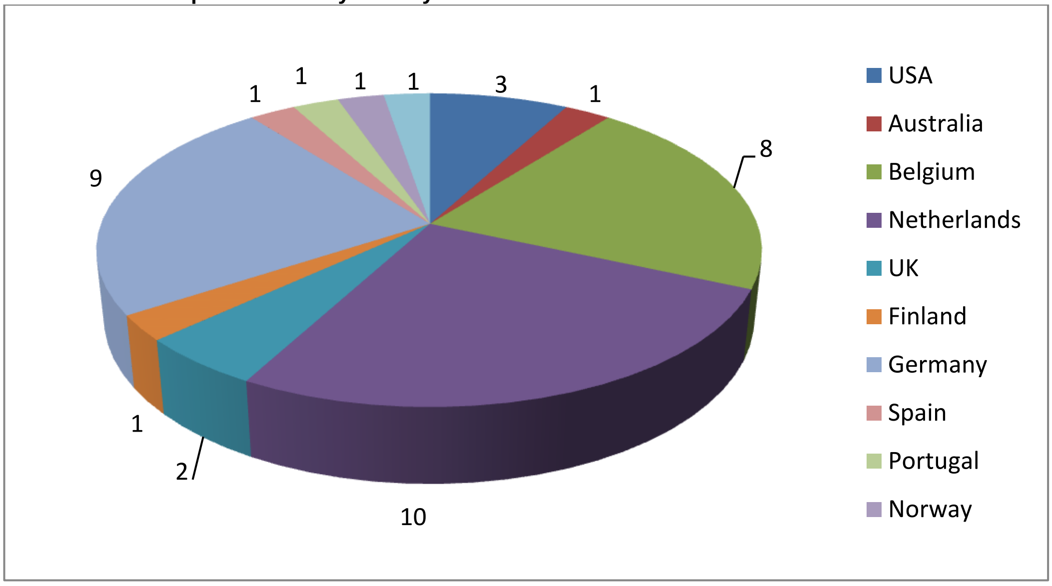
Findings of Task 6 were discussed at the international environmental workshop held on the 30th of April in Brussels. The workshop provided an opportunity to discuss the Task results and validate its findings in light of on-going exploration work. The organisation of the event allowed for an active participation in the form of interactive discussions, exchange of information, and feedback from the attendees.

A technology workshop was held the day prior (29th April 2014) at the same location, to enable participants to stay on to attend the environmental session.

6.1.1 Participants

Experts in deep-sea mining and environmental protection were invited from 10 different countries in the world. A total of 38 individuals participated, the countries of Germany, Netherlands and Belgium have been have been represented by the highest number of stakeholders, but experts from the United States, Brazil and Australia have also participates. A breakdown of representation by country is shown in the figure below.

Figure 6.1: Stakeholder representation by country



The workshop was organised in thematic sessions on the topics of:

- Land-based mining contrast;
- Current gaps of knowledge;
- Threats and mitigation measures;
- Good practices and,
- Policy perspectives e.g. criteria for operational targets on Good Environmental Status.

6.1.2 Outcomes

An abbreviated expert elicitation session was held during the one-day workshop. During this time, participants were first briefed on the methods and goals behind an expert elicitation survey. The group then participated in a short digitized survey that posed nine questions about the state of knowledge for each deep-sea marine mineral deposit type. The responses were graded using pre-determined scores as such:

- Very Good (8-9): The scientific information exists on this topic from a representative number of study locations, and there are peer-reviewed published papers available online.
- Good (6-7): There is some information available from some study locations on this topic, and there are a number of industry reports available.
- Poor (3-5): There is some information available from a few study sites on this topic available only as un-reviewed data and grey literature.
- Very Poor (1-2): There is little or no data available about this topic.

The results are as follows:

Question	Very Good	Good	Poor/Basic	Very Poor
Knowledge on ecology and biodiversity of benthic communities associated with SMS	5	8	16	4
Knowledge on ecology and biodiversity of benthic communities associated with manganese nodules	9	12	12	33
Knowledge on ecology and biodiversity associated with cobalt rich crusts	1	4	16	11
Knowledge on the biogeography of benthic communities associated with SMS	3	5	11	9
Knowledge on the biogeography of benthic communities associated with manganese nodules	2	6	9	11
Knowledge on the biogeography of benthic communities associated with cobalt rich crusts	2	4	11	11
Knowledge on the rates of ecologic succession of benthic communities associated with SMS	3	3	12	7
Knowledge on the rates of ecologic succession of benthic communities associated with manganese nodules	2	5	9	13
Knowledge on the rates of ecologic succession of benthic communities associated with cobalt rich crusts	2	2	7	16

Following the digitized survey, participants were divided into three break-out groups, one for each mineral deposit type. During an approximate 90-minute session, open dialogue was held, and groups discussed in further detail the state of knowledge – or lack thereof – for each deposit type.

The main conclusions of the workshop:

- Many environmental aspects remain unknown, this is true for all resource types
- Recovery of ecosystems following mining impacts are likely to be slow especially for crusts and nodule mining
- Environmental research need to continue
- Data collection is needed at both the regional and local scales
- Data sharing of environmental information is very important and data should be lodged in an open access database

- All environmental data collected by contractors licensed by the ISA should be made publically available soon after its collection
- Extensive collaboration will be needed between research groups on an international basis (e.g. joint projects on deep sea biodiversity)
- The environmental issues need to be considered collectively with the development of technology and governance
- A more coherent approach from the European Commission DGs (Environment, Mare, Enterprise) would be welcome
- Elements of the MSFD may be of value to the ISA in its development of a regulatory framework
- Examples of good environmental practice can be found in the dredging and hydrocarbon industries within Europe
- Alternative strategies such as improved recycling should be considered

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