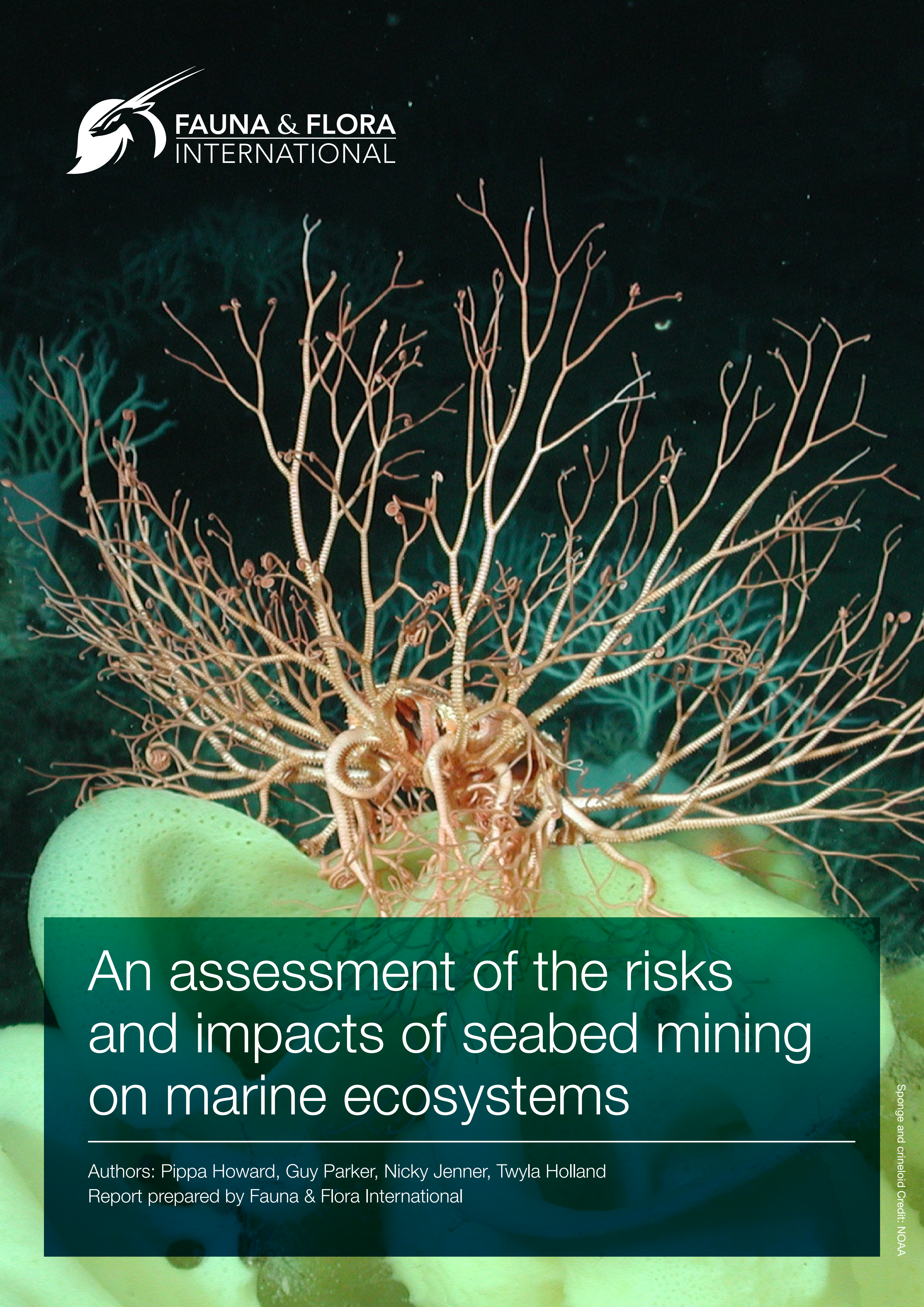

FAUNA & FLORA INTERNATIONAL

An assessment of the risks and impacts of seabed mining on marine ecosystems

Authors: Pippa Howard, Guy Parker, Nicky Jenner, Twyla Holland
Report prepared by Fauna & Flora International

Sponge and crinoloid Credit: NOAA

Fauna & Flora International (FFI) protects threatened species and ecosystems worldwide, choosing solutions that are sustainable, based on sound science and take account of human needs. Founded in 1903, FFI is the world's longest established international conservation body and a registered charity. For more information see: www.fauna-flora.org

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About this report

With the increasing interest in exploration and exploitation of seabed minerals particularly in deep waters, rapid pace of development of the deep-seabed mining sector, limited knowledge of deep-sea ecosystems, and the potential for adverse impacts from deep-seabed mining, there is an urgent need for a thorough assessment of whether and how seabed mining in deep waters could proceed using the good practice principles routinely applied to terrestrial mining without causing harm to ocean environments and their associated biodiversity, processes and functions.

This report offers a systematic impact and risk assessment based on a Strategic Environmental Assessment framework which draws on available information to: understand relevant existing and proposed legal and management frameworks; understand the baseline environment; consider technologies and processes under development or proposed for the mining of different mineral resources on the seabed; assess likely impacts of mining of different minerals and their associated ecosystems; and apply possible mitigation and impact management scenarios to objectively deduce the potential for no net loss or net gain for biodiversity.

In developing this Risk and Impact Assessment Report, FFI has built upon 25 years of experience working with mining sector partners in terrestrial locations, collaborated with expert deep-sea scientists and seabed mining specialists, and harvested current research from across the globe. The aim is to ensure comprehensive yet non-exhaustive coverage of the key issues, and provide input to the processes underway to generate standards and guidance for deep-seabed mining. In dealing with seabed mining in the marine realm it is recognised that there are a great range of subjects to cover: where topics cannot be covered in full, readers are either directed to suitable material, or gaps are identified for future research.

Acknowledgements

Development of this report would not have been possible without the support of Fauna & Flora International. Thanks are extended to Pew Charitable Trusts for funding participation in deep-seabed mining meetings at the headquarters of the International Seabed Authority, Jamaica.

Special thanks go to the principal authors Pippa Howard, Guy Parker, Nicky Jenner and Twyla Holland. Thanks to Daniel Jones, Principal Scientist at Natural Environment Research Council, Southampton, United Kingdom who provided a number of case studies, photographs and invaluable technical content, deep-water expertise and review. Barry Clark, Cape Town University, provided essential technical input relating to marine ecosystem monitoring and baselines. Special mention to Dom Ross, whose technical wizardry and patience enabled smooth production of the report.

Contributions and general moral support from Joanna Elliott and FFI's Marine and Communications teams: Abigail Entwistle, Daniel Steadman, Sarah Rakowski, Nathan Williams and Lizzie Duthie. We acknowledge the generous photographic galleries of the National Oceanic and Atmospheric Administration (NOAA), and the remarkable expedition footage of the NOAA Office of Ocean Exploration and Research as well as the BBC Natural History Unit's production of The Blue Planet and The Blue Planet II series, without which the deep oceans would be a mere figment of our imaginations. Finally, a deep appreciation and sincere thanks to Nicky Jenner who is responsible for the wonderful artwork and perceptive interpretation of ocean systems.

FFI would like to acknowledge the important work of the Deep Sea Conservation Coalition, the Deep Oceans Science Initiative, MIDAS and the International Institute for Sustainable Development for their tireless work in bringing the science and policies of deep-seabed mining to the fore. Their proactive engagement with the processes underway within the international policy arena relating to the activities of the International Seabed Authority and biodiversity beyond national jurisdictions (amongst others) highlights the responsibilities we all have to ensure our ocean are safeguarded. They bring essential expertise, credibility, science and transparency to this fundamental discourse.

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Foreword

Credit: Gary Morrisroe/FFI

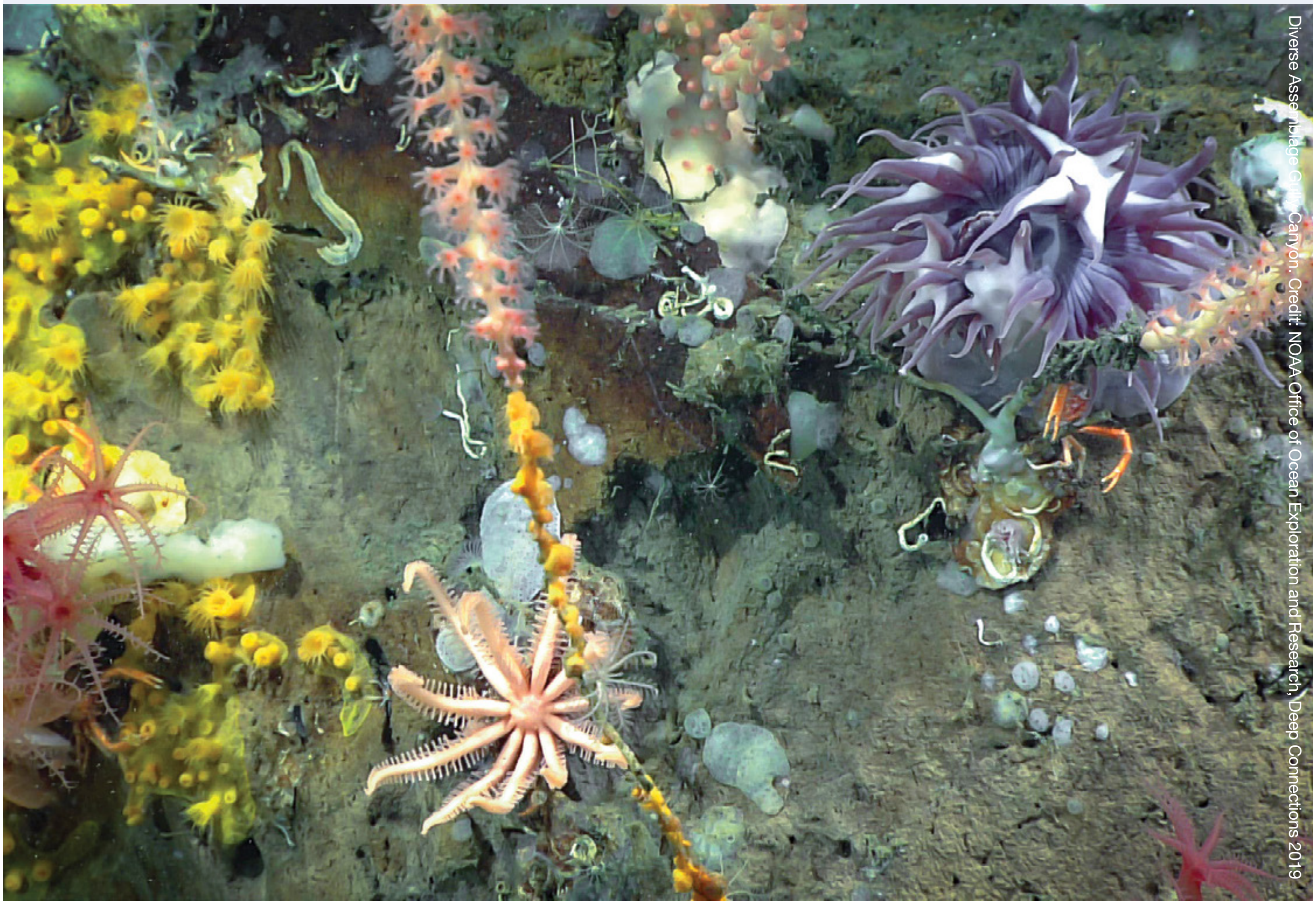
The depths of our oceans remain largely unexplored, but humankind's first tentative ventures into the blue abyss have revealed a hidden world full of wonders, where life thrives under great barometric pressure and far from the light of the sun. The fact that life exists at all in such unforgiving conditions, drawing energy from the chemicals expelled from the earth's core and locking away carbon from our atmosphere, is one of the world's uncelebrated marvels. What is more, we are now beginning to appreciate the extent to which life in the deep sea also affects the health of the planetary systems on which we all depend.

The fate of the deep sea and the fate of our planet are intimately intertwined. That we should be considering the destruction of these places and the multitude of species they support – before we have even understood them and the role they play in the health of our planet – is beyond reason.

This report by Fauna & Flora International highlights crucial evidence about the importance of the deep sea for the global climate and the proper functioning of ocean habitats. The rush to mine this pristine and unexplored environment risks creating terrible impacts that cannot be reversed. We need to be guided by science when faced with decisions of such great environmental consequence.

Sir David Attenborough OM FRS
Vice-president, FFI

Executive summary



Diverse Assemblage Gully Canyon. Credit: NOAA Office of Ocean Exploration and Research, Deep Connections 2019

Background and context

Deep-seabed mining: a new frontier

- Deep-seabed mining is a new frontier for extraction of the Earth's natural resources, fuelled by recent discoveries of wide-ranging mineral deposits (including polymetallic nodules and cobalt-rich ferromanganese crusts) and rising demand for their use in high-tech industries including electronics and battery storage.

- Deep-seabed minerals (more than 200 metres water depth) have been touted as essential for a decarbonised future yet other sources do exist (e.g. through untapped recycling potential) as well as new technologies for decarbonisation that are not dependent on metals.

- Mining in shallow water (less than 200 metres water depth) has occurred for decades in a number of locations and the marine ecosystems it impacts are relatively well understood. In contrast, we know next to nothing about the deep oceans, which means it is not possible to determine the impacts of mining with any confidence.

- There is a current rush to establish rights and concessions and gain the exploration licences to start extraction of minerals from the deep sea, with key decisions about regulations permitting commercial deep-seabed mining planned for mid- to late-2020.

- There are 30 current exploration contracts for the deep sea awaiting permitting for exploitation, with different contractors at different stages of development of the technology needed to proceed. These contracts are found in the Western Pacific, the Clarion Clipperton Fracture Zone, The Mid-Atlantic and the Indian Ocean.

- There remains controversy and uncertainty about the methods of deep-seabed mining: none of the technology is being developed to achieve "no serious harm" to the environment and decades of investment in seabed mining concepts has resulted in the development of machines and processes that may be highly impactful.

- Whilst efforts are underway to establish protection for biodiversity in the High Seas, deep-seabed mining has become an increasingly important geo-political issue, driving a number of diplomatic processes competing for seabed claims and an urgent need for High Seas legislation. It is portrayed as an exciting new economic frontier for the "blue economy", which seeks to realise the full economic potential of the ocean.

Deep-sea ecosystems: a largely unexplored realm

- The deep sea is a vast, pristine and largely unexplored area, with a rich biodiversity and biophysical systems that support key processes in carbon sequestration which affect global carbon cycles and climate regulation.

- Marine geosystems are as diverse and dynamic as terrestrial ones, but far more expansive. Changes in ocean systems can have global repercussions because the oceans are connected to one another, and water masses from different seas mix.

- Movements of currents and migratory animals connect all parts of the ocean, making conservation and sustainable use of biodiversity and ecosystems beyond national jurisdiction both complex and dependent on interconnectivity.

- While our perceptions of life on Earth are skewed by our daily encounter with photosynthesis-supported life on land, the deep sea is a fundamentally different environment where sunlight does not penetrate. In deep-sea environments, energy for life is generated through chemosynthesis, where energy from inorganic chemical reactions is used to convert dissolved carbon dioxide into the organic molecules (sugars, fats, proteins, etc.) that are the building blocks of life.

- Productivity fuels life in the ocean, drives its chemical cycles, and lowers atmospheric carbon dioxide. Nutrient uptake and export interact with circulation to yield distinct ocean regimes.
- Research to date indicates the oceans are rich in biodiversity - around 230,000 species of marine plants and animals have been scientifically described, but this represents a small fraction of the number of species that are likely to exist. Even seemingly inhospitable environments have been found to support an array of highly specialised life forms that have evolved to thrive in extreme conditions in the deep sea.
- Hotpots for biodiversity in the deep sea are often associated with deposits of rare minerals (such as cobalt, zinc and manganese) which may be associated with key geomorphologies such as hydrothermal vents and seamounts.

Growing concerns around the potential impacts of deep-seabed mining

- Determining the environmental risks and impact of mineral extraction depends on the knowledge, information and data available. For some mining operations in shallower waters (<200 metres), relatively detailed baseline information on biodiversity exists, allowing an impact assessment to be conducted with acceptable confidence. By contrast, the deep sea remains our least explored and largest environment on the planet. A considerable level of knowledge still needs to be acquired to assess and manage sustainable exploitation of deep-sea resources.
- The potential for environmental impacts through mining the deep seabed was recognised three decades ago but there are growing concerns about our ability to define, measure and mitigate these impacts - an issue exacerbated by our limited understanding of deep-seabed mining ecosystems and oceanic processes, especially in deep water, and a lack of clarity about how marine mining operations may actually harvest resources.
- These environmental concerns have led to calls for a moratorium on deep-seabed mining since 2011[1] by a range of non-governmental and ocean science organisations, and to date a number of national governments have announced their support for precaution and temporary suspension, as have representatives of other marine industries, such as fisheries.[2]

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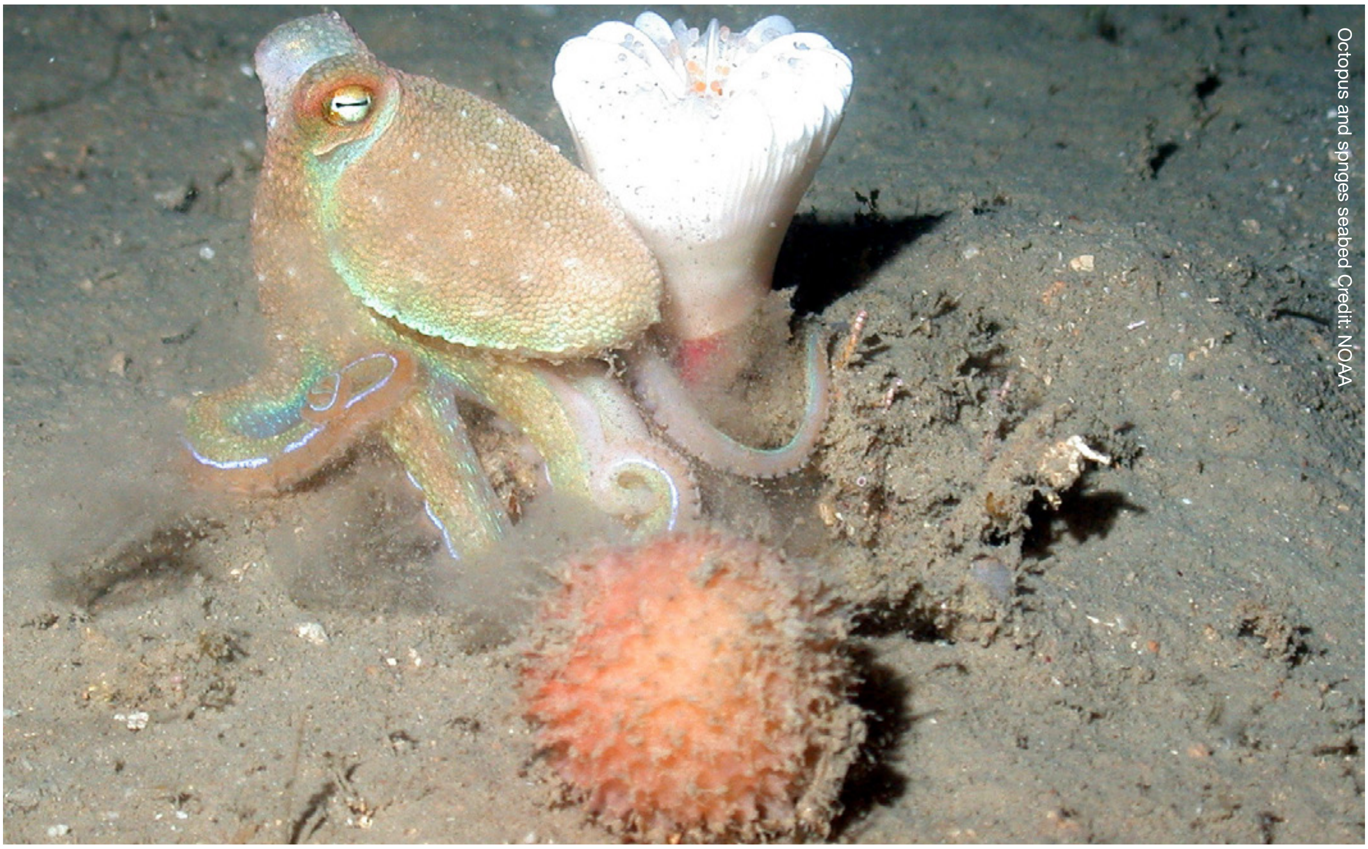
[1] https://wwf.be/assets/RAPPORT-POLICY/OCEANS/UK/WWF-Deep-Sea-Mining-position-2011.pdf; http://www.deepseaminingoutofourdepth.org/about/

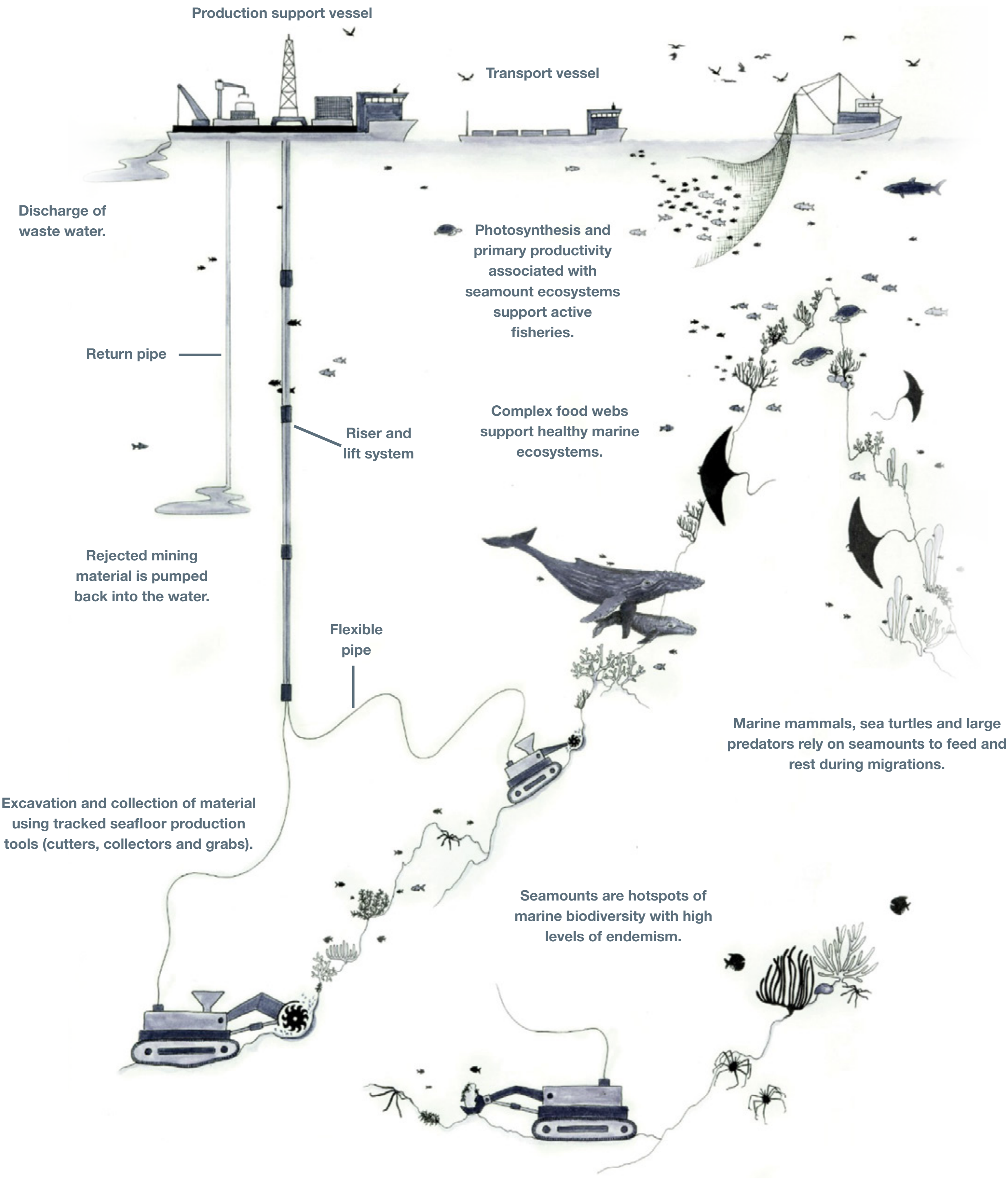
[2] https://www.ldac.eu/images/EN_LDAC_Advice_on_Deepsea_Mining_R.04.19.WG5_May2019.pdf



Octopus and spnges seabed Credit: NOAA

Mining of ferromanganese crusts on slopes and summits of seamounts. Illustration not to scale.

Adapted from Miller, Thompson, Johnston & Santillo (2018) doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

Depth: 800 – 2,500 meters

Purpose, approach and structure of this report

- With the increasing interest in exploration and exploitation of seabed minerals in shallow and deep waters, the rapid pace of development of seabed mining, limited knowledge of deep-sea ecosystems, and the potential for adverse impacts from seabed mining, there is an urgent need for a thorough assessment of whether and how deep-seabed mining could proceed - using the best practice principles routinely applied to terrestrial mining - without causing harm to deep-sea environments and their associated biodiversity, processes and functions.

- This report offers a systematic impact and risk assessment based on a Strategic Environmental Assessment framework which draws on available information to: understand relevant existing and proposed legal and management frameworks; understand the baseline environment; consider technologies and processes under development or proposed for the mining of different mineral resources on the seabed; assess likely impacts of mining of different minerals and their associated ecosystems; and apply possible mitigation and impact management scenarios to objectively deduce the potential for no net loss or net gain of biodiversity.

- The key to this approach is the application of a mitigation hierarchy, which requires prioritisation of avoidance, followed by minimisation and restoration of impacts to reduce residual harm to the environment to achieve a no net loss or net gain outcome. In some cases, offsets or compensation are supported, however impacts to deep-sea biodiversity are considered non-offsettable and, in most cases, immitigable.

- The report covers seabed mining, including mineral extractions in shallow waters to c. 200 metres depth and deep-seabed mining below 200 metres depth. This document does not deal with coastal or near-shore mining.

- This document is divided into three sections:

  PART A sets the context for assessing seabed mining, including key drivers of the industry and constraints to its development, and existing governance structures, policy and regulation relating to the management of marine biodiversity and ecosystems.

  PART B provides an overview of the marine baseline, synthesising available information on deep-sea habitats, their associated biodiversity, mineral deposits and biophysical processes, and considering the role of marine ecosystems in planetary processes.

  PART C presents the major types of deep-seabed mining under development, the proposed methods for mineral extraction, and draws on the available science to assess the potential risks and impacts to marine ecosystems and to determine what possible mitigation actions could be applied to avoid and reduce the extent of harm.

Fluresecent jellie Credit: NOAA

Governance of deep-seabed mining

- Deep-sea mineral deposits occur in various Maritime Zones in both national and international jurisdictions. At present, activities that impact on the seabed, including proposed mineral extraction, are set to be regulated differently depending on whether they are in the High Seas (beyond national jurisdiction) or on continental shelf areas (under a diversity of national jurisdictions).

- The 1982 United Nations Convention on the Law of the Sea (UNCLOS) is the primary legal instrument for the governance of the world's oceans and seas. UNCLOS established the jurisdictional framework for the management of ocean space and defined the rights, duties and responsibilities of States with respect to the use of ocean space and ocean resources - i.e. who can permit and govern marine mining activities (United Nations General Assembly, 1982).

- There is a patchwork of international bodies and treaties that govern ocean resources and human activity in areas beyond any state's national jurisdiction. These governance bodies vary greatly in their mandates. Jurisdictions often overlap, but virtually no mechanisms exist to coordinate across geographic areas and sectors and no existing governance organisation has a comprehensive mandate to effectively manage and conserve ecosystems on the High Seas.


Deepwater coral Credit: NOAA

- UNCLOS dictates that the High Seas (including the seabed and ocean floor and subsoil thereof, beyond national jurisdiction - the Area - is "the common heritage of mankind" and needs to be governed, managed and maintained for the benefit of all mankind. The concept of the common heritage of mankind promotes the uniform application of the highest standards for the protection of the marine environment and the safe development of activities in the Area.

- The role of seabed ecosystems in maintaining the stasis of ocean chemistry and climate regulation suggest that the "common heritage" of the seabed extends beyond its mineral resources to include substantial contributions to biodiversity, climate regulation and other ecosystem services — contributions that may be less quantifiable in terms of projected revenue, but indispensable to human life.

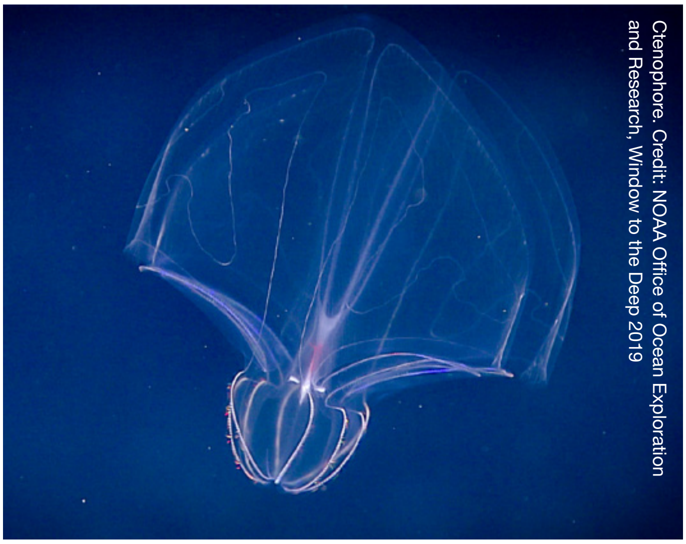
- However, the International Seabed Authority – authorised to act on behalf of mankind in respect of the Area - has interpreted this common heritage as the mineral wealth of the seabed without recognition or due consideration of the broader suite of functions and services the deep sea provides for humanity.

- Currently, there is no robust, precautionary approach in place to safeguard against impacts to biodiversity, and regulations for deep-seabed mining in the Area are only in the early stages of development. Under current International Seabed Authority rules it is necessary for a mining project to conduct an Environmental Impact Assessment (EIA), but there is little legislation in place to ensure minimum standards for EIAs, and no means of monitoring.

Establishing the baseline environment

Deep-sea ecosystems under threat from deep-seabed mining

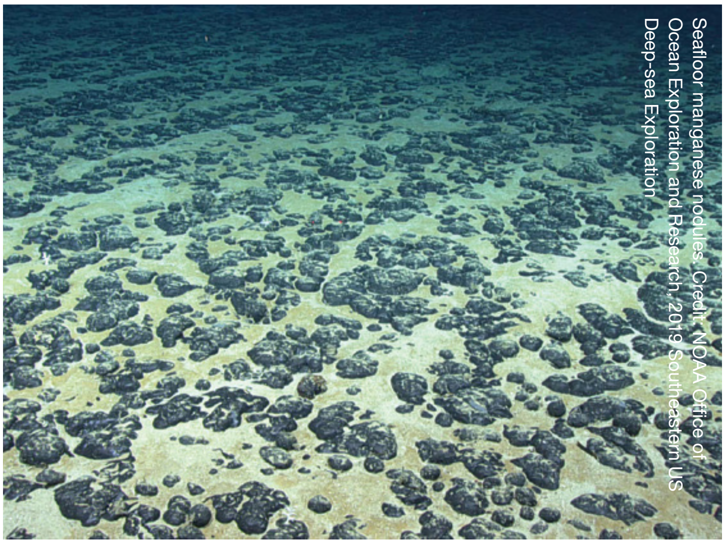
Oceans contain an astounding array of habitats, from the intertidal zone to the hadalpelagic waters more than 6,000 metres below the surface. Given the highly connected nature of the marine environment, it is important to consider the full range of marine habitats within a project's area of influence when conducting a baseline assessment. The report considers estuarine, coastal and deep-sea habitats. Alluvial mining of aggregates and extraction of placer diamonds are typically associated with shallow water habitats to c.180 metres depth along the continental shelf, whereas phosphate mining and the three mineral resource types commonly considered for deep-seabed mining are associated with distinct types of geosystems in waters from 200 metres to more than 6,000 metres depth.



Ctenophore. Credit: NOAA Office of Ocean Exploration and Research, Window to the Deep 2019

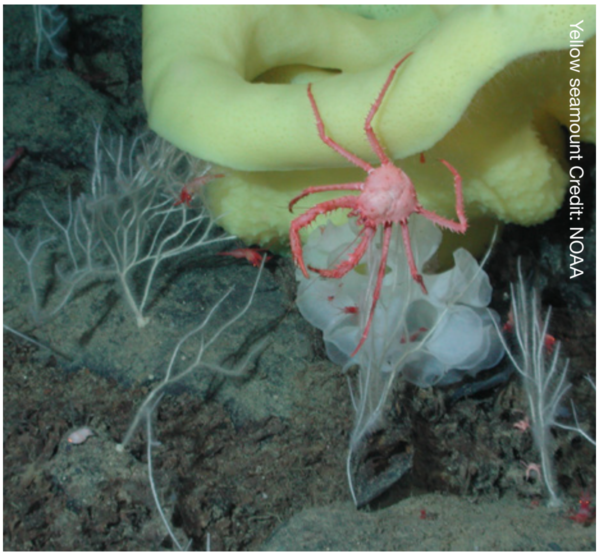
Polymetallic ferromanganese nodules from abyssal plains

- Though the abyssal plains were once assumed to be vast, desert-like environments, research shows they teem with a wide variety of microbial life and other larger creatures.
- They exert significant influence upon ocean carbon cycling, dissolution of calcium carbonate, and atmospheric carbon dioxide concentrations over time scales of a hundred to thousands of years.
- Polymetallic nodules associated with abyssal plains are metallic concretions on the sea bottom which are formed of concentric layers of manganese and iron hydroxides around a core.
- New scientific evidence suggest microbes on polymetallic nodules fix trace metals onto the nodules, contrary or in addition to theories that diagenetic and hydrogenetic processes (how oil and coal are made) are responsible. The removal of trace metals from seawater is likely to stabilise ocean chemistry and maintain healthy oceanic conditions through the balancing of metal-based elements and reducing potentially toxic metal compounds.
- The chemosynthetic microbial communities thriving on nodules and the seafloor are the basis of primary production and life on the abyssal plains. They are found within the seafloor sediment, as bacterial mats on the seafloor, within larger invertebrate organisms in the community, and they act as the base of the food chain for an extensive and unique collection of organisms.
- Polymetallic nodules are targets for mining of a range of elements including cobalt, titanium, strontium, tellurium, and rare earth elements (REEs), copper, nickel, zinc, lithium, aluminium, and cadmium.



Seafloor manganese nodules. Credit: NOAA Office of Ocean Exploration and Research, 2019 Southeastern US Deep-sea Exploration

Cobalt-rich ferromanganese crusts



Yellow seamount Credit: NOAA

- Seamount systems support deep-sea corals that thrive on and around seamounts and host more than 1,300 different species of animals; some are unique to seamounts themselves and some live only on a specific species of coral.
- Seamounts rising into the ocean create obstacles that shape ocean currents and direct deep, nutrient-rich waters up the sloping sides of seamounts to the surface. These factors combine to make seamounts fertile habitats for diverse communities of marine life, including sponges, crabs, sea anemones, commercially important fish, and deep-sea corals. Seamounts also support important fisheries and a diverse range of marine megafauna. Marine mammals, sea turtles and large predators, for example, rely on seamounts to feed and rest during migrations.
- Seamounts are associated with cobalt-rich ferromanganese crusts cobalt-rich ferromanganese crusts, a potential resource a potential resource primarily for cobalt, but also titanium, cerium, nickel, platinum, manganese, thallium and tellurium, among others.
- In low-temperature mineral deposits like cobalt crusts, chemosynthetic and biochemical processes occur – maintaining the stasis of the oceans' chemistry and their ability to regulate the climate as well as metal concentrations.

Polymetallic sulphides from hydrothermal vents, seeps and sulphide massive systems

Cold seep tube worms Credit: NOAA

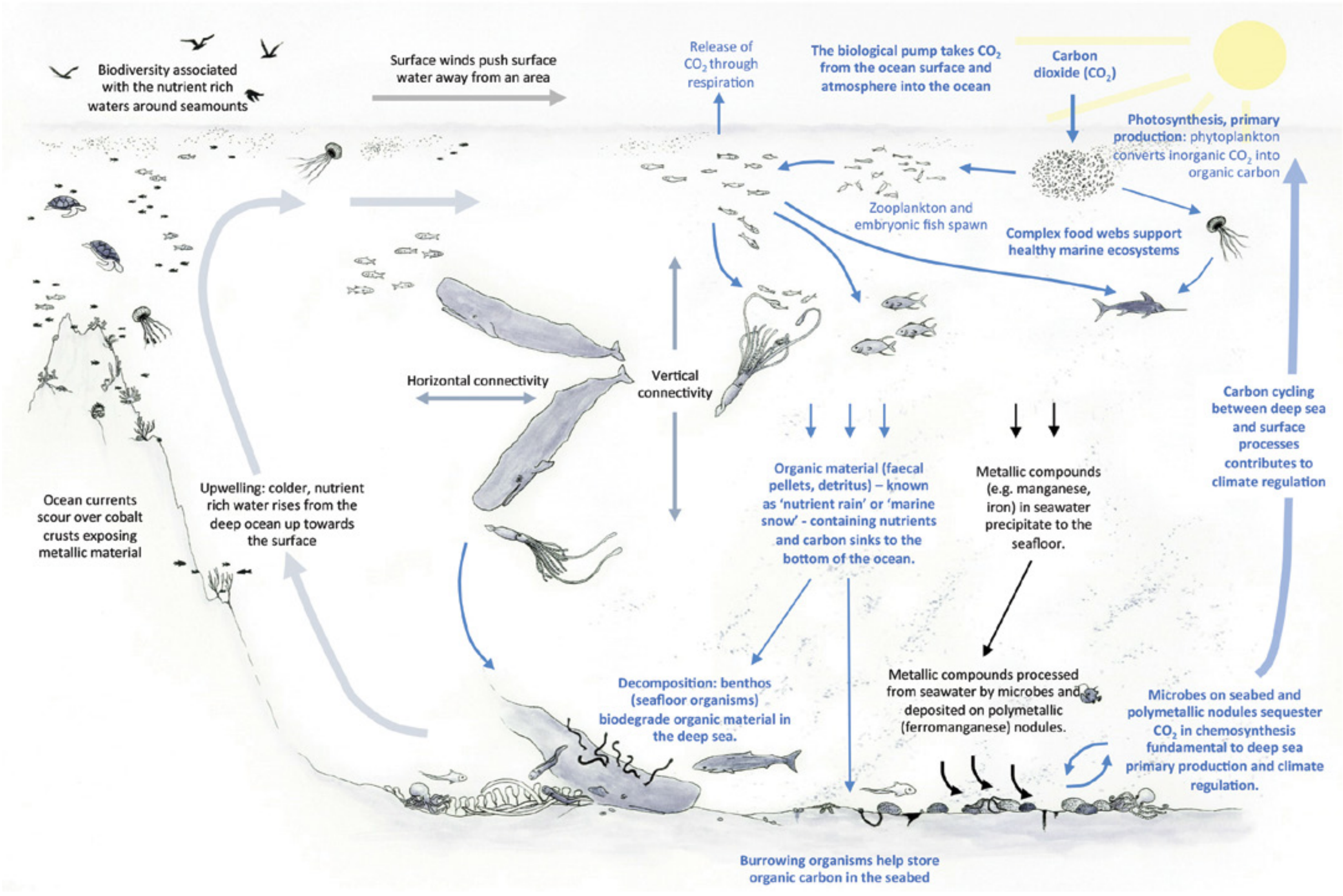
- Deep-sea hydrothermal vents and seeps represent one of the most physically and chemically diverse biomes on Earth, providing a figurative buffet of chemical reactions that can fuel abundant chemosynthesis-driven microbial life. Microbial communities form the basis of life around these systems, supporting extensive and unique communities of highly specialised organisms.
- Globally, the active vent ecosystem is a rare habitat, comprising an estimated 50 square kilometres, that supports high levels of endemism and holds significant ecological importance.
- In addition to their rich biodiversity, hydrothermal vents and seeps constitute important carbon sinks in which microorganisms specifically adapted to these environments consume and sequester carbon and methane, a greenhouse gas with roughly 25 to 50 times the potency of carbon dioxide.
- These ecosystems are a vast genomic repository of unique value to screen for highly specific metabolic pathways and processes. The vent and seep biota thus constitute a unique pool of potential for the provision of new biomaterials, medicines and genetic resources.
- Hydrothermal vents create polymetallic sulphide deposits, which are usually rich in copper and zinc as well as silver, gold, lead, manganese and cobalt.

Ocean processes, currents and connectivity

- Deep-sea ecosystems are globally important: for earth system regulation, climate regulation and climate change mitigation services, fisheries and other ecosystem services, genetic and evolutionary processes, and the maintenance of ocean chemistry and primary productivity.
- Ocean biology is responsible for the storage of more carbon away from the atmosphere than the terrestrial biosphere in a process referred to as the 'biological pump' in which organic matter sinks into the ocean interior where it is returned to dissolved inorganic carbon and nutrients through bacterial decomposition.

- Complex physical processes (involving energy and temperature flux and fluid dynamics) and biochemical processes (involving novel primary production processes such as chemosynthesis) underlie the functioning of the biological pump, balancing ocean chemistry and associated key trace metals driving climate regulation and the ocean's ecological health and function – thereby supporting life on earth. We are yet to fully understand the fundamental biological, geophysical and biochemical processes underpinning these processes
- There is a relationship between the geophysical and biogeological processes that drive the trace element budgets on the planet (i.e. the amount of trace metals available for biological processes). Trace elements fundamental to biological processes (including ion and nutrient transport, reproduction, respiration and photosynthesis) are fixed by microbes on polymetallic nodules. These same trace elements are at the core of deep-seabed mining (e.g. cobalt, manganese, iron, zinc, nickel, tellurium etc.).
- We don't yet understand fundamental biological, geophysical and biochemical processes of the oceans. The implications of disruption of these processes thus requires very precautionary consideration.
- Most ocean ecosystems have no obvious physical boundaries. They are defined by powerful currents that transport nutrients and small marine organisms, and by highly mobile species that can migrate across entire ocean basins for feeding and reproduction. This horizontal and vertical movement connects the open ocean to coastal waters and the deep ocean, links national waters and exclusive economic zones to areas beyond national jurisdiction, and plays a fundamental role in maintaining healthy and productive ecosystems.
- Our interactions with the ocean do not occur in isolation. The impacts we have in one place can have consequences elsewhere, crossing ecological and jurisdictional boundaries. Acknowledging the complex nature of ocean currents and connectivity is fundamental to anticipating and managing risks related to the dispersion of contaminants and sediments, and altered fluid dynamics and nutrient balances resulting from seabed mining and mining processes. Similarly, a lack of dispersion and dilution due to the absence of ocean mixing can exacerbate impacts when localised.

Illustration of oceanic processes including primary productivity and the biological pump, and connectivity. Illustration not to scale.



Credit: Nicky Jenner/FFI

Risks and impacts of seabed mining and options for mitigation

Shallow water

- Shallow water (<200 metres) ecosystems are often highly dynamic due to wave action and input from rivers, and some may be receptive to passive recovery or restoration, especially where natural sedimentation rates are high and biodiversity is adapted to disturbance.

- Direct impacts from shallow water mining include removal and fragmentation of benthic habitats and direct mortality of benthos, mobilisation of sediments and disturbance from noise. Impacts are likely to be more significant from bulk mining of minerals which are dredged at speed from large areas, as opposed to the mining of diamond placer deposits, where a patchwork of small areas are targeted over longer time periods. As with all seabed mining, the severity of impacts to biodiversity will depend upon the sensitivity and uniqueness of the marine environment.

Deep water

- Most deep-sea ecosystems (below 200 metres depth) targeted for mining have some combination of ecological characteristics that make them particularly sensitive to human disturbance, such as being largely pristine, highly structured, very diverse, dominated by rare species and (extremely) slow to recover.

- Direct impacts will result from the physical removal of target material and associated organisms within the mining area leading to the destruction of biota as well as habitat loss, fragmentation, and modification through altered mineral and sediment composition, geomorphology (e.g. sediment destabilisation) and biogeochemical processes (e.g. gas hydrate release).

- Mining activities can upset the chemical energy supplies that fuel microbial life in deep-sea ecosystems, disrupting the ecological functions that microscopic life provides and the amount and type of life that can be supported. Despite their importance, microbial organisms have been somewhat overlooked in planning related to the assessment and evaluation of possible environmental impacts related to deep-seabed mining.

- Impacts on species connectivity as a result of habitat loss or alteration may lead to fragmentation of species and populations, loss of connectivity for migration and demographic connectivity, adverse effects on larval dispersion, and disturbance to reproduction and larval traits.

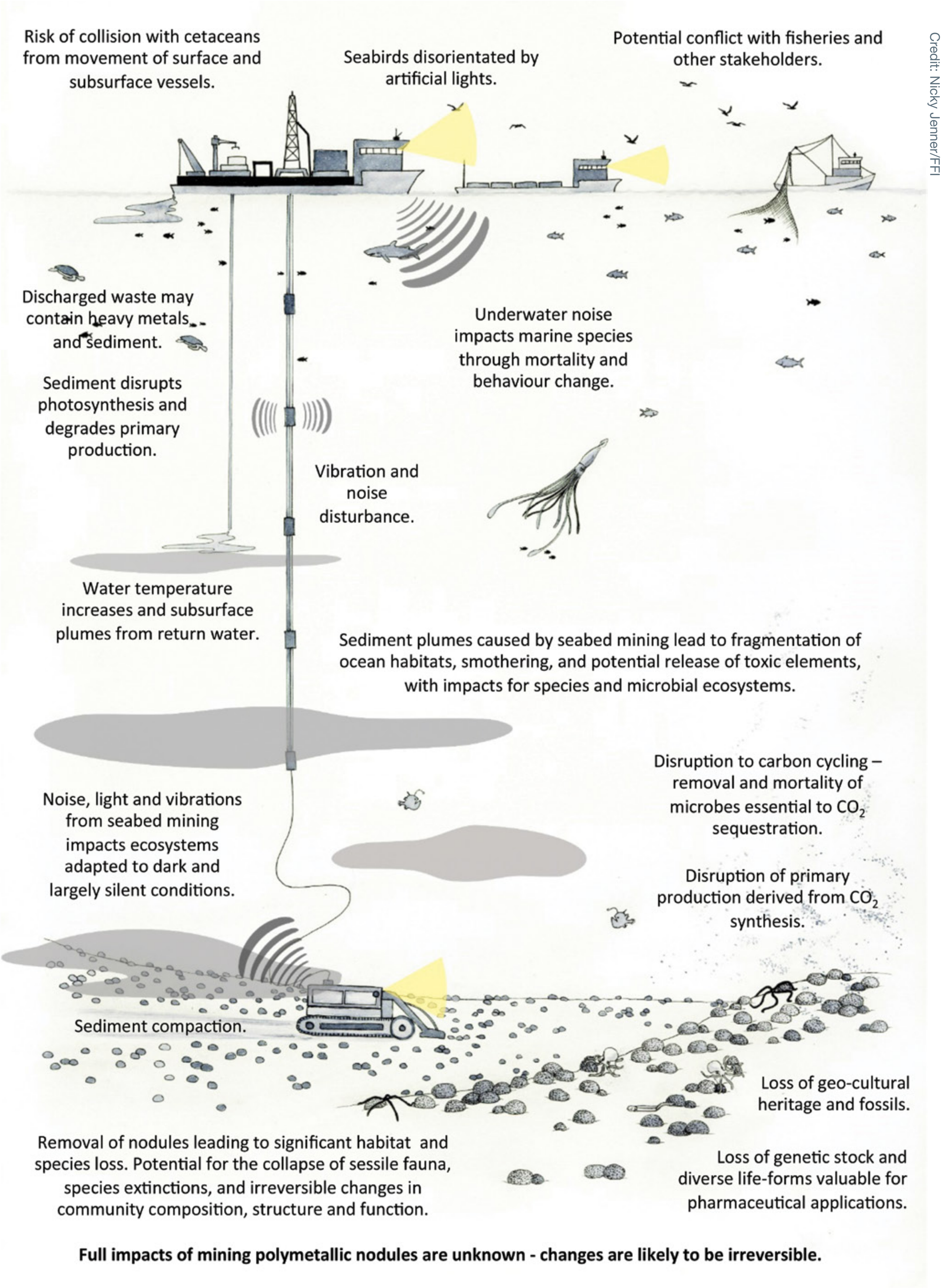
- The loss or disturbance of methanogenic microbial-rich sediments from large scale deep-seabed mining could have implications for the climate. The volume of methane released from the ocean floor is significantly reduced via microbial anaerobic oxidation of methane, leading to the sequestration of carbon in methane-derived carbonates that get buried in the sediments. This interface of geological and biochemical processes limits the emission of this potent greenhouse gas whilst capturing carbon as part of the ocean's biological pump and climate regulation.

- Indirect impacts on the seabed and water column - both within and beyond directly mined areas – are likely to be diffuse and difficult to predict. Impacts include smothering of habitat and species as a result of sediment plumes, interference with feeding activities, and the release and spread of nutrient-rich and toxin-laden water affecting deep-sea and pelagic ecosystems. Other potentially harmful diffuse effects include those from light, noise and electromagnetic disturbance.

- The scale over which these impacts are likely to occur is largely unknown and most of the effects remain unstudied. The highly connected and dynamic nature of the ocean and the complex biochemical and physical processes that drive ecosystem function implicate widespread impacts that are likely to be very difficult to control and contain.

Potential risks and impacts of mining polymetallic nodules on abyssal plains. Illustration not to scale.

Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0

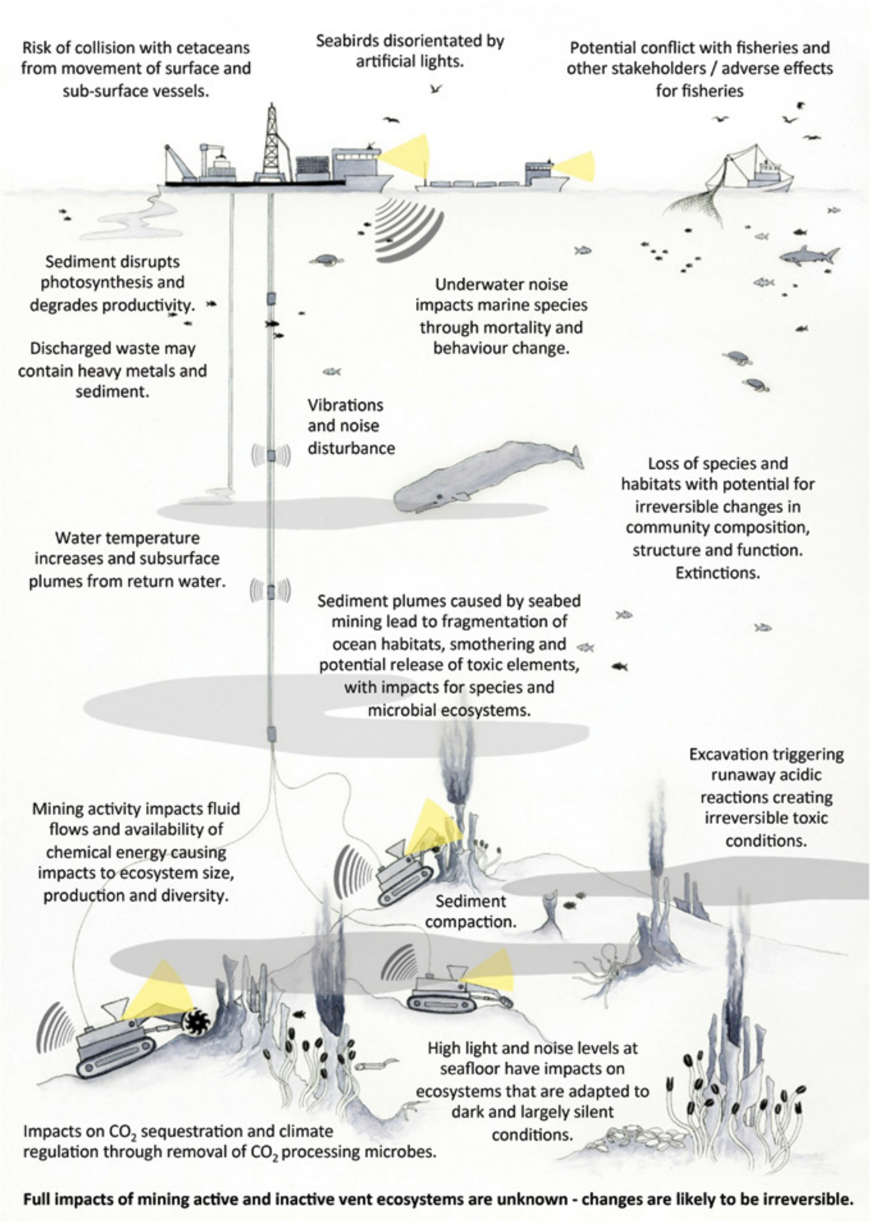


Credit: Nicky Jenner/FFI

- The consequences of disruption to large-scale processes through deep-seabed mining are poorly understood. Interfering with the geophysical and biogeological processes that drive the trace element budgets on the planet could have ramifications we cannot currently understand, and at timescales and over areas that may be difficult to comprehend. Industrial scale removal and mobilisation of such trace elements could cause disruption to ocean chemistry, the biological pump, ecosystem function (primary production and dependent food webs) and climate regulation.
- The implications of mobilisation and disturbance of these global nutrient budgets needs very precautionary consideration as the potential knock-on effects upon ocean health and ecosystem function could be considerable.
- Impacts for ecosystem functioning as a result of sediment burial on soft and hard substrate ecosystems and through physical alteration and removal of ecosystem niche habitats and connectivity.
- Ecosystem stress through disturbance of food and energy flows through deep-sea ecosystems, changing the ocean chemistry through depletion of nutrients fundamental to physiological processes.

Potential risks and impacts of mining seafloor massive sulphides on hydrothermal vents. Illustration not to scale.

Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

Application of the Mitigation Hierarchy

Shallow water

- Avoidance and minimisation of impacts to sensitive biodiversity can be achieved through spatial and temporal planning, e.g. adapting timing and location of operations to avoid whale migrations
- In dynamic shallow water ecosystems, there is potential for passive recovery or restoration. For diamond extraction and aggregate mining, which disturb relatively small areas in a patchwork, recovery of ecosystem function has been observed.
- Physical recovery is generally dependent on substrate type, sedimentation rates and the strength of ocean currents, with fastest restoration in fine muds and sandy deposits. Whilst evidence suggests a recovery in the composition, structure and function of benthic ecosystems, and the potential for no net loss of biodiversity, ongoing long-term monitoring rremains important to understand the the long-term recovery. There may be potential to apply biodiversity offsets to contribute to biodiversity gains in shallow water ecosystems affected by mining, depending on the national legal and institutional frameworks, governance opportunities and opportunity for biodiversity and ecosystem services conservation.

Deep water

- Deep-seabed mining is likely to result in significant biodiversity loss, and the significance of this to ecosystem function is not known.
- In the face of uncertainty and absence of knowledge a precautionary approach and strict adherence to the mitigation hierarchy is essential.
- **Avoidance** is the only way to achieve no harm or no net loss outcomes as impacts are immitigable in time and space. Best options are through marine spatial planning and setting aside areas of high biodiversity and ecosystem service value as 'no go' areas. To date, a number of countries (including Canada, Mexico, Portugal and the United States) have created Marine Protected Areas (MPAs) to protect hydrothermal vent ecosystems.
- **Minimisation** could be achieved through application of best designed mineral extraction technology prescribing no net loss and no harm objectives. To date, proposed minimisation measures include designing seabed mining tools to minimise sediment disturbance; returning sediments to the seabed mining location; screening sediments for harmful compounds prior to return to the seabed; minimising the intensity and frequency of noise and light both at the sea surface and at depth; and stopping mining when large numbers of target organisms are detected; and using the latest mining technology to ensure full resource extraction to minimise the need for re-mining an area.
- **Restoration** has rarely been attempted and typically only in shallow waters. Restoration at depth is unlikely through any means other than by passive restoration over time. Geological time frames apply in the deep sea – millennia to millions of years (nodules take >10 million years to form)
- **Offsetting** is impossible for biodiversity in deep-sea environments. This results from the vulnerable nature of deep-sea environments to mining impacts, currently limited technological capacity to minimise harm, significant gaps in ecological knowledge, and uncertainties of recovery potential of deep-sea ecosystems

Purple octopus 1,550m. Credit: NOAA INDEX 2010 "Indonesia-USA Deep-Sea Exploration of the Sangihe Talaud Region"

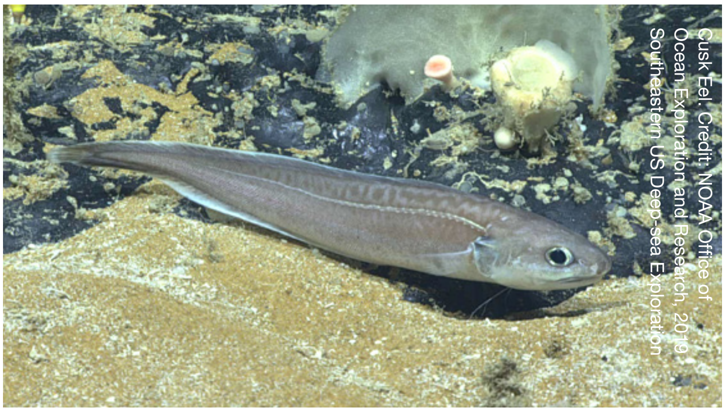
Conclusions

Shallow water

- There is a growing body of evidence to suggest that, under certain conditions and contexts, some forms of shallow seabed mining could take place with no net loss of structure, composition and function of the habitats associated with shallow seabed extraction. This requires the strict adherence to best practice standards and principles throughout the life of operation, including commitment to no net loss of biodiversity, an adaptive approach that is receptive and responsive to the latest advances in science and technology, and ongoing monitoring and adaptive management. The 'net' in no net loss acknowledges that there is an impact and there are losses but that these can be mitigated in such a way that losses can be balanced with gains elsewhere.
- Physical recovery in shallow seabed sites which have been mined for aggregates and where dredging has ceased is generally dependent on substrate type and the strength of tidal currents, with fastest restoration in fine muds and sandy deposits. Restoration of open coastal habitats subject to dredging is only possible by the removal of dredging operations, prevention of other impacts such as the use of heavy bottom gear by fishing vessels, and then allowing the system to recover over time through natural processes.
- Similar impacts and restoration profiles occur for marine placer diamond extraction, with removal of benthic sediments and return to the water column producing sediment plumes. Whilst evidence suggests a recovery in the composition, structure and function of benthic ecosystems, and the potential for no net loss of biodiversity, ongoing long-term monitoring remains important to understand the long-term recovery.

Deep water

- The potential effects of marine phosphate (or any similar bulk sediment) mining operations on marine ecosystems is likely to be considerable whilst potential for achieving no net loss of biodiversity remains debated and is unlikely for phosphate mining due to bulk removal of substrate.
- This large-scale review reveals evidence for significant, and currently immitigable impacts of deep-seabed mining on biodiversity.



Cusk Eel. Credit: NOAA Office of Ocean Exploration and Research, 2019 Southeastern US Deep-sea Exploration

- The report raises the importance of poorly understood biogeochemical processes that drive ocean chemistry and ocean ecological function, including primary production and trace metal fixation by chemosynthetic organisms beyond the photic zone.
- It further showcases recent science which builds a strong case for the important role of deep-sea biological systems in driving planetary systems of carbon sequestration.
- Deep-seabed mining has the potential to cause disruption and potential collapse of these processes and could exacerbate our current crises of climate change and biodiversity loss, if it is developed without due care and consideration for knock on effects on benthic carbon cycle processes and on methane storage. Impacts that are likely to be irreversible.
- The application of a mitigation hierarchy approach in this assessment reveals that the impacts of deep-seabed mining cannot currently be effectively mitigated or managed. Combined with the considerable gaps in the knowledge of ocean complexity and how this relates to earth-system processes, gaps in basic baselines of the biodiversity and ecosystem function of the ocean, and clear indications within the existing science base that impacts are likely to be considerable, there is an inadequate basis on which to grant mining exploitation contracts.

Recommendations

This report recommends and calls on the international community, the International Seabed Authority and those attempting to progress seabed mining to:

1) Ensure all decision-making associated with the exploration and exploitation of seabed minerals is driven by a **commitment to no net loss of biodiversity.**
2) Develop Standards and Principles that **require the application of the Precautionary Principle**, takes into account an **ecosystem-based approach** considering the health, function and resilience of the ocean and recognises the roles of the ocean in regulating climate.
3) Address the current applicability of the interpretation and intent of **UNCLOS** and the principle that seabed mining should be **for the good of all humankind.**
4) Promote a **globally harmonised governance system** for protecting the seabed to avoid fragmented, inconsistent approaches to regulating activities in different zones that takes into account stressors such as ocean acidification, climate change and pollution.
5) **Promote circular economy** approaches to reduce the demand of raw primary materials.
6) Incorporate minerals into **climate and energy planning.** Given the centrality for minerals and metals to the future diffusion of low-carbon technologies, materials security should be actively incorporated into formal climate planning.
7) Further develop the robust business case that recognises and **supports new technologies** such as hydrogen fuel cells and hybrid ion capacitors which are not dependent on metal-rich materials. We need to **leapfrog to new alternative low-metal futures** in addition to low-carbon futures.
8) Develop and implement a **research agenda** for addressing key scientific questions that must be **answered before commercial-scale mining** commences
9) In order to a**dequately assess the impacts of deep-seabed mining and establish the potential for effective mitigations,** address a number of **fundamental knowledge gaps** to establish levels of certainty fit to inform decision making and policy.[3]
10) **Ensure** the application of the mitigation hierarchy and **adherence to no net loss,** and ideally net gain **commitments** for biodiversity and ecosystem services for all seabed mining.
11) Develop **effective and precautionary legislation** which clearly promotes **'no-go'** status for habitats and situations where no net loss is considered unlikely and, via the r**egional environmental management planning** process, large representative areas identified according to scientific criteria are ruled off-limits to seabed mining.
12) Undertake a **full review of the International Seabed Authority** including governance and accountability, conflicts of interest, resourcing and competencies for regulatory activities, such as contract reviews, inspections, audits, environmental monitoring, and enforcement.
13) Critically review the **scope and objectives of the proposed International Seabed Authority Mining Code** to ensure incorporation of a process for protecting biodiversity and assessing and avoiding significant environmental impacts that (a) is responsive to independent scientific advice, (b) offers stakeholders a meaningful opportunity for participation, (c) enables rejection of mining proposals where the impacts are deemed too great or too uncertain, and (d) provides for the potential closure of large, ecologically important areas of the deep sea to mineral extraction.

Based upon the evidence assessed in this report, **a moratorium on deep-seabed mining (>200 metres depth) is strongly recommended** until at least such time as these recommendations have been fulfilled and exploitation technologies and operational practices are able to demonstrate no serious harm to the environment and no net loss of biodiversity.

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[3] This includes but is not limited to: ongoing scientific research and monitoring of the oceans to better understand the diversity and biomass of life associated with seabed ecosystems; the life cycles of highly mobile marine organisms; nutrient cycling in deep water ecosystems; interactions between mineral deposits and biodiversity; carbon sequestration and cycling by seabed organisms; trace metal and mineral cycling; the processes and risks of runaway acidic reactions associated with sulphide minerals; deep ocean hydrography and the implications on ecosystem function of changing topography by removal of substrates; the extent and impact of sediment plumes on biodiversity and ecosystem services; the responses of seabed life to light, noise, vibration and electromagnetism.

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Definitions and Terms used in the Report

Definition of terms used in the report.
Readers of this report are also referred to the A-Z of Biodiversity Terms.

Adaptive management. A structured, iterative process of decision making that incorporates new information and achieves management goals by managing uncertainty and by reducing uncertainty over time through environmental monitoring and assessment. For example, as more specific information is obtained concerning habitat distribution, population connectivity and the scale of human impacts, the size and distribution of Chemosynthetic Ecosystem Reserves may be modified to achieve management goals.

The Area. The seabed (that is, the ocean floor and subsoil thereof) beyond the limits of national jurisdiction. The Area is a legal term contained within the United Nations Convention on the Law of the Sea. See also “Areas Beyond National Jurisdiction” and “High Seas”.

Areas Beyond National Jurisdiction. The seabed (that is, the ocean floor and subsoil thereof) beyond the limits of national jurisdiction and/or the water column beyond national jurisdiction; that is any portion of the sea that lies beyond national jurisdiction. See also “High Seas” and the “Area”.

Authigenic carbonate. A carbonate precipitate structure (pebbles, rocks, boulders, mounds) typically produced by activity of anaerobic methane-oxidizing microbes at seeps.

Biodiversity. The diversity of life assessed at multiple levels, for example, ecosystem, habitat, community, species, population and genetic.

Biogeochemistry. A scientific discipline that studies the integration of biological, geological, chemical and physical process and reactions, with a focus on systems that may be driven by or have an impact on biological activity.

Biogeography. The distribution of species and assemblages over space and time, and the factors that influence these distributions.

Biogeographic province. A fundamental biogeographic unit characterized by broad-scale taxonomic similarities; turnover of major taxa is observed between provinces.

Bioprospecting. The search for genetic and biochemical resources for commercial purposes (for example, for therapeutic agents, cosmetics, biochemical catalysts and substances used in other commercial industries).

Bioregion (or ecoregion). Regions within biogeographic provinces with similar community structure (that is, species composition and relative abundance) and environmental conditions (for example, oceanographic, geologic and geochemical).

Chemoautotroph. Organisms that derive their energy from chemical reactions and synthesise all necessary organic compounds from carbon dioxide. Chemoautotrophs use inorganic energy sources such as hydrogen sulphide, elemental sulphur, ferrous iron, molecular hydrogen and ammonia.

Chemoautotrophy. Production of organic matter independently of photosynthesis and sunlight through the oxidation of reduced chemical compounds.

Chemosynthetic Ecosystem Reserve (CER). Areas of the seabed managed to achieve the conservation goal of protecting natural diversity, ecosystem structure, function, and resilience of chemosynthetic ecosystems.

Chemosynthetic Ecosystem Reserve (CER) Networks. CER Networks within a bioregion or biogeographic province include multiple CERs with some level of connectivity (that is, exchange of organisms) among components of the network, managed together to achieve shared-use goals and objectives.

Chemosynthetic Ecosystem. An ecosystem that depends on microbial primary production based on chemoautotrophic processes.

Community composition. The list of species (taxa) occurring within a community.

Community structure. The composition, relative abundance, trophic structure, diversity and size structure of species (or higher-level taxa) occurring in a community.

Connectivity - population. Linkage between species or populations through larval or other dispersive stages, resulting in the transfer of individuals and genetic material. By definition, connectivity plays an important role in sustaining metapopulations.

Connectivity - ecosystem. Linkage between ecosystems through transfer of organisms, materials and energy from one ecosystem to another. Ecosystem connectivity can play an important role in sustaining the structure, function and productivity of an ecosystem through transfers from donor to recipient ecosystems.

Deep sea. The deep sea starts where the sunlight starts to fade, around 200m below the surface of the ocean. Natural light does not penetrate the deep sea.

Diagenetic. The process that describes physical and chemical changes in sediments caused by increasing temperature and pressure as they get buried in the Earth's crust. As the rock is carried deeper by further deposition above, its organic content is transformed into kerogens and bitumens.

Ecologically and Biologically Significant Areas (EBSA). Areas which, through scientific criteria, have been identified as important for the healthy functioning of our oceans and the services that they provide. An EBSA is an area of the ocean that has special importance in terms of its ecological and biological characteristics: for example, by providing essential habitats, food sources or breeding grounds for particular species. In 2008, a process to recognise these special areas was put in place by the United Nations Convention on Biological Diversity (CBD). Based on a set of seven scientific criteria, this process provides a framework to methodically and objectively describe those areas of the ocean that are crucial to the healthy functioning of the global marine ecosystem (www.Gobi.org).

Ecological Function. Ecological functioning reflects the collective life activities of plants, animals, and microbes and the effects these activities (e.g., feeding, growing, moving, excreting waste) have on the physical and chemical conditions of their environment. Ecological functions (sometimes also referred to as ecosystem processes or ecological processes) are an integral part of biodiversity, and can thus be broadly defined as the biological, geochemical and physical processes that take place or occur within an ecosystem.

Ecosystem. Functional unit consisting of biotic and abiotic components linked together through factors including nutrient cycles, energy flow, species-habitat associations.

Ecosystem-based management. A management approach that considers the whole ecosystem– including human dimensions–to achieve management goals.

Ecosystem services are the benefits that people derive from ecosystems and which make human life both possible and worth living. They are underpinned by inherent biodiversity values. Ecosystem services are generally classified as:

1. **Provisioning services –** goods or products obtained from ecosystems such as biological raw materials (limestone etc.) and food (fish, octopus, seaweed etc.)

2. **Regulating services -** benefits obtained from the regulation of ecosystem processes such as flood attenuation, climate regulation and waste attenuation.

3. **Cultural services -** nonmaterial benefits people obtain from ecosystems such as recreation, sense of place.

4. **Supporting services -** natural processes that maintain the other services such as primary production and nutrient cycling. In the deep ocean, these are most likely fundamental ecosystem function processes and those important to long term ocean health.

Ecosystem structure and function. The components (biotic and abiotic), connections, processes and services that occur within an ecosystem. Key elements include trophic components and pathways, productivity and nutrient cycling.

Environmental and Social Impact Assessment (ESIA). A process for predicting and assessing the potential environmental and social impacts of a proposed project, evaluating alternatives and designing appropriate mitigation, management and monitoring measures.

Exclusive Economic Zone (EEZ). An area of coastal water and seabed within a certain distance of a country's coastline, to which the country claims exclusive rights for fishing, drilling, and other economic activities.

Habitat heterogeneity. The variety, relative abundance and spatial configuration of habitat types (based on geological, geochemical, physical and biological parameters) found in an environment.

High Seas. A legal term from the United Nations Convention on the Law of the Sea to mean the water column of oceans, seas, and waters beyond national jurisdiction. As a legal term, the High Seas do not include the seabed and its resources. See also "Areas Beyond National Jurisdiction" and the "Area".

Hydrogenetic. The precipitation of metals directly from seawater.

Hydrothermal vent. An ecosystem associated with submarine volcanic systems and the subsurface reaction of seawater and rock at high temperatures that delivers reduced chemicals to the seafloor. These chemicals fuel microbial chemoautotrophic production and methanotrophy that in turn support specialized metazoan communities distinct from the background community. Vents comprise the full cycle of hydrothermal activity, from inception of venting and microbial primary productivity through successional stages that ultimately culminate in cessation of fluid flow and relict or fossil deposits

Impacts.

> **Direct impact**s are the physical footprint of project activities (including project infrastructure and the incremental transportation and energy infrastructure required to support it) plus the area affected by emissions and effluents.
>
> **Indirect impacts** the physical footprint of non-project activities in the surrounding area that are caused or stimulated by the project plus the area affected by their emissions and effluents.
>
> **Cumulative impacts** the overall impacts occurring in the project seascape caused by the project and non-project activities (related and unrelated to the project), generally including clusters of projects, land use change trends, and/or foreseeable developments.

Macrofauna. Small invertebrates living within the benthic zone, typically 500 microns - 2cm in sizeManagement unit. A broad-scale marine area that takes into account fundamental natural and human boundaries for the purpose of coordinated resource use and habitat protection.

Marine/Maritime Spatial Planning (MSP). A spatially-based management approach that engages multiple users to make informed and coordinated decisions about human uses of marine ecosystems and the conservation of marine biodiversity and ecosystem structure and function.

Marine Protected Area (MPA). Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment.

Megafauna. Animals more the 2cm in size.

Meiofauna. Animals between 32 and 300 microns in size.

Metapopulation. A group of spatially separated populations of the same species that interact through exchange of individuals (for example, via migration and larval recruitment). Although no single population may guarantee the long-term survival of a given species, the combined effect of many populations may accomplish this.

Methanotrophy. The process of carbon dioxide reduction to methane as a source of energy by methane-producing bacteria, especially archaea.

Mitigation. Methods for moderating or compensating for the force or intensity of an impact to a species assemblage or ecosystem.

Mitigation hierarchy. The mitigation hierarchy is a tool designed to help users limit, as far as possible, the negative impacts of development projects on biodiversity and ecosystem services. It involves a sequence of four key actions—'avoid', 'minimise', 'restore' and 'offset'—and provides a best practice approach to aid in the sustainable management of living, natural resources by establishing a mechanism to balance conservation needs with development priorities (Cross Sector Biodiversity Initiative (CSBI), 2015).

No net loss and net positive A target of 'no net loss' for biodiversity aims to counterbalance adverse impacts of a development project or programme by positive actions that avoid and minimise, then restore and if necessary, offset biodiversity such that there is no overall reduction in the type, amount or condition of biodiversity. It implies a legacy of no overall harm compared to what would have occurred in the project's absence. A net positive outcome for biodiversity is achieved when there is a positive impact on biodiversity that not only balances but exceeds losses caused by development impacts.

Natural Conservation Unit. For individual species, Natural Conservation Units are defined by genetic markers as areas that share similar genetic diversity within a species. Natural Conservation Units may or may not be shared across species, and are often determined by scales of dispersal and connectivity.

Oxygen minimum zone or oxygen depleted zone. Also known as the shadow zone, the oxygen minimum zone [OMZ] is the lowest zone of oxygen concentration in the ocean's seawater. Depending on local circumstances OMZs happens at depths of approximately 200 to 1,500m [660-4920ft]. OMZs are normally found along the western coast of continents hence found worldwide. Biological and physical processes interplay concurrently to create them: biological processes lower the oxygen concentration whereas physical processes restrict the mixing of this water with the surrounding waters. This creates a pool of water in which the concentration of oxygen falls to below 2mg/l from the normal range of 4-6m/l. (www.worldatlas.com)

Placer deposit or **placer.** A surficial deposit containing economic quantities of valuable minerals. The minerals found in placer deposits are those which have a high density and are resistant to chemical weathering and physical abrasion, such as gold, platinum, magnetite, chromite, ruby, diamonds and so on. They can be concentrated by various sedimentary processes.

Precautionary Principle and supporting Precautionary Approach. A strategy to cope with possible risks where scientific understanding is yet incomplete. A precautionary approach emphasises preventive action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possibly harmful actions; and increasing public participation in decision making (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240435/)

Different stakeholders, experts and jurisdictions apply different definitions of the principle, mainly depending on the degree of scientific uncertainty required for the authorities to take action (https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_IDA(2015)573876)

Principle 15 of the Rio Declaration states that: "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 scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Resilience. In ecology, resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly.

Restoration. The act, process or result of returning a degraded ecosystem to a condition that resembles as closely as possible the pre-disturbance state. Alternatively, recovery of selected pre-disturbance attributes may be a restoration goal.

Seafloor Massive Sulphide (SMS). Deposits that may be rich in copper, gold, zinc and other metals, generally created as a result of past or present hydrothermal vent activity.

Seep. A cold seep is an area of the ocean floor where hydrogen sulphide, methane and other hydrocarbon-rich fluid seepage occurs, often in the form of a brine pool. Also known as methane seeps, they occur along continental margins where reduced methane and sulphide emerge from ocean sediment. Seeps host seafloor ecosystems fuelled primarily by chemoautotrophic production based on hydrocarbons generated by microbial and/or thermogenic degradation of organic material. Active seeps typically support intense microbial production by which support structure-forming, symbiont-bearing tubeworms, mussels, clams, sponges and snails. Inactive seeps consist of exposed or buried carbonates, often with fossilized seep organisms.

Shallow water. The area from the low water mark on the continental shelf down to a maximum of 200 metres water depth.

Strategic Environmental Assessment (SEA). A Strategic Environmental Assessment is a structured assessment that helps to better protect the environment, aims to ensure that any development is sustainable, and increases opportunities for public participation in decision making. It ensures that expert views are sought at various points in the preparation process from the public and the consultation authorities.

Thermocline. A thermocline is a thin but distinct layer in a large body of fluid in which temperature changes more rapidly with depth than it does in the layers above or below. In the ocean, the thermocline divides the upper mixed layer from the calm deep water below.

Vulnerable Marine Ecosystems. Marine ecosystems which may be vulnerable to damage from fishing activities because of their physical and functional fragility. In 2006, the UN General Assembly invited the Food and Agriculture Organization of the United Nations (FAO) to consider creating a global database of information on Vulnerable Marine Ecosystems (VME) in marine Areas Beyond National Jurisdiction (ABNJ), to assist States in assessing any impacts of bottom fisheries on these benthic ecosystems (www.fao.org).

Vulnerability. Vulnerability refers to how susceptible an ecosystem is to stress (which may be natural or man-made.

Vulnerable Marine Ecosystems. Marine ecosystems which may be vulnerable to damage from fishing activities because of their physical and functional fragility. In 2006, the UN General Assembly invited the Food and Agriculture Organization of the United Nations (FAO) to consider creating a global database of information on Vulnerable Marine Ecosystems (VME) in marine Areas Beyond National Jurisdiction (ABNJ), to assist States in assessing any impacts of bottom fisheries on these benthic ecosystems (www.fao.org).

Acronyms and Abbreviations

APEI	Areas of particular environmental interests
BAT	Best available technology
BES	Biodiversity and ecosystem services
BPEO	Best Practicable Environmental Option
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCFZ	Clarion Clipperton Fracture Zone
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CDB	United Nations Convention on Biological Diversity
CER	Chemosynthetic Ecosystem Reserve
CITES	(The Conference of Parties to) The Convention on International Trade in Endangered Species of Wild Fauna and Flora
DOSI	Deep Ocean Science Initiative
DSM	Deep seabed mining
EBSA	Ecological and Biologically Significant Areas
EC	European Community
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
FAO	Food and Agriculture Organization of the United Nations
GFCM	General Fisheries Commission for the Mediterranean
IATTC	Inter-American Tropical Tuna Commission
IMO	International Maritime Organization
IWC	International Whaling Commission
IBAT	Integrated Biodiversity Action Tool
ICCAT	International Commission for the Conservation of Atlantic Tuna
IFC	International Finance Corporation
IMO	International Maritime Organization
IOTC	Indian Ocean Tuna Commission
IPCC	Intergovernmental Panel on Climate Change
ISA	International Seabed Authority
ITLS	International Tribunal for the Law of the Sea
IWC	International Whaling Commission
MAP	Mediterranean Action Plan for the Barcelona Convention
MAR	mid-Atlantic Ridge
MH	Mitigation hierarchy
MIDAS	Managing Impacts of Deep-seA reSource exploitation
MPA	Marine Protected Area
MSP	Marine Spatial Planning
NAFO	Northwest Atlantic Fisheries Organization
NEAFC	North East Atlantic Fisheries Commission
NOAA	National Oceanic and Atmospheric Administration
NPAFC	North Pacific Anadromous Fish Commission
NPFC	North Pacific Fisheries Commission
OSPAR	OSPAR Commission (from the Oslo and Paris Conventions)
SEAFO	South East Atlantic Fisheries Organization
SIOFA	South Indian Ocean Fisheries Agreement
SPREP	Secretariat of the Pacific Regional Environment Programme
SPRFMO	South Pacific Regional Fisheries
WCPFC	Commission Western and Central Pacific Fisheries

Introduction

Oceans and climate change Credit: NOAA

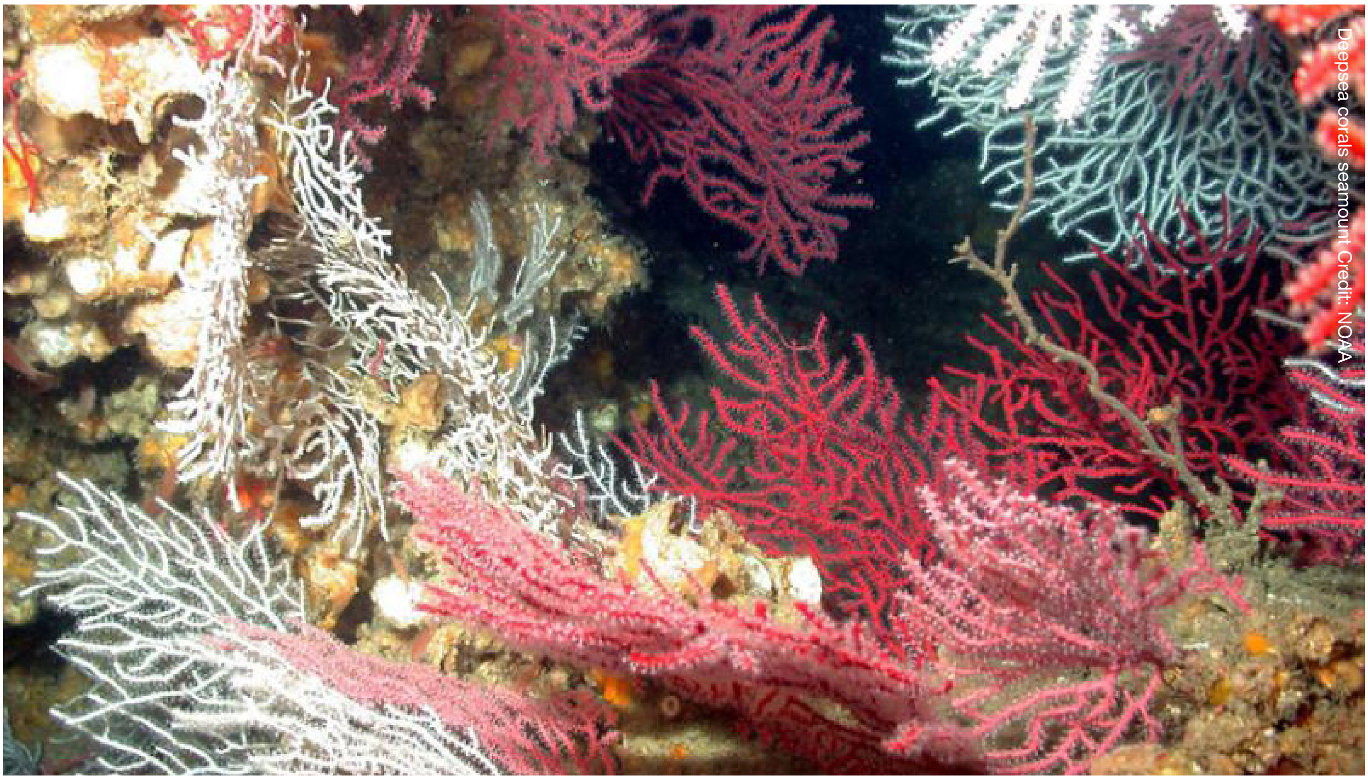
Our oceans

Oceans dominate the planet. They cover 70% of the Earth's surface at an average depth of 3,700 metres and contain 97% of all the planet's water.

Oceans constitute over 90% of the habitable space on the planet, and display an astounding array of habitats, from the intertidal zone to the mid ocean ridges, and from the photic zone at the surface of the sea down to the hadalpelagic waters below 6,000 metres depth.

As a result, oceans are biologically diverse: from single celled organisms which form the first layer of the food chain to the largest animals on earth - around 230,000 species of marine plants and animals have been scientifically described. Yet this known biodiversity only represents a small fraction of the number of species that are likely to exist (Block *et al*., 2011).

The ocean has a much higher phylogenetic diversity than on land: there are 28 phyla[4] living in the sea, of which 15 are exclusively marine (this compared to 11 terrestrial phyla). Exclusively marine phyla include the echinoderms (starfish and their relatives), ctenophores (comb jellies), hemichordates (acorn worms) and echiurans (trumpet worms).


Deepsea corals seamount Credit: NOAA

Marine ecosystems can be very productive and highly diverse within concentrated areas, such as coral reefs, which are recognised as biodiversity hotspots. On some tropical coral reefs, there can be 1,000 species per square metre. Others, such as the abyssal plain, are spatially more homogenous yet contain one of the largest reservoirs of biodiversity on Earth, spread at low density over a vast area (Rex and Etter, 2011).

While our perceptions of life on Earth are skewed by our daily encounter with photosynthesis-supported life on land, the deep sea is a fundamentally different environment where sunlight does not penetrate. The majority of deep-sea life relies on the fall of particles from the sunlit waters above. In addition, in deep-sea environments, energy for life is also generated through *chemosynthesis*, where energy from inorganic chemical reactions is used to convert dissolved carbon dioxide into the organic molecules (sugars, fats, proteins, etc.) that are the building blocks of life.

4. Phyla – plural of phylum, a taxonomic ranking that comes third in the hierarchy of classification, after *domain* and *kingdom*. Organisms in a phylum share a set of characteristics that distinguishes them from organisms in another phylum

Oceans are essential to our survival and well-being. A common misconception is that rainforests are the primary source of oxygen on the planet, yet oceans are responsible for producing more than two thirds of oxygen in the atmosphere. Further, the oceans play a vital role in regulating our climate by transporting warm water from the equator to the poles, and cold water from the poles to the tropics. This mass movement of water and energy stabilises the climate and makes many places more habitable for humans.

More than one half of the world's human population live in coastal zones and depend on ocean resources for their survival. It is estimated that nearly 60 million people globally are employed in fisheries and aquaculture (Food and Agriculture Organization of the United Nations, 2018). One billion people globally rely upon fish as their primary source of protein.

Other vital services provided by the ocean to people include transport routes through shipping, storm protection provided by sand dunes, mangroves and reef systems, and the deep cultural and spiritual connections with the oceans fostered by many coastal communities.

1.1 The importance of oceanic processes in climate regulation

The ocean plays a central role in regulating the Earth's climate and in mitigating climate change by serving as a major heat and carbon sink. Carbon is sequestered through biological and physical processes which take carbon from the atmosphere into the ocean. The 'biological pump' - in which organic matter sinks into the ocean interior where it is returned to dissolved inorganic carbon and nutrients through bacterial decomposition - is estimated to transfer 5-15 billion tons of carbon each year from the surface ocean to the ocean interior playing a crucial role in global carbon sequestration. On average a carbon atom spends about 5 years in the atmosphere, 10 years in terrestrial vegetation, and 380 years in intermediate and deep ocean waters (Quéré *et al.*, 2018). Carbon can remain locked up in ocean sediments or fossil fuel deposits for millions of years.

The Fifth Assessment Report published by the Intergovernmental Panel on Climate Change (IPCC) in 2013 revealed that the ocean has thus far absorbed 93% of the extra energy from the enhanced greenhouse effect, with warming now being observed at depths of 1,000 metres. This has led to increased ocean stratification (prevention of water mixing due to different properties of water masses), changes in ocean current regimes, and expansion of depleted oxygen zones. Changes in the geographical ranges of marine species and shifts in growing seasons, as well as in the diversity and abundance of species communities are now being observed. At the same time, weather patterns are changing, with extreme events increasing in frequency.

mate is regulated by the ocean Credit: NOAA

Atmospheric warming is leading to the melting of inland glaciers and ice, causing rising sea levels with significant impacts on shorelines (coastal erosion, saltwater intrusion, habitat destruction) and coastal human settlements. The IPCC projects global mean sea level to increase by 0.40 [0.26–0.55] metres for 2081–2100 compared with 1986–2005 for a low emission scenario, and by 0.63 [0.45–0.82] metres for a high emission scenario. Extreme El Niño events are predicted to increase in frequency due to rising greenhouse gas emissions. The ocean, and those dependent on it, thus bear the brunt of climate change, as evidenced by changes in temperature, currents and sea level rise, all of which affect the health of marine species, near-shore and deep ocean ecosystems and the functions and services they provide for people.

Carbon dioxide emissions are also making the ocean more acidic, making many marine species and ecosystems increasingly vulnerable. Ocean acidification reduces the ability of marine organisms, such as corals, plankton and shellfish, to build their shells and skeletal structures. It also exacerbates existing physiological stresses (such as impeded respiration and reproduction) and reduces growth and survival rates during the early life stages of some species.

Despite their importance to humans, the oceans are a partially understood environment: they have been mapped only crudely, with just 15% of the ocean floor having been covered in any detail. The deep sea remains largely unknown and discovery rates for species and habitats remain high (Copley, 2014a).

1.2 Development of marine industries and implications for marine ecosystems

Oceans and seas have tremendous potential to contribute to the provision of food, feed, energy and natural resources. The emerging concepts of “Blue Growth” and “Blue Economy” have put the development of new marine industries on the political agenda. As marine industries expand, spatial interconnections and industry boundaries are being drawn and the potential for the combined use of marine space must be explored.

Marine ecosystems and the species and services they support are under threat both from direct uses (e.g. recreational and comextraction and transportation of oil and gas, exploitation of seabed minerals, and shipping) and from upstream or upwind activities (e.g. land use change and habitat loss from agriculture, forestry, mining, transportation, manufacturing, energy generation).

Further, coastal tourism, port and harbour developments, damming of rivers, urban development and construction, mining, fisheries, aquaculture, and manufacturing, among others, are all sources of marine pollution threatening coastal and marine habitats.

Excessive nutrients from sewage outfalls and agricultural runoff have contributed to the number of low oxygen (hypoxic) areas known as dead zones, where most marine life cannot survive, resulting in the collapse of some ecosystems. By the year 2100, without significant changes, more than half of the world’s marine species may stand on the brink of extinction.

Invasive species and climate change are further driving ecosystem change. Today, 60% of the world’s major marine ecosystems that underpin livelihoods have been degraded or are being used unsustainably (UNESCO, no date b). Commercial overexploitation of the world’s fish stocks is so severe that it has been estimated that up to 13% of global fisheries have ‘collapsed.’

Facts and figures on marine biodiversity (UNESCO, no date b)

Why oceans matter

- The ocean constitutes over 90% of the habitable space on the planet.
- Oceans have a much higher phylogenetic diversity than land: 30% of phyla are exclusively marine, whereas only one phylum is exclusively terrestrial.
- Tiny phytoplankton provide 50% of the oxygen on earth and form the basis of the ocean food chain up to fish and marine mammals, and ultimately human consumption.
- Coral reefs are the nurseries of the oceans, they are biodiversity hotspots. On some tropical coral reefs, for example, there can be 1,000 species per square metre².
- Today, fisheries provide over 15% of the dietary intake of animal protein.
- Approximately 470 to 870 million of the poorest people in the world rely heavily on the ocean for food, jobs, and revenues and live in countries that will be most affected by simultaneous changes in ocean biogeochemistry caused by climate change.
- Coastal systems such as such as mangroves, salt marshes and seagrass meadows have the ability to absorb, or sequester, carbon at rates up to 50 times those of the same area of tropical forest. Total carbon deposits in these coastal systems may be up to five times the carbon stored in tropical forests.

Loss and degradation of marine ecosystems

- By the year 2100, without significant changes, more than half of the world's marine species may stand on the brink of extinction.
- Today 60% of the world's major marine ecosystems that underpin livelihoods have been degraded or are being used unsustainably.
- Ocean acidification may threaten plankton, which is key to the survival of larger fish.
- If the concentration of atmospheric carbon dioxide continues to increase at the current rate, the ocean will become corrosive to the shells of many marine organisms by the end of this century. How or if marine organisms may adapt is not known.
- Ocean acidification may render the oceans inhospitable to coral reefs, affecting tourism, food security, shoreline protection, and biodiversity.
- There are now close to 500 dead zones covering more than 245,000 square kilometres globally, equivalent to the surface of the United Kingdom.
- Between 1980 and 2005, 35,000 square kilometres of mangroves were removed globally.
- Between 30% and 35% of the global extent of critical marine habitats such as seagrasses, mangroves and coral reefs are estimated to have been destroyed.

Box 1 (cont.)

Threats

- Commercial overexploitation of the world's fish stocks is so severe that it has been estimated that up to 13% of global fisheries have 'collapsed.'
- Agricultural practices, coastal tourism, port and harbour developments, damming of rivers, urban development and construction, mining, fisheries, aquaculture, and manufacturing, among others, are all sources of marine pollution threatening coastal and marine habitats.
- Excessive nutrients from sewage outfalls and agricultural runoff have contributed to the number of low oxygen (hypoxic) areas known as dead zones, where most marine life cannot survive, resulting in the collapse of some ecosystems.
- Technological change and the emergence of new economic opportunities such as deep-seabed mining, more intensive fishing, and deeper oil and gas drilling increase risks to areas that historically were not under threat.

Protection of marine ecosystems

- Marine Protected Areas are essential to conserve the biodiversity of the oceans and to maintain productivity, especially of fish stocks. World Heritage marine sites represent in surface area one third of all Marine Protected Areas.
- Approximately 12% of the land area is protected, compared to roughly 1% of the world oceans and adjacent seas.
- Further research and collective action are needed to mitigate the underlying causes of the loss of biodiversity.
- The Blueprint for ocean and coastal sustainability (UNESCO, no date a) includes proposals to address these issues.

1.3 Seabed mining: a new frontier

Seabed mining is a new frontier for extraction of the earth's natural resources, fuelled by recent discoveries of wide-ranging mineral deposits (pollymetallic nodules, phosphorite nodules and cobalt-rich ferromanganese crusts) and rising demand for the use of some of these minerals in high-tech industries including electronics and battery storage.

While there are some shallow water (<200 metres) operations in existence, currently there is a rush to establish rights and concessions and gain the exploration licences to start extraction of minerals specifically from the deep sea, with key decisions about regulations permitting commercial deep-seabed mining planned for mid- to late-2020. There are 30 exploration Contracts awaiting permitting for deep-sea exploitation, with different contractors at different stages of development of the technology needed to proceed. These contracts are found in the Western Pacific, the Clarion Clipperton Fracture Zone, The Mid-Atlantic and the Indian Ocean.

Determining the environmental risks and impacts of mineral extraction depends on the knowledge, information and data available. The deep sea remains our least explored and largest environment on the planet. A considerable level of knowledge will therefore be required to assess and manage sustainable exploitation of deep-sea resources.

The potential for environmental impacts through mining the deep seabed was recognised three decades ago but there are growing concerns about our ability to define, measure and mitigate these impacts; an issue exacerbated by our limited understanding of marine ecosystems and oceanic processes, especially in deep water, and a lack of clarity about how marine mining operations may actually harvest resources.

These environmental concerns have led to calls for a moratorium on deep-seabed mining since 2011[5] by a range of non-governmental and ocean science organisations, and to date a number of national governments have announced their support for precaution and temporary suspension, as have representatives of other marine industries, such as fisheries.[6]

1.4 Purpose and approach of this assessment

The potential for environmental impacts through mining the deep sea was first recognised in the 1960's and more widely three decades ago (Thiel, 1992). However, concerns have been raised about our ability to define and measure these impacts, which may be hampered first by our limited understanding of marine biodiversity and ecosystem services, especially in deep water, and second by a lack of clarity about how marine mining operations may actually harvest resources. This lack of knowledge could create uncertainty in defining impacts and establishing mitigations for biodiversity and ecosystem services. Much needs to be drawn and learned from other sectors, including the environmental, social and governance frameworks for terrestrial extractives, as well as international protocols and treaties governing our common heritage.

The seabed mining industry has developed rapidly in the past decade, with companies now actively exploring for minerals in territorial and international waters. However, the enabling policy and governance structures to oversee seabed mining remains in a nascent state. There is now a great pressure to develop environmental policy that safeguards marine biodiversity and ecosystem services, but a limited understanding of whether and how best practice for biodiversity and ecosystem services from related industries could be applied to seabed mining, and to what effect.

This report was stimulated by concerns relating to the lack of knowledge, uncertainty and time pressure pervading the deep-seabed mining industry, and the need to develop policy to adequately protect marine biodiversity and ecosystem services.

The overall purpose of this report is to assess the potential risks and impacts of seabed mining to biodiversity, ecosystems and their associated functions and services and to determine whether sufficient knowledge is available to inform decisions that would result in no harm outcomes.

This Risk and Impact Assessment report follows the format of a traditional Strategic Environmental Assessment (SEA) and has the following specific aims:

- Assess the degree of knowledge that exists on marine biodiversity and ecosystem services and evaluate the feasibility of baseline definition for mining in shallow and deep sea environments;
- Determine if there is sufficient knowledge to identify no-go or avoidance areas based on biodiversity and ecosystem services risk and values;
- Define the risks and likely impacts of the main classes of marine mining and at each stage of the project cycle in different geographies and contexts, from exploration to decommissioning, and including supporting activities relating to ports and shipping, based upon the most feasible techniques and emerging technologies;
- Collate mitigations, focusing upon avoidance and minimisation measures, drawing upon emerging technologies and practices by existing extractive operations in the marine environment, and assessing their potential efficacy;
- Assess the feasibility of no net loss and net positive outcomes of seabed mining under different conditions and in different locations;
- Present conditions and principles under which no net loss or net positive outcomes (see Box 2) for biodiversity and ecosystems services may be possible, and where it may not be possible;
- Identify significant gaps in knowledge and uncertainties to be addressed in priority order; and
- Inform responses and advice relating to marine mining, including potential policy and advocacy interventions, including potential red line / no go recommendations where applicable.

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[5] https://wwf.be/assets/RAPPORT-POLICY/OCEANS/UK/WWF-Deep-Sea-Mining-position-2011.pdf; http://www.deepseaminingoutofourdepth.org/about/

[6] https://www.ldac.eu/images/EN_LDAC_Advice_on_Deepsea_Mining_R.04.19.WG5_May2019.pdf

This report takes a precautionary and evidence-based approach, using the best available science and case studies from industry to define impacts and risks, and identify effective mitigations according to the mitigation hierarchy (Box 2). The report draws upon the operational experiences of leading scientific and research organisations, marine biodiversity specialists and experts working in governance and operations of the seabed mining sector. One such rich repository of science and knowledge is the European MIDAS Project (Box 3).

In exploring the pathways towards feasibility of a net positive outcome for biodiversity and ecosystem services, this report applies a suite of broader conservation principles such as ecological function, connectivity, irreplaceability of ecosystem components, vulnerability of the ecosystem to change and degradation, resilience in the face of climate change and anthropogenic degradation **(Part B).**

BOX 2

Mitigation hierarchy

The mitigation hierarchy comprises the following steps, to be implemented sequentially to avoid and mitigate risks and impacts on biodiversity and ecosystems:

- Avoidance: measures taken to avoid creating impacts from the outset, such as careful spatial or temporal placement of elements of infrastructure, in order to completely avoid impacts on certain components of biodiversity.
- Minimisation: measures taken to reduce the duration, intensity and / or extent of impacts that cannot be completely avoided, as far as is practically feasible.
- Rehabilitation / restoration: measures taken to rehabilitate degraded ecosystems or restore cleared ecosystems following exposure to impacts that cannot be completely avoided and / or minimised.
- Compensation or Offset: measures taken to compensate for any residual significant, adverse impacts that cannot be avoided, minimised and / or rehabilitated or restored. Measures to achieve No Net Loss or a Net Gain of biodiversity for at least as long as the project's impacts are biodiversity offsets. Offsets can take the form of positive management interventions such as restoration of degraded habitat, arrested degradation or averted risk, where there is imminent or projected loss of biodiversity. Measures that address residual impacts but are not quantified to achieve No Net Loss or not secured for the long term are compensation, otherwise known as compensatory mitigation.

No Net Loss, Net Positive Impact and Net Gain

No net loss, net positive impact, and net gain are targets for development projects in which the impacts on biodiversity caused by the project are balanced or outweighed by measures taken to first avoid and minimise the project's impacts, then to undertake on-site rehabilitation and/or restoration, and finally to offset the residual impacts (if any, and where appropriate and at the appropriate geographic scale (e.g. local, landscape-level, national, regional)). Where the gain exceeds the loss, the term Net Positive Impact or Net Gain are used instead of No Net Loss.

It should be noted that:
- The term Net Positive Impact and Net Gain can be used interchangeably.
- The 'net' in No Net Loss, Net Positive Impact and Net Gain acknowledges that some biodiversity losses at the development site are unavoidable, and that biodiversity gains may not be perfectly balanced in regard to the time, space, or type of biodiversity affected.

Additional Resources: Business and Biodiversity Offsets Programme (BBOP), 2011; Gardner and Von Hase, 2012.

BOX 3
MIDAS (Managing Impacts of Deep-seA reSource exploitation) (MIDAS, 2016)

The MIDAS project was conceived to address increasing concerns over the lack of scientific knowledge required to understand and mitigate the likely impacts associated with the extraction of mineral resources from the deep sea. Funded by the European Union's Framework 7 programme for a period of 3 years (2013-2016), the MIDAS project involved 32 partners from around Europe comprising leading scientists, policy experts and industry representatives. Together, the MIDAS consortium carried out research on a wide array of topics aimed at assisting the nascent deep-seabed mining industry, regulators and civil society to understand the potential impacts of mining on deep-sea ecosystems.

The project focused mainly on the potential impacts associated with extraction of manganese nodules and seafloor massive sulphides (SMS) from the deep sea, but also addressed environmental issues related to the exploitation of methane gas hydrates, and the potential of deep-sea muds in the North Atlantic as a source of Rare Earth Elements (REEs). Study areas included the mid-Atlantic Ridge (MAR), the Clarion Clipperton Zone (CCZ) in the central Pacific (nodules), and the Black Sea, Norwegian and Svalbard continental margins (gas hydrates). Additionally, the Canary Islands, Palinuro Seamount (central Mediterranean), Norwegian fjords and Portmán Bay (Spain) were used as proxy sites for various mining impact experiments. Large volumes of new data were collected via 30 research expeditions to these areas to satisfy a range of scientific questions.

MIDAS included much more than scientific research. Industry partners provided links to the commercial sector to provide information on likely mining scenarios, and to enable the determination of best practice in other sectors of offshore exploitation. The combination of new scientific data with projected mining scenarios and accepted best practice has enabled MIDAS to put forward an environmental management framework that could facilitate responsible mining whilst taking account of environmental concerns. MIDAS also identified the technology that might offer the most value in monitoring the impacts of deep-seabed mining, including technology gaps where existing instrumentation requires further development.

MIDAS incorporated a social dimension through close engagement with civil society, providing accurate information about likely impacts of mining activity, and listening to NGOs' concerns about this emerging industry. MIDAS focused on developing practical, workable solutions with due regard of the legal aspects and worked closely with the International Seabed Authority to provide scientific input to the development of a mining code for the exploitation of deep-sea minerals. This process will continue well beyond the lifetime of MIDAS, but it will benefit from this new knowledge as well as a gap analysis of information that is of high importance but not currently available.

The timing of the MIDAS project was opportune, coinciding with the International Seabed Authority's development of a mining code for the exploitation of deep-sea minerals. MIDAS research has already produced 50+ papers in peer-reviewed journals, with many more to come beyond the end of the project. The final output from the project - a summary report on the MIDAS recommendations to the EC and the International Seabed Authority - is publicly available from the MIDAS website (www.eu-midas.net).

1.4.1 Methodology: the risks and impact assessment

Using a Strategic Environmental Assessment (SEA) framework, this report assesses the risks and implications of seabed mining to biodiversity and ecosystem services in the marine environment. A SEA is a systematic way of evaluating the environmental consequences of a policy or programme and using this information to inform decision-making.

Best practice risk management approaches usually use a quantitative risk assessment process to identify and mitigate environmental risks. The approach of this assessment is strategic and high level, but it draws upon the methods of the Environmental Impact Assessment (EIA) process in order to provide more detailed analysis of risk. This assessment will take the following approach:

- "Scoping", defining the boundaries of investigation, assessment and assumptions required, including regulation,
- "Documentation of the state of the environment", effectively a baseline on which to base judgments,
- "Determination of the likely (non-marginal) environmental impacts and potential avoidance and mitigation actions", usually in terms of Direction of Change rather than firm figures,
- Influencing "decision taking" based on the assessment and,
- Recommendations for further work and monitoring of the effects of plans and programmes after their implementation.

This approach is applied to different seabed mining scenarios to determine whether, and to what degree, impacts can be determined and mitigations devised.

1.5 Information not included in this report

This report is not a good practice guidance. There is a comprehensive process underway by Pew Charitable Trusts and the International Seabed Authority to develop good practice guidance for deep-seabed mining. Pew is working internationally to help write an International Seabed Authority Mining Code – an excellent resource covering these initiatives and White Papers is found here:

https://www.pewtrusts.org/en/projects/seabed-mining-project

This report does not consider the following related topics:

- Financial structures within the contracting and governance of the International Seabed Authority
- Legal aspects of seabed mining other than regulation pertaining to biodiversity and ecosystem services in the marine environment
- Coastal and beach mining, including iron sands and near-shore mining for diamonds
- Deposit of tailings from terrestrial mines in marine environments

1.6 Who this assessment report is for

This assessment report is designed to provide a pragmatic reference on seabed mining for stakeholders, and in particular regulators and policy makers, who need to evaluate risks and impacts to marine biodiversity and ecosystem function, and who desire to minimise impacts to marine biodiversity and ecosystems and their associated functions and services. Specifically, this report assesses the current state of knowledge, and will help regulators to decide whether enough information exists to judge that seabed mining can proceed with acceptable outcomes for biodiversity and ecosystem services. The content herein is designed for all seabed mining operations but is especially geared towards those operations located in sensitive deep water environments, and where the goal is no net loss for biodiversity, or a net positive approach.

The governance of the oceans and specifically seabed non-living resources by both State Agencies and the International Seabed Authority is largely dependent on the understanding and exercise of laws governing this domain. Assessing the knowledge base, risks and uncertainties relating to seabed mining will help to inform decision making processes permitting exploration, exploitation and impact management. In turn, this will support the application of the best practice objectives articulated in the United Nations Convention on the Law of the Sea (UNCLOS) which encapsulates the Precautionary Principle, the need to protect the common heritage of mankind and ensure the safeguarding of the marine environment.

1.7 How this report is structured

The main focus of this report is on deep sea (>200 metres) mining with some commentary of existing shallow-water (<200 metres) mining. The report is divided into three sections.

PART A sets context for assessing seabed mining, including exploration of the key drivers of the industry and the constraints to its development. This is followed by a summary of existing governance, policy and regulation relating to the management of marine biodiversity and ecosystems, along with relevant standards and guidance. The methodology for undertaking a strategic environmental assessment is outlined – with information on conducting a marine biodiversity baseline through to impact assessment, mitigation planning, and monitoring.

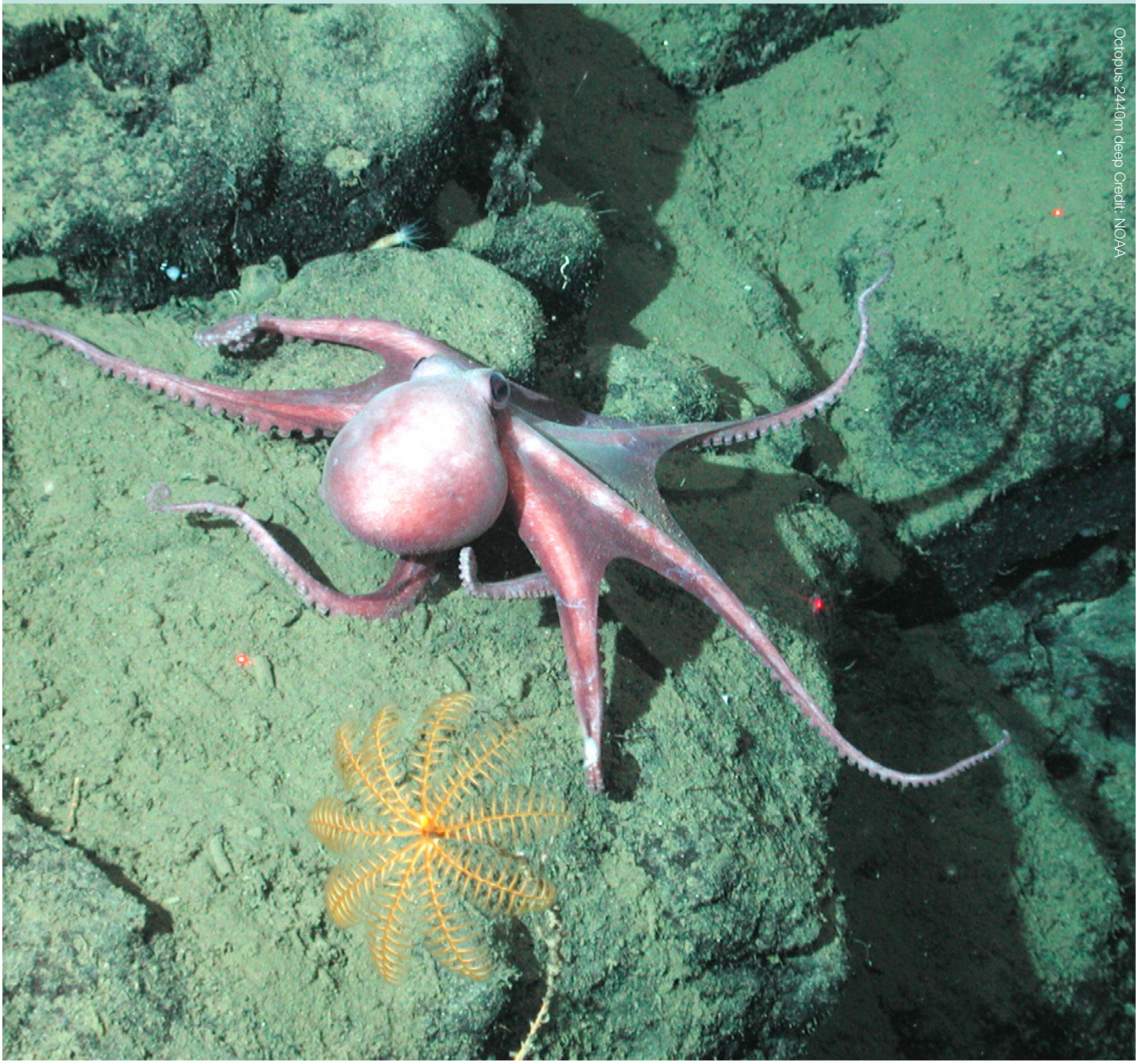
PART B contains an overview of the marine baseline that synthesises available information on the marine environment with a focus on deep-sea habitats, their associated biodiversity, mineral deposits and biophysical processes, and considering the role of deep-sea ecosystems in planetary processes.

PART C summarises the different types of deep-seabed mining under development, presents the proposed methods for mineral extraction, and draws on the available science to assess the potential risks and impacts to marine biodiversity and ecosystem services. This includes key systemic risks and impacts of deep-seabed mining observed by the MIDAS project and other key scientific initiatives in the deep sea. A precautionary approach and mitigation hierarchy framework are employed to determine what possible mitigation actions could be applied to avoid and reduce the extent of harm from seabed mining. Although not the focus of this report, a sub-section on shallow water mining is also included for completeness.

Based upon the thorough assessment of the current state of knowledge relating to seabed mining and the marine environment, this report concludes with key recommendations for deep-seabed mining going forwards.

Benthic coral assessmblage Credit: NOAA

PART A



Octopus 2440m deep Credit: NOAA

2. Context for seabed mining

In this section, the context for seabed mining is set by exploring the key business drivers of the industry and identifying the physical and environmental constraints to its development. The jurisdictional boundaries of the ocean are explained, and a summary of existing governance, policy and regulation relating to the management of marine biodiversity and ecosystems is presented, along with relevant standards and guidance. Information on conducting a baseline for marine biodiversity and ecosystem services is outlined.

2.1 Mining in our oceans

Marine minerals are not a recent discovery with the first polymetallic nodules discovered in the deep sea in the 1860's. However, until recently there wasn't the knowledge of their extent nor the expertise to exploit them. Today, deep-seabed mining is a new frontier for extraction of the Earth's natural resources, fuelled by recent discoveries of wide-ranging mineral deposits (including phosphorite nodules and cobalt-rich ferromanganese crusts) and rising demand for their use in high-tech industries including electronics and battery storage.

Seabed mining already occurs in shallower territorial waters. For example, mining for marine-based diamonds off the coast of Namibia has occurred since the 1980s. More recently, however, deep-water licences to mine have been awarded for the exploitation of seafloor massive sulphide deposits by the government of Papua New Guinea (Miller *et al.*, 2018), for metal-rich sediments in the Red Sea jointly by the Governments of Saudi Arabia and Sudan, and for offshore phosphorites (with environmental clearance pending at the date of publication of this report) by the governments of Namibia and New Zealand. Other companies and government agencies are submitting permit applications for exploitation within some national jurisdictions.

Exploration is now increasingly occurring in many deep sea locations globally (e.g. the Clarion Clipperton Zone, the mid-Atlantic Ridge, the Indian Ocean) – though the legislation is not yet in place to enable mining in international waters. New approaches are enabling the exploration of ocean areas that were previously inaccessible. As technologies advance and the global demand for resources increases, the potential for exploration in remote, fragile ecosystems that were previously difficult and/or uneconomic to assess becomes ever greater. Deep-sea minerals have also been touted as essential for a decarbonised future yet other sources do exist (e.g. through untapped recycling potential) as well as new technologies that are not dependent on metals.

Though full extraction is not yet occurring in international waters, there is a current rush to establish rights and concessions and gain the exploration licences to start extraction of minerals from the deep sea, with key decisions about regulations permitting commercial deep-seabed mining planned for mid- to late-2020. At the time of writing, there were 29 current exploration licences awaiting permitting for exploitation, with different contractors at different stages of development of the technology needed to proceed. These contracts are found in the Western Pacific, the Clarion Clipperton Fracture Zone, The Mid-Atlantic and the Indian Ocean.

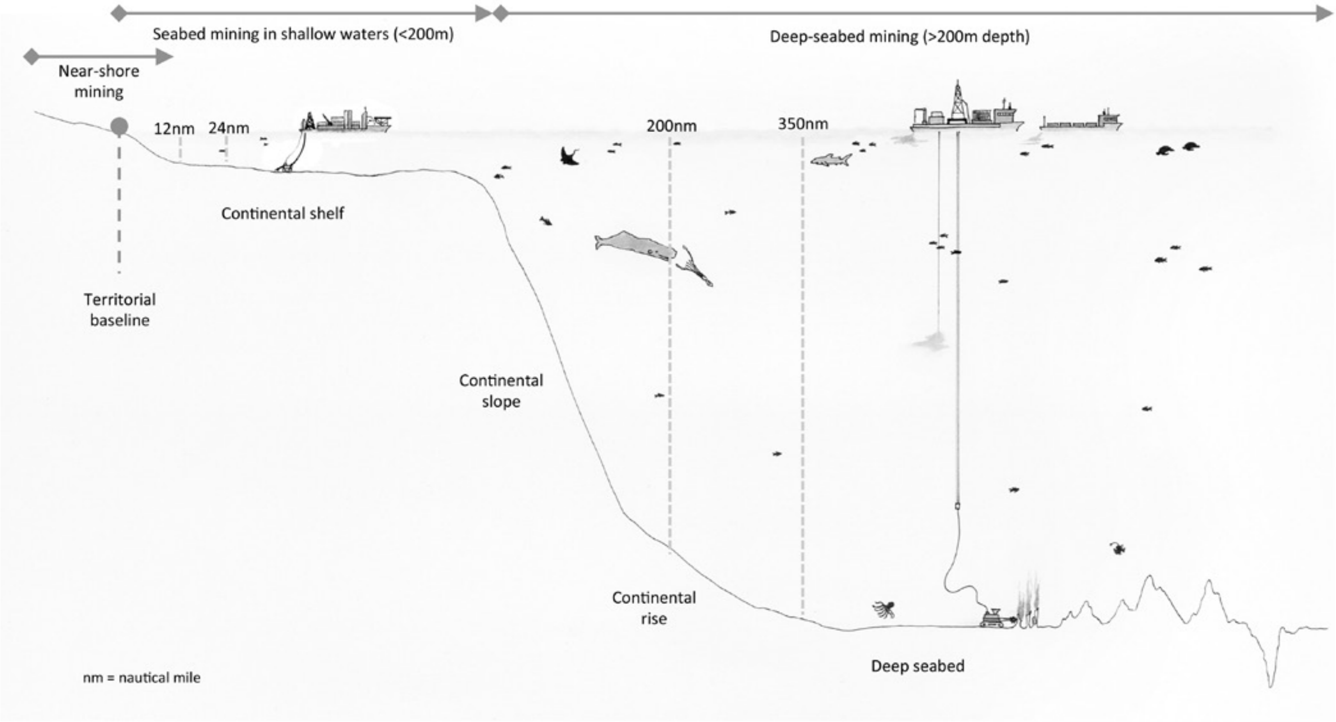
Whilst efforts are underway to establish protection for biodiversity in the High Seas, deep-seabed mining has become an increasingly important geo-political issue, driving a number of diplomatic processes competing for seabed claims and an urgent need for High Seas legislation. It is portrayed as an exciting new economic frontier for the "blue economy", which seeks to realise the full economic potential of the ocean.

Despite the rush to exploit deep-sea minerals, our knowledge of the marine environment is focused mainly upon shallow waters, and we have only patchy information on deeper water systems. We are therefore poorly placed to understand how deep-seabed mining could affect the world's oceans. In the following section the different types of seabed mining are summarised based upon water depth. In Part B of this report we discuss gaps in data relating to the marine environment.

2.2 Zones of seabed mining

For the purposes of clarity, we describe three zones of seabed mining: near-shore mining; shallow seabed mining; and deep-seabed mining (Figure 1).

Figure 1: Zoning of seabed mining



Credit: Nicky Jenner/FFI

2.2.1 Near-shore mining

Near-shore and inter-tidal seabed mining already exist and typically focus on sand, gravel, mineral sands (titanium/ilmenite), coral, alluvial precious metals and stones. Near-shore aggregate mining normally uses trailing suction dredge technology. This is commonly used to extract building materials and as part of land reclamation projects. There are also a number of active near-shore mining operations targeting precious stones (e.g. diamonds) and mineral sands (e.g. ilmenite) in countries including Madagascar, Mozambique, Namibia and South Africa. Near shore diamond extraction uses small diver based suction tools as well as small boat suction hose operations.

This assessment report does NOT deal with mineral sand or near-shore mining for gold and diamonds. On the whole, the permitting process defining near-shore mining is the same as for terrestrial mining and greater information is available on the biodiversity and ecosystem services of near-shore environments and Environment and Social Impact Assessments (ESIAs) and environmental management plans have been completed for these operations. While information gaps still exist, there is greater certainty associated with near-shore environments than with shallow water or deeper water environments.

2.2.2 Shallow water seabed mining

Shallow water seabed mining includes operations from the low water mark to the depth of 200m. Seabed mining technologies in shallow waters differ depending on the type of deposit. Aggregate mining typically uses a method of dredging called trailing suction dredge technology. Marine diamond extraction relies on accurate positioning of vessels and seabed tools to target identified resource blocks using vertical or horizontal tools which extract the target sediments and transport them to the vessel for processing. Only the processed diamond concentrate is sent ashore for final sorting, the rest of the material is returned to the water from the vessel, before settlement back to the seabed mining area.

Minerals derived by mechanical erosion from continental rocks and transported to the sea have been concentrated in marine placer deposits, which have been sorted by water motion (waves, tides, currents) according to the varying density (mass per unit of volume) of the constituent minerals. These minerals contain heavy metallic elements (barium, chromium, gold, iron, rare earth elements, tin, thorium, tungsten, zirconium) and non-metals (diamonds, lime, siliceous sand, gravel). Of the metals, gold is mined intermittently offshore from Alaska dependent on price (producing as recently as the 1990s) and tin continues to be mined at sites off Thailand, Myanmar and Indonesia.

Of the non-metals, a viable diamond-mining industry exists off the coast of Namibia and the adjacent coast of South Africa (in water depths of ~120 metres, or horizontal distance to about 30-40 kilometres from shore), with recovery of 1.378 million carats of diamonds produced in 2018 by the principal producer (Debmarine Namibia, 2019). Sand and gravel are being mined from shallow offshore accumulations at many sites around the world for construction material (concrete) and beach restoration; these are the marine materials with the highest annual production value.

Shallow water seabed mining is included in this report primarily for comparative purposes with deep-seabed mining. On the whole, the permitting process defining shallow seabed mining is more defined than for deeper water and as much of it falls within the territorial waters / EEZ, it falls under compliance legislation and environmental regulations of the applicable host country. There is also more information available on the biodiversity and ecosystem services of shallow water environments and Environment and Social Impact Assessments (ESIAs) and environmental management plans have been completed for many of the operations. While information gaps still exist, there is greater certainty associated with shallow water environments than with deeper water environments. So although the focus of this report is on deep water mining much can be learned from shallow water seabed mining.

2.2.3 Deep-seabed mining

There is some confusion as to what constitutes ‘deep-seabed mining’ (also referred to as ‘deep-sea mining’) and a variety of definitions exist according to which the cut offs between ‘shallow water seabed mining’ and ‘deep-seabed mining’ are set at different depths. Those different definitions are typically shaped by:

- Whether specialised equipment is required due to the pressures that are encountered at depth, or whether more conventional technology (i.e. dredging) can be used;
- Whether it is occurring at depths in which sunlight can still penetrate (the photic zone);
- The kind of corals, fish and other sea life that exist at different depths;
- Whether it is likely to interact with other resource uses such as commercial fishing.

These factors are variable and imprecise. For example, sunlight penetration is heavily influenced by the turbidity of the water, dredging can be done in very deep waters, different countries have different limits and practices around bottom trawling fishing, and some marine mammals can range from the surface to more than 2,000 metres deep in their diving.

For the purposes of this report, we consider deep-seabed mining to be mining of the seabed and associated ecosystems in depths greater than 200 metres below sea level.

We consider deep-seabed mining to cover the extraction of minerals (usually metalliferous) from the deep ocean. There are three common resource types:

- polymetallic (or manganese) nodules that occur in surficial seafloor sediments in abyssal plain muds, mainly in the Pacific and Indian Oceans;
- cobalt-rich ferromanganese crusts that occur as a surface encrustation on seamounts and rock outcrops in all oceans, but with the richest deposits having been found in the western Pacific;
- seafloor massive sulphides that are formed at seafloor hot springs along ocean plate boundaries.

Phosphate mining has also been proposed between 150 - 400 metres and therefore falls between shallow and deep-seabed mining. Additionally, there is potential to mine metal-rich muds under dense brines in the Red Sea (Bertram *et al.*, 2011), and the mining of deep-ocean sediments to recover rare earth elements (REEs) has also been suggested (Kato *et al*., 2011).

The start of deep-seabed mining is imminent. The first deep-seabed mining operation was scheduled to commence in the offshore waters of Papua-New Guinea in 2019 (Miller *et al.*, 2018). However, it has encountered severe financing set-backs and faces growing concerns about the potential impacts of deep-seabed mining. This has led to calls for a moratorium on seabed mining in both national and international waters.

2.3 Drivers, constraints and alternatives for development of the seabed mining industry

2.3.1 Drivers for seabed mining and alternatives

The projected value of seabed mining is currently estimated to be in the order of about $2 billion a year (compared to $100 billion for oil & gas), but the International Seabed Authority estimate projections of growth once deep-sea minerals are exploited are of an order of magnitude greater. From an economic perspective, interest in deep-seabed mining is predominantly driven by the metals' markets. Currently, a key driving force is the increase in metal prices due to inadequate supply that is caused by decreasing metal grades, increasing metal demand and improved mining efficiency (SPC, 2013).

Since the mid-1900s there has been a steady decrease in metal grades in terrestrial mineral deposits. Thus, terrestrial mining activities require increasingly larger land areas, as more material must be mined to generate the same amount of metal. This increases the environmental footprint of the activities, and a high amount of waste rock lowers the overall mining efficiency. Marine mineral deposits are significantly more mineral-rich (i.e. have much higher metal gradients) than terrestrial deposits. For example, a recent investigation of a seamount in the Atlantic Ocean has revealed a crust of rock with concentrations of the scarce substance tellurium (which has applications in the production of a type of advanced solar panel) in concentrations 50,000 times higher than in deposits on land (Shukman, 2017).

At the same time, the increased demand for metals in the global market has resulted in an increase in metal prices. Together with an expected increase in world population and gross domestic product per capita, an increased metals consumption due to a growing production of consumer goods (mostly electronics and other metal-intensive products) serves as the market logic behind developing the industry of seabed mining. Furthermore, a peak in copper production is forecasted at around 2040.

As we advance on a low-carbon economy—with more renewables and electric vehicles, and greater energy efficiency and electrification—global demand for copper and other non-ferrous metals rises. The World Bank's 2017 report "The Growing Role of Minerals and Metals for a Low Carbon Future" illustrates how fundamental primary and secondary raw materials are to many sectors of the economy, particularly as they aim for carbon neutrality. As demand for raw materials increases, optimising the flow of energy and materials, reducing waste generation and smart use of by-products in co-located processes—the elements of a truly circular economy—become key to sustainably meeting that demand (see Box 4).

BOX 4
Overconsumption and the need for a circular economy.

Concerns have been raised that no country can meet basic human needs at a level of resource use that is globally sustainable (O'Neill *et al.*, 2018). Reducing overall consumption in tandem with implementing a circular economy will make a significant impact on fulfilling demands to manufacture new technology and alleviate waste. Improved recycling technology and careful product design will help to maximize resources (Gordon, Bertram and Graedel, 2006; Grandell *et al.*, 2016).

Successful implementation of a circular economy will involve changing patterns of consumption and represents a huge, but not insurmountable, challenge for societies around the globe. A combination of measures such as policy, pricing and a shift in demand could allow economic growth while simultaneously slowing global material use (Krausmann *et al.*, 2017). For example, policy could require companies to manufacture technologies that are fully recyclable at end-of-life, extending product lifespans and eliminating built-in obsolescence. Other changes in behaviour could be incentivized by improvements to public transport, including bike lanes, car sharing, shared use of white goods and less frequent upgrades of personal technology.

Policy measures could help to encourage metals recycling and reuse on a global level. The volume of electronic waste (e-waste) is increasing but recycling certain components can be technically and logistically challenging (Tansel, 2016). Metals have the potential for "almost infinite recovery and reuse", but recycling can be challenging if it involves extracting metals that have previously been disposed of in landfill (Gordon, Bertram and Graedel, 2006). Policy could be used to guide collection, tracking, safe handling, recovery and onward sale of reusable materials. Grandell *et al.* report that the metals market is dominated by input from the mining industry (Grandell *et al.*, 2016). As metals become scarce, prices will rise and, in turn, recycling infrastructure will develop. Grandell *et al*. (2016) recommend research to find substitute metals to use in green technologies so that reliance widens from using only a few crucial metals.

Another important political driver is the desire of individual countries to be self-sufficient in sourcing strategic minerals and to decouple from countries that may hold monopolies on certain minerals (e.g. cobalt from Democratic Republic of Congo, or rare earth metals from China). Seabed mining is attractive for countries short of natural resources, such as Belgium, United Kingdom or Japan, as an opportunity to secure their future supply of minerals.

Some commercial advantages of seabed mining have been identified, as compared to terrestrial mining, including: inexpensive transportation by sea (with respect to distribution); utilising already existing port facilities for establishing supply hubs and unloading mineral products; and performing onshore processing at preferable locations with respect to processing costs or proximity to market (Earney, 2010).

Additional societal and industry drivers and restricting forces for developing seabed mining as an industry are summarised in Table 1.

Table 1: Drivers and restricting forces for marine mineral mining (Frimanslund, 2016)

	Society	Industry
Primary Drivers	Global economic growth	
	States securing access to resources, hence increasing independence with respect to mineral supply	
Secondary Drivers	Increased focus on, and support of environmental and social sustainability driving “green technologies”	
	Emerging appliances and markets	
Restricting Forces	Price volatility	Limited availability of finance
		Environmental and Social Safeguards requirements of Lenders prohibiting financing to deep-seabed mining
	Uncertainty regarding environmental impact	Uncertainty relating to the business model and profitability
		Regulatory uncertainties
		Obligations to share knowledge

2.3.2 Who benefits from the extraction of marine mineral resources?

As with terrestrial mining, seabed mineral resources have the potential to provide socio-economic benefits to national gross domestic product and economic development. Whilst this report focuses on the environmental aspects of seabed mining, there is a need to also address the social and economic impacts and opportunities, including to local communities and Indigenous Peoples, particularly in national waters. Environmental and Social Impact Assessment need to take this into consideration and should include financial and social aspects such as tax revenues, employment, human rights, gender inclusion and health.

UNCLOS stipulates in Article 140 that activities within the “Area”, defined as the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (see section 3.1 for more information on maritime zones) are to be carried out for “the benefit of mankind as a whole” (UN General Assembly, 1982). Currently, the International Seabed Authority interprets ‘benefit’ primarily in economic terms and has not addressed if and how resources recovered from the Area could be distributed globally and equitably (Kim, 2017). Social and environmental impacts, costs and any benefits of activities in the Area were neither properly recognised nor fully appreciated when UNCLOS was being negotiated. Costs or benefits that stretch inter-generationally are still yet to be addressed.

In light of the numerous stressors threatening ocean ecosystems including climate change, ocean acidification, de-oxygenation, pollution (including plastics) and poor fisheries management, some have argued that the socioeconomic benefits of seabed mining may not outweigh the potential impacts (Nash *et al.*, 2017). Kim (2017) suggests that it is time to question the assumption that commercialising the Area will benefit all humankind and asks:

"Is commercial exploitation of non-renewable resources from the ocean floor today really in the interest of humanity?"

Others have adopted a pragmatic approach, recognising the likelihood that commercial deep-seabed mining may commence in the near future, and a range of policy and management options for the industry have been suggested. Some argue that a coherent global policy that integrates science, policy and stakeholder dialogue is necessary for deep-seabed mining to be managed effectively (Boetius and Haeckel, 2018). Mengerink *et al.* (2014) discuss the establishment of a fund, in lieu of conventional restoration, to cover research, monitoring and contingency for damage arising from human activities in the deep sea. Danovaro *et al.* (2017) suggest the establishment of an agency under the United Nations (UN) to facilitate monitoring in the Area, but seabed monitoring is costly. Gramling (2014), for example, estimates that seafloor research can cost up to US$ 80,000 per day. Also, a regulatory body administering a common fund would need the power to appoint independent experts, fine contractors and, if necessary, halt detrimental mining activities (Halfar and Fujita, 2002). Management that incorporates a 'cessation clause' may incentivise contractors to minimise environmental harm but could not prevent it altogether. It is essential that there is clarity on who (contractors, the International Seabed Authority or governments) is responsible for activities at every stage of deep-seabed mining (Ardron, Ruhl and Jones, 2018; Durden *et al.*, 2018).

UNCLOS, as amended by the 1994 Implementing Agreement, does not prescribe the financial mechanism through which benefits of seafloor mineral exploitation could be redistributed – it rather describes benefits as needing to be 'equitable' (Article 160 UNCLOS; Bourrel, Thiele and Currie, 2016). This raises the question of intergenerational equity as well as broader questions such as access to and sharing of marine genetic resources. Given the potential scale and irreversibility of impacts from deep-seabed mining, mechanisms must be found with urgency to address fundamental questions regarding the justification for, and acceptability of, extraction of seabed minerals (Lallier and Maes, 2016; Van Dover *et al*., 2017; Durden *et al*., 2018). The physical, ecological and societal implications of decisions to allow seabed mining are wide ranging and complex (Box 5).

BOX 5

Key considerations and issues influencing potential costs and benefits of deep-seabed mining

Key issues to be addressed when evaluating the costs and benefits of deep-seabed mining. and which justify broad societal engagement in guiding policy decisions, include:

(1) Deep-seabed mining could damage the marine environment for many centuries (Van Dover *et al.*, 2017);

(2) Deep-seabed mining activities could affect fish stocks (Levin *et al.*, 2016);

(3) There are considerable knowledge gaps in understanding marine biodiversity and ecosystem services;

(4) Absence of a framework or process to monitor and inspect this industry, made all the more difficult as its activities are predominantly out of sight;

(5) No liability regime exists for deep-seabed mining and, if established, would warrant the establishment of a fund to cover gaps in liability coverage, such as impecuniosity of operators;

(6) A system to distribute deep-seabed mining benefits to current and future generations of the global community has not yet been defined (Kim, 2017);

(7) Advocating the continued exploitation of Earth's resources is likely to reinforce unsustainable patterns of consumption;

(8) Deep-seabed mining could affect carbon sequestration in sediments (Nagender Nath *et al.*, 2012);

(9) Potential deep-sea marine genetic resources could be degraded before they have been evaluated (Armstrong *et al.*, 2012).

2.4 The business case for biodiversity and ecosystem services

Biodiversity is the foundation that supports societies and economies, producing a range of processes and services that benefit people and sustain the health of the planet (Norris and Fitter, 2011). Despite recognition of its importance, global biodiversity has declined over the past four decades with little indication of a reduction in the rate of decline (Tittensor *et al.*, 2014; Mace *et al.*, 2018). For the fourteenth year in a row, the World Economic Forum have registered biodiversity loss as one of the most critical environmental risks facing business. Biodiversity loss poses significant operational, regulatory, financial, and reputational risks to businesses, which are inextricably linked with other social, geopolitical, and environmental risks (Dempsey, 2016).

Below are several reasons why biodiversity and ecosystem services may be an important consideration for the seabed mining industry.

2.4.1 The value of ecosystem services to communities and operations

There is growing recognition that the natural environment provides efficient and inexpensive ecosystem services including pollution, air quality and climate control, as well as fresh water, waste treatment, erosion control, food and energy. Such services have demonstrable value to coastal communities and mining operations alike, and for the global population.

Coastal communities are likely to benefit from a range of marine ecosystem services. People’s livelihoods may be reliant upon marine resources (e.g. net and collection fishers) as well as benefitting from the storm protection that reefs and mangroves offer. If seabed mining operations were perceived to impact services valuable to coastal communities (e.g. sediment plume dispersal disrupting fish and crustacean breeding cycles) then loss of livelihoods and access to natural benefits could become a source of conflict between communities and mining companies.

Seabed mining operations are likely to depend on a range of ecosystem services to support operational activities and to manage environmental and social risks. For example, dilution and bio-remediation support the removal of effluent in the wider marine ecosystem. Preserving these values therefore makes good business sense, not only from an operational perspective, but also in terms of safeguarding the natural resources used by surrounding communities.

2.4.2 Impacts to deep sea biodiversity are not yet understood

Concerns have been raised about the ability of deep-seabed mining operations to establish baseline conditions for biodiversity and ecosystem services, given the gaps in our knowledge, especially in deeper water. An effective baseline also quantifies variability in the environment. This is difficult to assess in deep water as the rate of processes are often slow.

Further, it is difficult to establish the nature of impacts from deep-seabed mining. MIDAS has highlighted that the challenge for the development of environmental management for deep-seabed mining relates to uncertainties around the technology to be used. Based on consultation undertaken by MIDAS in 2016 (MIDAS and Shirshov, 2016), it was clear that the deep-seabed mining industry is at a very early stage: most companies are at the resource exploration stage, developing conceptual extraction scenarios or planning field trials. Continued consultation with industry throughout the MIDAS project cycle has confirmed that while rapid progress is being made in the development of both technologies and processes for deep-seabed mining, there is considerable variability in the approach to mining and many uncertainties remain.

There is also uncertainty in the response of the environment and biological receptors to the physical changes that result from mining: given our lack of knowledge of marine ecology, we simply don’t know how different elements of biodiversity and ecosystem services may react to mining impacts.

Formal taxonomy lags behind discovery and ecological analyses, creating a major gap in our biogeographic knowledge of deep-sea biota. As we stand on the brink of commercial exploitation of deep-sea resources, we cannot say with any degree of certainty what the risk of extinctions will be, even for large charismatic megafauna (MIDAS, 2017).

Finally, MIDAS notes that, since deep-seabed mining has not yet begun there is very limited information about the environmental management practices that may be used in the industry. This was highlighted as a gap during industry consultation, and the need was identified for high-level guidance to assist in conducting Best Available Technique and Best Practicable Environmental Option assessments, as well as the need to develop and implement mitigation measures.

2.4.3 Corporate standards

To strengthen international efforts and accelerate action to combat biodiversity loss, international environmental agreements have been established, such as the Convention on Biological Diversity, along with broader societal goals, like the UN Sustainable Development Goals, that embed biodiversity conservation in multiple areas of sustainable social and economic development (UN, undated). Businesses are recognised as important actors in supporting efforts to halt biodiversity loss not only because they contribute to significant biodiversity impacts (Maxwell *et al.*, 2016; Addison, Bull and Milner-Gulland, 2019) but because many businesses are inextricably linked with and dependent on biodiversity (Dempsey, 2016). In response to this, some businesses have begun to set their own biodiversity commitments at both the operational and corporate level. In terrestrial mining, increasing recognition of the business case for managing corporate impacts to biodiversity has helped drive corporate commitments to no net loss and net positive impact. Since the first public commitment to net positive impact in 2001, >65 multinational companies have set similar goals. (Silva *et al.*, 2019)

The terrestrial mining sector increasingly recognises that the ability to continue business, and to access new resources, is dependent on the ability to explore for and develop reserves without adversely affecting biodiversity and ecosystem services. This principle is equally likely to apply to the seabed mining sector.

Jones *et al* (2019) have undertaken a major review of best practice environmental management across the deep-seabed mining and allied industries (also in the MIDAS reports: Review of existing protocols and standards applicable to the exploitation of deep-sea mineral resources which is available to download from the MIDAS website). The report provides something of a blueprint for good practice and includes information on corporate approaches to optimise company environmental performance, focusing on the company itself, including the corporate structure, governance, environmental codes of conduct and internal processes that encourage an environmentally sustainable operation. The report has reviewed protocols and standards for environmental management that could be applicable throughout a deep-seabed mining project. This includes protocols and standards for environmental impact assessment and reporting, environmental risk assessments, baseline assessment and monitoring and environmental management and monitoring plans. Environmental operations across multiple mining projects are covered, with a particular focus on strategic environmental assessment.

2.4.3.1 Voluntary sustainability standards

Voluntary sustainability standards (VSS) and safeguards are mechanisms that can be used to track and reduce corporate environmental and social impact, improve transparency and to promote best practice. Transforming the way we produce goods is a key target of many environmental conservation organisations and is reflected in global targets including SDG 12 and Aichi target 4.

Standards, which are the core component of a sustainability certification system such as the Initiative for Responsible Mining (IRMA), are typically a set of guiding principles and criteria, are owned and governed by a specific body with its own set of constituents and stakeholders who ensure that these principles remain robust and fit for purpose. In order to be certified against a particular standard and achieve regulatory compliance and/or access the benefits of certification, a proponent must typically go through third party assurance and verification to ensure that the process is unbiased.

Voluntary Sustainability Standards	Industry
Voluntary Sustainability Standards (VSS) are market-based tools to address key social, economic and environmental issues in production and processing. They are developed to assure consumers, retailers, investors and other supply chain actors that the products they buy have been produced, traded and processed sustainably.	Safeguarding policies are defined by the World Bank as instruments applied by the bank in its operations to protect the interest of the beneficiaries, clients, shareholders and the World Bank. Each safeguard must meet the following objectives: - Do no harm – protect people and environment from adverse impacts - Do good – enhance social equity and promote environmental sustainability - Reduce and manage risk for the client and for the World Bank - Respond to a worldwide constituency

The MIDAS Report also covers stakeholder assessment of deep-seabed mining sustainability, including the protocols and standards used by direct stakeholders, such as financial institutions and contractors and state sponsors, as well as other stakeholders to assess deep-seabed mining projects. MIDAS identified gaps and areas for future development. Emphasis is placed on protocols and standards directly relevant for the extraction of seafloor massive sulphides, polymetallic nodules and cobalt-rich ferromanganese crusts. Allied industries, such as aggregate extraction, industrial deep-sea bottom trawling and hydrocarbon exploitation that have developed their own protocols and standards, are included in the review where appropriate.

Many lenders, such as the World Bank, have an obligation and duty to ensure that 'people and the environment are protected from adverse impacts'[7]. In addition, a lender or investor's reputation can be damaged as a result of association with a borrower who has caused social and/or environmental damage. A key mechanism to ensure this is through safeguard policies, which address environmental and social issues throughout the lifecycle of projects and also provide a framework for consultation with communities and for public disclosure which borrowers are required to comply with as a condition of the loan.

Lender safeguards typically address the following principles:

- Avoid negative impacts where possible, otherwise minimise, reduce, mitigate, compensate
- Match level of review, mitigation and oversight to level of risk and impacts
- Inform public and enable people to participate in decisions which affect them
- Integrate environmental and social issues into project identification

2.4.4 International financial institution standards

Corporate environmental goals have been encouraged by International Financial Institution lender requirements, which stipulate the standards that a company must adhere to when borrowing finance. Whilst various standards have been produced, the International Finance Corporation's (IFC) Performance Standards have become globally recognised as a benchmark for environmental and social risk management in the private sector. While many projects are legally committed to comply with the Performance Standards through lending agreements, others have chosen to voluntarily adopt this standard as a means of demonstrating good international industry practice for biodiversity in response to increasing societal demands to do so.

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[7] https://projects.worldbank.org/en/projects-operations/environmental-and-social-policies

2.4.5 Policy and regulation

In addition to financial mechanisms, a number of countries have enacted biodiversity policies relating to no net loss and net positive impact. There is considerable existing regulation for terrestrial mining, seabed mining in national waters and for oil and gas exploitation, including experience in the application of no net loss and net gain approaches. However, there are differences and challenges compared with application in the deep sea and areas beyond national jurisdiction, not least of all the dynamic and connected nature of the marine realm.

Instruments for conservation and sustainable development in marine systems are now integral parts of international, domestic and customary law in many countries and international instruments and regulations are under development for seabed mining which is expected to drive the integration of biodiversity and ecosystem services into practice if the industry develops.

However, the deep-seabed mining sector differs from the nearshore and shallow water mining, oil and gas or terrestrial mining sectors in terms of permitting, regulation and governance standards. Some activities take place within national jurisdiction and are subject to the laws of the host country, but nearly all planned deep-seabed mining operations lie in international waters under the governance of the International Seabed Authority, (see Section 3 for further details). With 2020 being the Ocean Year and a focus on the Post 2020 Biodiversity Agenda, significant attention is being given to the safeguarding of the oceans and marine natural resources. International instruments governing the oceans within and beyond national jurisdiction are covered in more detail in Section 3.

Regulations for the exploitation of mineral resources in the deep seabed beyond the limits of national jurisdiction (the Area) are currently under development by the International Seabed Authority. Under the UNCLOS, social and environmental concerns are to be a prominent feature of any future mining regime. UNCLOS designates the Area and its [mineral] resources as the “Common Heritage of Mankind” and charges the International Seabed Authority with managing the Area and its resources on behalf of all humankind.

Working drafts of International Seabed Authority Regulations and Standard Contract Terms, focused on procedural and financial issues, have been issued for consultation and draft regulations for environmental components are expected to follow in early 2020. These documents will include details of how environmental impact statements are to be prepared, submitted and assessed; processes for public participation in their review; and requirements for an environmental permit and societal licence in order to proceed to exploitation. Procedures will also be elaborated for site-specific Environmental Management and Monitoring Plans, including emergency orders to alter operations to prevent serious harm, and Closure Plans. The environmental regulations will also place on the International Seabed Authority the requirement to develop regional-scale Environmental Management Plans (sometimes referred to as Strategic Environment Management Plans) and a Seabed Mining Directorate or Mining Inspectorate.

There are clear gaps in the International Seabed Authority’s current Draft regulations, and they are ramping up towards self-imposed 2020 deadlines for completion of their new Mining Code. The Code will be the definitive regulations governing all deep-seabed mining in the Area. Suggestions to draw from other international legal policy are fundamentally important, including the London Protocol, the Madrid Protocol Article 3 (Environmental Principles) and the Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA). Kirkham *et al* (2020) provide important exploration of regulatory precedents relevant to deep-seabed mining from which policy options can be drawn to assist the International Seabed Authority, as well as the international community, to achieve its balancing act of precaution-based development of deep-sea minerals and successful protection of deep-sea ecosystems.

The established recognition of Antarctica’s dominant role in regulating regional and global climate systems, and its prolific inclusion throughout CRAMRA and the Protocol, gives this provision substantial reach (Kirkham, Gjerde and Wilson, 2020) – Box 6. Lessons from this process need to be applied to those underway within the International Seabed Authority.

BOX 6

The Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA) and provisions relevant to the governance of deep-seabed mining

The following provisions from CRAMRA potentially provide useful models for rules, regulations and procedures, as well as institutional capacity, of the International Seabed Authority to meet a high level of environmental protection while seeking a precaution-based approach to future deep-seabed mining operations (Kirkham, Gjerde and Wilson, 2020):

1. **A dependent and associated ecosystem** (CRAMRA Preamble) is a provision that recognises impacts on ecosystems that depend on or are associated with deep-seabed mining sites regardless of distance. Inherent in this provision is a recognition of the deep sea's wider role in regulating regional and global climate.
2. **The sufficient information requirement** (CRAMRA Article 4(1)) that places the burden of acquiring sufficient information regarding environmental impacts on the potential operator prior to approval of plans of work. This provision includes the negative assumption of approval until such a time that the contractor's capacity to provide sufficient information exists. In other words, if they lack the capacity, no mining will take place.
3. **Cumulative impact assessments** under CRAMRA (Article 4(5)) require environmental impacts be assessed cumulatively with all other users of the Antarctic content, irrespective of activity or objective. This wide-scale approach is not limited to mineral resource activities only - as is the case within the International Seabed Authority's current draft exploitation regulations - and aggregates the requirement of sufficient information prior to application approval.
4. The vital and far-reaching role of an **independent scientific, technical and environmental advisory committee** under CRAMRA (Article 23) ensures that the Antarctic environment, and CRAMRA's strict precaution-based measures, are represented throughout the approval process. Although the mandate of the International Seabed Authority's Legal and Technical Committee includes many environmental functions, a specifically focused committee could be in a better position to address the many and diverse environmental challenges that have arisen and will arise.
5. CRAMRA's **alternative of not proceeding** provision (CRAMRA Article 26) requires potential Antarctic operators to assess the environmental baselines of an area and the impacts on that environment if resource development did not occur. This consideration could be part of a requirement for the applicant to show that no significant adverse impacts will occur due to the mining activities and to encourage a proactive development of alternatives to mineral extraction in the Area.

2.4.6 Heightened public awareness and reputation

Heightened public awareness of human impacts on the oceans is likely to increase scrutiny on the seabed mining sector. This awareness stems from publicity surrounding industrial accidents, such as the Deepwater Horizon in the Gulf of Mexico, documentaries highlighting human impacts on the oceans such as Blue Planet 2, and numerous campaigns to minimise marine plastics. Consequently, the seabed mining sector is likely to experience reputational, operational and financing risks in response to any governmental and societal concerns about declining biodiversity and ecosystem services.

The reputational and financial implications of poor environmental performance are well recognised, and the most material way in which biodiversity risk expresses itself is by preventing or delaying business activity. This may lead to loss of access to market and generate long-lasting reputational damage. Conversely, the reputational benefits of responsible environmental practice may be realised through improved access to tenements and resources which may translate to an improved share price.

Concerns about the role the deep sea has in regulating regional and global climate systems, as well as affecting distant but still associated ecosystems, underscores the need to consider the interconnectedness of the "marine environment" when developing the regulations and assessing deep-seabed mining impacts (Kirkham, Gjerde and Wilson, 2020). A need to recognise the globe-regulating functions of the deep ocean, prior to deep-seabed mining activities commencing, has been highlighted by deep-sea scientists (Franks *et al.*, 2010). Preserving the deep ocean's biodiversity, its natural ability to regulate ocean and climate systems and its potential for future scientific discoveries has a currently unknown value, as does its' dependent and associated ecosystems (Davies, Roberts and Hall-Spencer, 2007). There are benefits in clarifying the requirement to recognise and protect dependent and associated ecosystems for them to be better understood and applied.

2.5 Managing risk

Investment in seabed mining will only occur in situations where risk can be adequately balanced with benefits. Managing risk is approached through the assessment of trade-offs and the perceived acceptability of impact versus benefit. This approach is driving the economic argument to access seabed mineral resources. Core to understanding the economic potential of marine resource extraction, and in particular seabed mining, is to:

1) determine the in-situ value of minerals given the technologies available to exploit them;

2) deduct from the in-situ value of minerals the capital and operating costs and risk-adjusted private returns associated with investing in the location, appraisal and exploitation of mineral deposits; and

3) consider how any costs attributable to social and environmental impacts are treated, for purposes of weighing the net private and public benefits of seabed mining, taking into account the public cost of environmental impacts.

Where a high level of uncertainty is associated with any of the three factors highlighted above, investment is less likely. Further, the regulatory mechanisms through which risks are allocated among private and public actors are far from fully developed. Any assessment of the overall cost/benefit of proceeding with seabed mining, therefore, faces a set of challenges that is significantly greater than typically encountered in the case of terrestrial mining (Box 7). To date, there have been rather few comprehensive evaluations of the cost/benefit of seabed mining, other than those contained in project-specific submissions by project sponsors to regulators and financial institutions.

The final point relating to the costs of impacts, is particularly difficult to attribute and is highly contentious, as the specific impact of seabed mining on marine life and habitats, particularly in the deep sea, and impacts for the arger ocean ecosystem remain largely unknown.

BOX 7

Summary of challenges and considerations for the exploitation of deep-seabed minerals

- **No deep-seabed mining currently taking place:** So far, only deep-sea exploration in the Area and in a limited number of countries is taking place. The seabed mining sector is still in its developmental, frontier stage. There are many unknowns and concerns that need to be carefully addressed if this seabed mining industry is to progress.
- **Management of health, cultural and other social risks:** Some developing nations generating significant revenues from extractive industries have experienced a range of social challenges. The trigger for these challenges varies and includes the impacts of environmental degradation, the rapid influx of money into the local economy and the presence of larger numbers of returning nationals and foreign nationals in the community over the medium to long term.

BOX 7 (cont.):

- **Lack of seabed data:** The deep-seabed mining sector is an emerging industry, and there is still limited data currently available on the deep seabed and associated environment. National Governments also expect this to be the case for the seabed in the Area for which the host nation becomes a sponsoring state. The lack of data may complicate decisions on the necessary initial investment, technology, risks, impacts, environmental assessments and mitigation measures. The collection and review of data from exploration activities is expected to assist in overcoming the current lack of information and understanding of issues related to mining activities.

- **Reliability of data sourcing:** The source of new data about deep-seabed resources and the associated environment, which is required to assist the International Seabed Authority and Government decisions about mining activities, is likely only to come from private sector entities (i.e. companies given Titles or Contracts to conduct prospecting and exploration), given the high cost of marine scientific research in the deep oceans.

- **Environmental protection:** It remains a critical priority of all responsible Governments that seabed mining activities be carried out in a manner that does not lead to significant impact on marine ecosystems and are consistent with internationally accepted rules, standards, principles and practices and care for the environment (under UNCLOS) and other relevant conventions, treaties and agreements (See Annex 1: Legal Frameworks). A lack of data (see above) may compromise effective environmental management, while monitoring and enforcement activities may be complicated by the remoteness of seabed mining activities, in terms of the distance of both: surface ships from shore; and mining activities from the surface.

- **Government capacity to administer the legislative scheme:** Most governments, but in particular Small Island States (SIS) where much of the current foreign investment focus is occurring, have limited resources to ensure adequate legislative regimes are established and implemented. In the case of SIS, geographical remoteness and the further remoteness of seabed mining activities challenge the ability to provide sufficient numbers of suitably qualified, trained and experienced personnel to the institutions responsible for the licensing, environmental, fiscal and safety regulation of mining activities. Management of conflict of interest and avoidance of undue influence are also challenges facing small Governments. Capacity training and international support is fundamental to avoid coercion or collusion and to enable sovereign control over a nation's seabed mineral resources.

- **Attracting suitable investors:** Investors will only be interested in the seabed resources if they consider the investment secure (and profitable) and the operating environment to be relatively risk-free. The higher the costs of seabed mining activities incurred by investors, the lower the profits (and the less attractive as an investment). Efforts from the international Banking Community need to ensure full application of environmental, social and governance safeguards. Alignment to the standards set by the Equator Principle Finance Institutions and the United Nations Environment Programme's Finance Initiative are fundamental to ensure full accountability of both company and their Lenders to deliver best practices throughout the cycle of any proposed project.

- **Full accountability:** There can be no cost-cutting or short-cuts taken. Factors that need to be internalised in feasibility studies include: regulatory controls, environmental protection measures, costs of best available technology and equipment, and the market value of minerals and metals. For example, all costs of conducting seabed mining under national jurisdiction affect the international competitiveness of the nation among potential investors, and may impact its capability to attract the highest quality investment.

3 Existing policy, regulation, standards and guidance

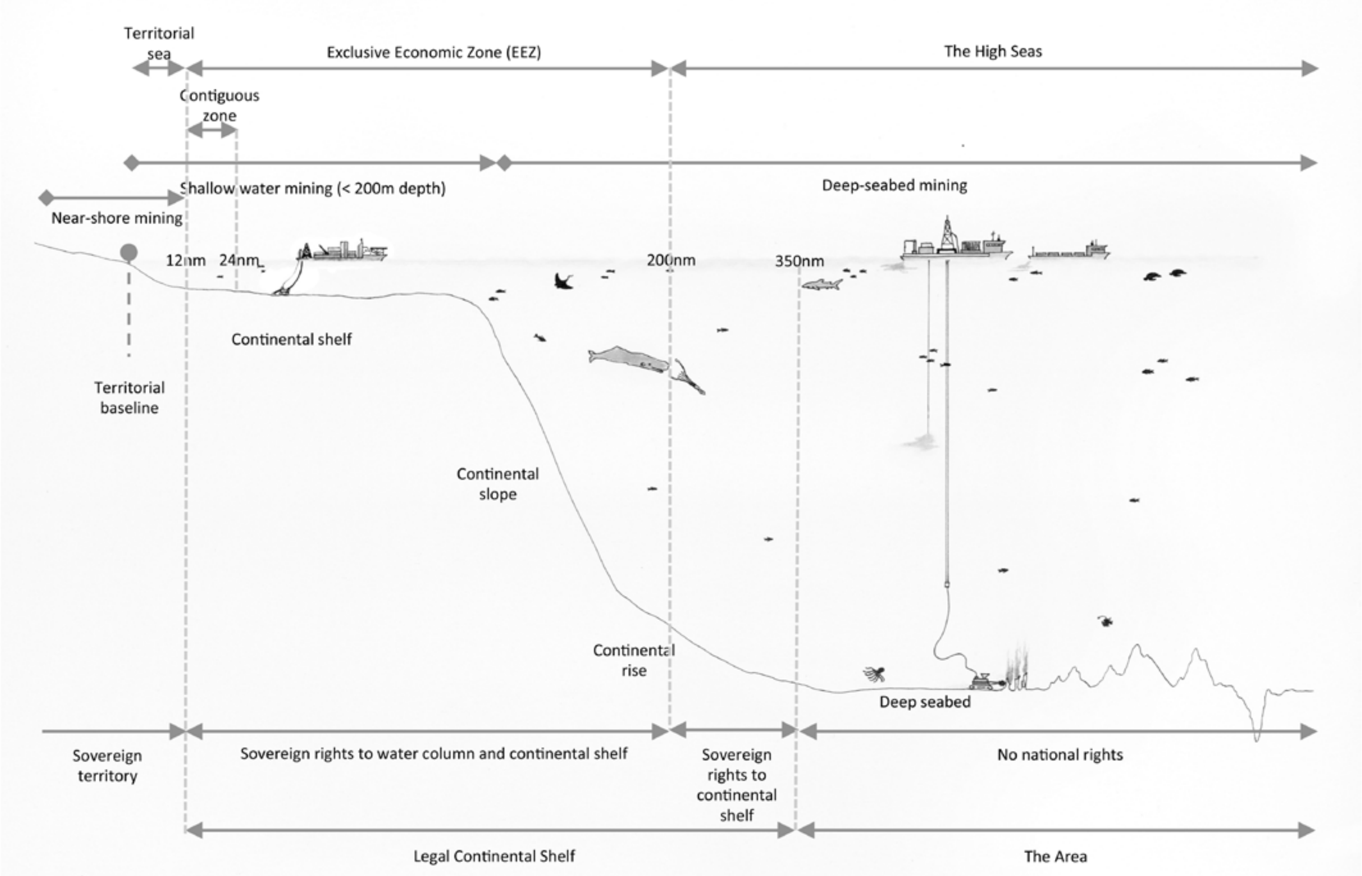
In this section, existing and emerging governance, policy and regulation relating to the management of marine resources are presented, along with relevant standards and guidance.

At present, activities that impact on the seabed, including proposed mineral extraction, are set to be regulated differently depending on whether they are in the Area (beyond national jurisdiction) or on continental shelf areas (under a diversity of national jurisdictions). The UNCLOS, which entered into force on 16 November 1994, established the jurisdictional framework for the management of ocean space and defined the rights, duties and responsibilities of States with respect to the use of ocean space and ocean resources (United Nations General Assembly, 1982).

3.1 Maritime zones and the jurisdictional limits of seabed mining activities

Deep-sea mineral deposits occur in various Maritime Zones (Figure 2). Maritime Zones are defined and described under UNCLOS, the primary legal instrument for the governance of the world's oceans and seas. It sets out the following rules governing all uses of the oceans and their resources and who has rights and jurisdiction over them – i.e. who can permit and govern seabed mining activities.

Figure 2 : Maritime zones under UNCLOS and operating jurisdictions of seabed mining (nm = nautical mile). Illustration not to scale.



Credit: Nicky Jenner/FFI

Clarity over these territories is important and is often a hotly disputed issue. The undisputed territory and jurisdictional limit of a Nation can be determined by the UNCLOS process which includes the following considerations:

3.1.1 Baselines

In order for States to determine and measure the maritime zones applicable to their territories, States start by determining their baselines – which is essentially the definition of and sovereign claim to offshore, ocean and seabed territory. Once a coastal State has determined its baselines, it must make those baselines publicly known in charts or lists of geographical coordinates and deposit a copy of each such chart or list with the Secretary General of the United Nations, in terms of Article 16(2).

3.1.2 Territorial Sea

The breadth of a coastal State's territorial sea is up to a limit not exceeding 12 nautical miles, measured from its baselines.

3.1.3 Contiguous Zone

The contiguous zone is the area 'contiguous' to the costal State's territorial sea, which may not extend beyond 24 nautical miles from the baselines from which the breadth of the territorial sea is measured.

3.1.4 Exclusive Economic Zone (EEZ)

The Exclusive Economic Zone (EEZ) is an area beyond and adjacent to the territorial sea, which in addition shall not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured (see Box 8).

BOX 8

Example of EEZ in the Pacific Ocean, an area under intense exploration for seabed minerals in both national and international waters

The total area of EEZs controlled by Pacific Island Countries and Territories is 27.8 million square kilometres (compared with a land area of about 531,000 square kilometres - a ratio of 52:1) - see below. Additionally, the area of Extended Continental Shelf (ECS) represents an additional 2.0 million square kilometres, over which coastal states exercise jurisdictional rights over mineral resources.

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3.1.5 Continental Shelf

According to the Commission on the Limits of the Continental Shelf, the Continental Shelf of a coastal State comprises the submerged prolongation of the land territory of the coastal State - the seabed and subsoil of the submarine areas that extend beyond the coastal State's territorial sea to the outer edge of the continental margin, or to a distance of 200 nautical miles where the outer edge of the continental margin does not extend up to that distance. The continental margin consists of the seabed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.

3.1.6 The "Area"

The "Area" is defined in Article 1 of UNCLOS as the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction. The Area and its resources are the "common heritage of mankind" as stated in Article 136. All rights in the resources of the Area are vested in "mankind as a whole." The concept of the common heritage of mankind promotes the uniform application of the highest standards for the protection of the marine environment and the safe development of activities in the Area (Weaver and Billett, 2018). It is the International Seabed Authority which is authorized to act on behalf of mankind in respect of the Area.

3.2 Governance of the High Seas and instruments to protect marine biodiversity

Pew Charitable Trusts have published an excellent summary of the Governance Gaps on the High Seas (2017). The report highlights the patchwork of international bodies and treaties that govern ocean resource and human activity in areas beyond any state's national jurisdiction. However, these governance bodies vary greatly in terms of their mandate, which determines their geographic scope and objectives, the legally binding nature of decisions they adopt, and whether they regulate one or several activities. Their report points out that jurisdictions often overlap, but virtually no mechanisms exist to coordinate across geographic areas and sectors. Too often, this piecemeal governance approach leads to the degradation of the environment and its resources, and makes deploying management and conservation tools such as environmental impact assessments and Marine Protected Areas, including marine reserves, challenging both legally and logistically.

A new treaty is under discussion to govern biodiversity beyond national jurisdictions. The following maps (Figures 3, 4 and 5) help to illustrate the current governance gaps on the High Seas and emphasise the critical need for this treaty. For governance organisations to effectively manage and conserve life on the High Seas, three key elements are necessary: regulatory authority, a mandate to conserve the ecosystem as a whole, and the ability to manage across multiple sectors. Although some organisations have two of these three elements, they all lack comprehensive mandates to effectively manage and conserve ecosystems on the High Seas.

Although there are many examples of multiple organisations managing the same region, few mechanisms exist to facilitate communication or coordinate activities among them (Pew, 2017). Most organisations with a mandate that extends to areas beyond national jurisdiction do have regulatory authority, or the ability to create binding management measures (Figure 3). However, the vast majority of these organisations are limited to fisheries management.

High Seas governance organisations differ greatly with respect to the emphasis their mandates place on conservation. Pew points out that "most are charged primarily with managing resources, such as fisheries, though some of those organisations have mandates that call for the additional application of the ecosystem and/or the precautionary approach. In fisheries management this means accounting for impacts of fishing on the ecosystem and erring on the side of caution, even in the face of scientific uncertainty, if a decision could result in serious damage to the environment". Only the organisations shown in Figure 4 have a mandate that focuses primarily on conserving the marine environment.

Figure 3: Organisations having regulatory authority on the High Seas. Credit: Pew Charitable Trust 2017

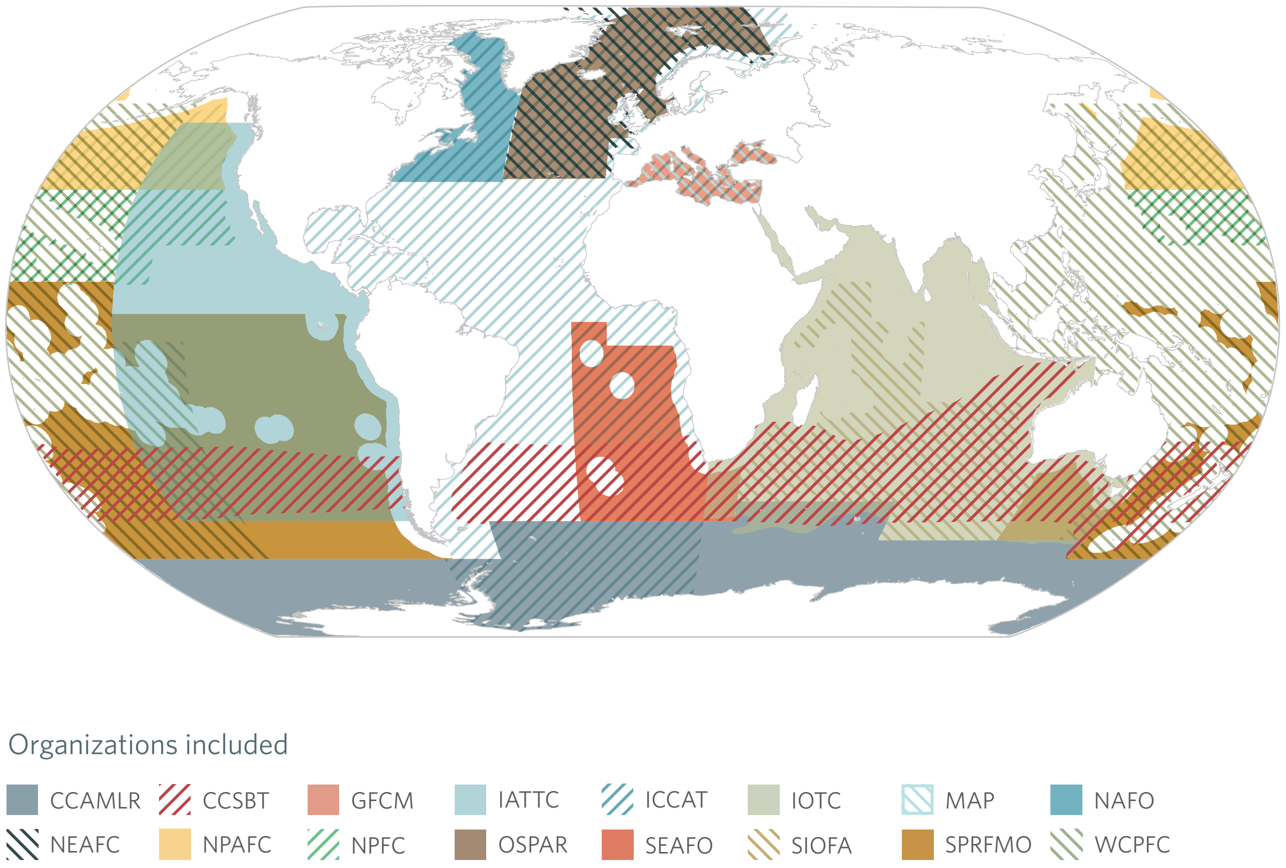
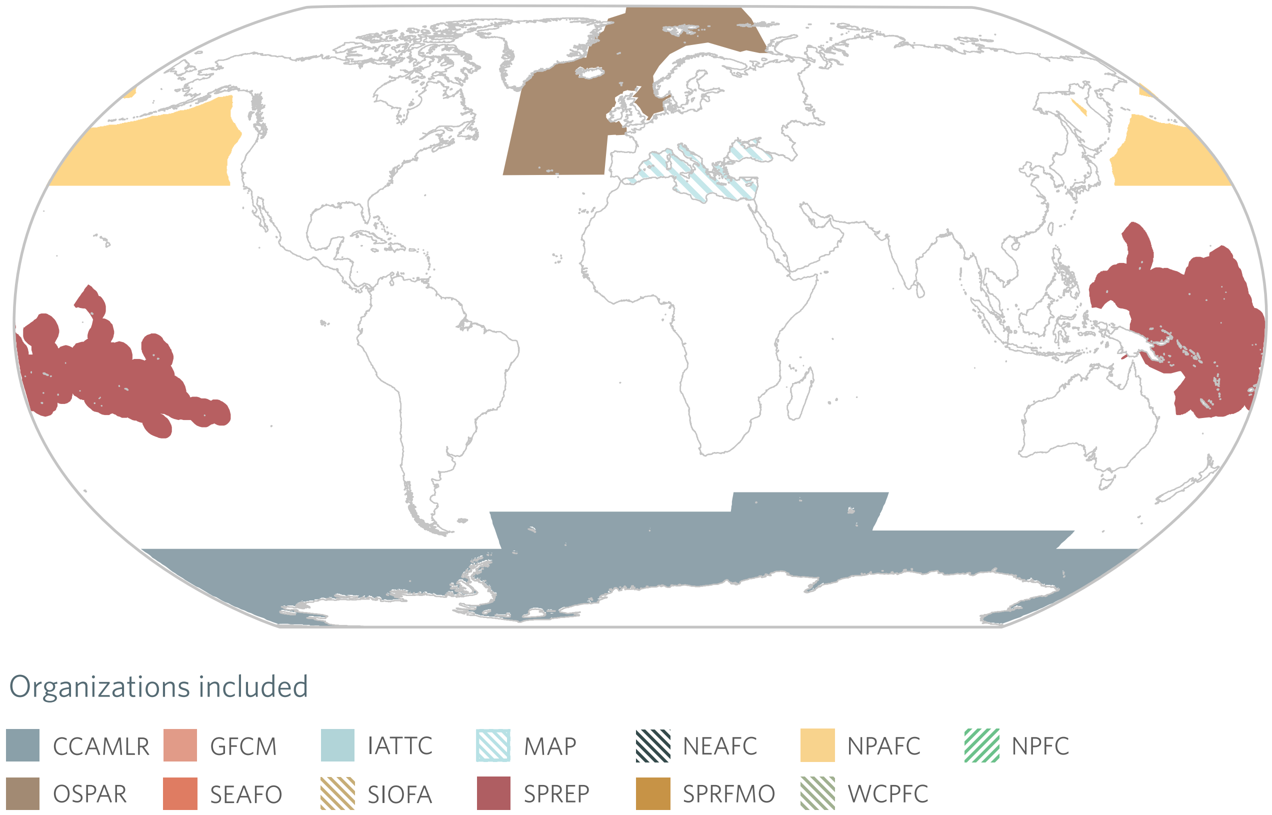


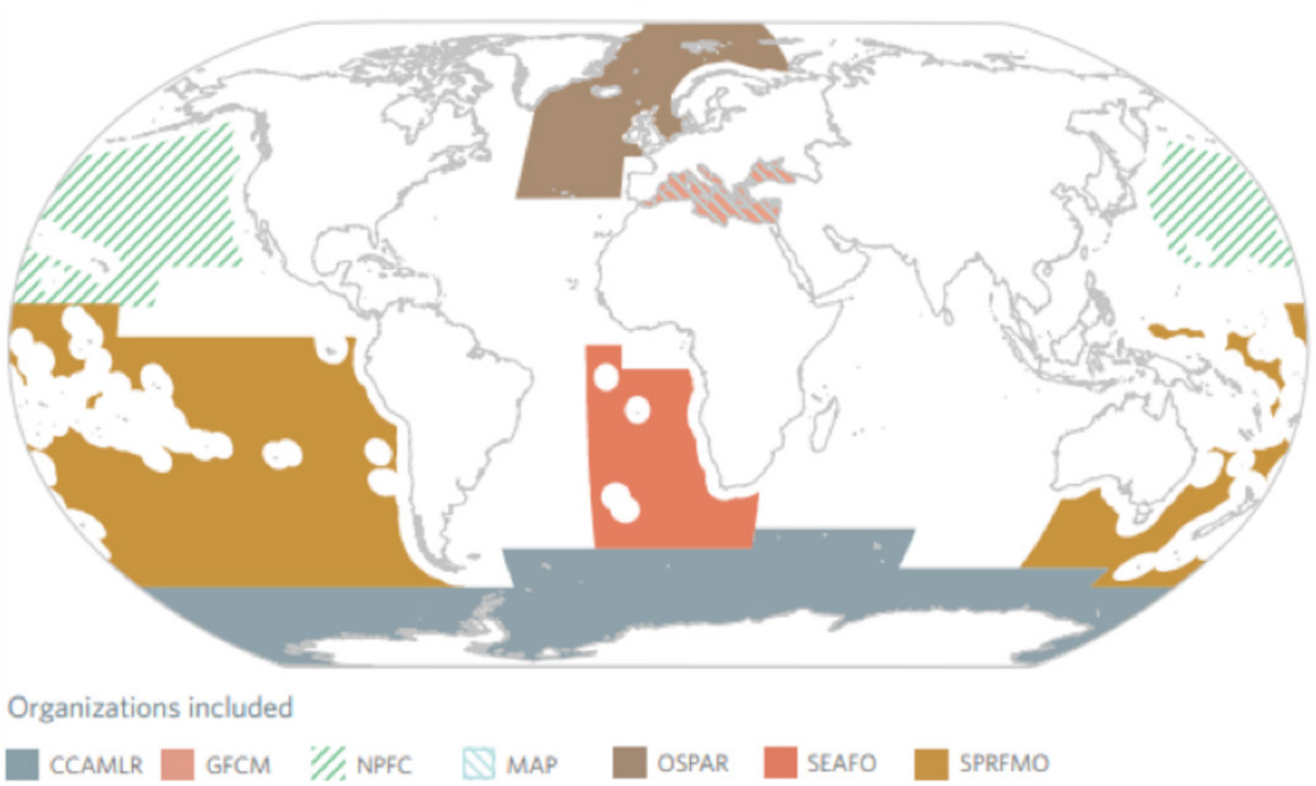
Figure 4: High Seas organisations with primary conservation mandate. Credit: Pew Charitable Trust 2017



Single-sector management organisations face many challenges in governing areas in the High Seas, in part due to a lack of communication and coordination with spatially overlapping organisations. Comprehensive, multi-sector, ecosystem-based management is a key element of accounting for ecosystem synergies and maintaining High Seas biodiversity. Yet no mechanism currently exists to account for the cumulative impacts of fishing and mining in a region, even though environmental impacts may escalate if both activities happen concurrently. Lack of coordination could endanger their shared ecosystem.

Most High Seas governance organisations operate under mandates that consider only one sector, such as fisheries, shipping, or mining. A handful of those single-sector organisations are empowered to create legally binding measures that broadly address the ecosystem, giving them an advantage over other single-sector organizations (Figure 5).

Figure 5: High Seas organisations able to create legally binding measures for ecosystem management. Credit: Pew Charitable Trusts 2017



Instruments for conservation and sustainable development in marine systems are now integral parts of international, domestic and customary law. As of 2014, 162 nations have ratified the UNCLOS (which also entails being an International Seabed Authority member), putting 42% of the world's oceans under the control of coastal nations. These nations have a legal right to extend their respective maritime claim and hold a seat on the commission that reviews seabed mining plans. The United States has not ratified the UNCLOS, and holds an observer status. In practice, the EEZ is recognised by most states. Companies interested in exploiting marine resources are required to obtain a licence prior to initiating their operation, and the application is required to be sponsored or partnered by a country under the UNCLOS. In international waters outside countries' 200 nautical miles EEZ, the International Seabed Authority issues exploration and mining licences. Currently, the International Seabed Authority has issued 26 deep-sea exploration licences for international waters covering seabed area of 1.2 million square kilometres, and national governments have granted licences or received applications for a total of 25 explorations and mining campaigns located within their EEZ. While the legal framework for mineral exploration is in place, the overall regulatory regime for the international seabed does not yet include seabed exploitation (Frimanslund, 2016).

The UNCLOS addresses issues such as the delineation of maritime space, rights over marine resources, protection of the marine environment from pollution and other harmful effects, and conditions for the conduct of marine scientific research in all areas of jurisdiction. One of the key prerequisites to effective spatial management is to understand the different jurisdictional aspects of maritime space, and to appreciate that different regimes apply within national jurisdictions, on the High Seas, and in the Area. For example, seafloor massive sulphide deposits and their associated deep-sea chemosynthetic ecosystems may be found entirely within national jurisdiction, on the outer continental shelf (which is under national jurisdiction although the overlying water column is subject to the regime for the High Seas), or in the Area.

A special regime, elaborated in Part XI of the UNCLOS and a related implementation agreement, deals with the development of mineral resources in the seabed and subsoil of the Area beyond national jurisdiction. The UNCLOS also establishes the International Seabed Authority as the institution through which States Parties to the UNCLOS are to organise and control prospecting, exploration and exploitation of mineral resources in the Area. Such activities may not be carried out without a licence issued by the International Seabed Authority in accordance with its rules, regulations and procedures.

To date, the International Seabed Authority has issued regulations governing prospecting and exploration for polymetallic nodules (adopted 13 July 2000) and polymetallic sulphides (adopted 7 May 2010). These regulations include requirements relating to environmental protection, including for exploration licence holders to collect and report environmental baseline data, carry out environmental monitoring programmes under the supervision of the International Seabed Authority, and to establish environmental baselines against which impacts from anticipated mining activities can be assessed. The International Seabed Authority Legal and Technical Commission issues recommendations to guide licensees in performing these obligations and regularly reviews reports and data collected. These recommendations are periodically reviewed with the assistance of the scientific research community, industry representatives, and other stakeholders to ensure they are based on the best available knowledge and reflect current best practice.

A number of other international instruments are also relevant to the conservation of biodiversity in the marine environment:

- The Stockholm Declaration (arising from the 1972 Stockholm Conference on Environment and Development) laid the groundwork for acceptance of sustainable development as a core principle for the management of human impact upon the environment.
- This principle is reaffirmed and elaborated in subsequent declarations and instruments, including the Rio Declaration (1992) and the Convention on Biological Diversity (CBD) (1993).
- One of the main goals of the CBD is conservation of all biodiversity, recognising that ecosystems, species and genes must be used for the benefit of mankind, but that this use should be accomplished without a long-term decline in biodiversity and irresponsible environmental damage.
- The Rio Declaration and the CBD support the ‘Precautionary Principle’, which emphasises preventive action in the face of uncertainty and shifts the burden of proof to those who wish to undertake or continue an activity that poses a threat of serious or irreversible damage.
- The CBD further endorses an ecosystem approach (Secretariat of the Convention on Biological Diversity (CBD), 2004) as a preferred strategy for integrated and adaptive management to promote conservation and sustainable use.
- The CBD promotes the use of area-based management tools and has adopted a set of seven scientific criteria to identify Ecologically and Biologically Significant Areas (EBSAs) in the global marine realm (CBD, 2019). These are considered *“special areas in the ocean that serve important purposes, in one way or another, to support the healthy functioning of oceans”.*
- The CBD includes also the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization, which entered into force on 12 October 2014, applies to genetic resources within the scope of CBD Article 15 (Access to Genetic Resources).

Delegates at the World Summit on Sustainable Development called for the establishment of representative networks of Marine Protected Areas, consistent with international law and based on scientific information by 2012 to promote conservation and management of the oceans (Johnson *et al*., 2020). Further, the UN General Assembly, as part of its annual review of oceans and the UNCLOS, has passed several resolutions regarding the protection of the ocean, notably resolutions UN General Assembly 61/105 (2006)11 and 64/72 (2009)12 which set out to protect Vulnerable Marine Ecosystems from the damaging effects of bottom fishing. Hydrothermal vents, together with seamounts and cold-water corals, are cited as examples of Vulnerable Marine Ecosystems in UN General Assembly 61/105, which recognises “the immense importance and value of deep-sea ecosystems and the biodiversity they contain” (Watling and Auster, 2017). Consistent with UNCLOS obligations, UN General Assembly resolutions, and decisions reached in the framework of the CBD, a number of regional arrangements have implemented measures for the protection of the marine environment, including the environment in areas beyond national jurisdiction (Box 10).

BOX 9

Applying the precautionary principle

Where there is uncertainty, the threat of environmental damage and the potential for threats to lead to serious or irreversible harm, a precautionary approach must be applied. A lack of certainty regarding the threat of environmental harm should never be used as an excuse for not taking action to avert that threat. Delaying action until there is compelling evidence of harm will often mean that it is then too costly or impossible to avert the threat (Niner *et al.*, 2018). In practical terms, this means:

- Use of the best information available and meaningful engagement with all relevant stakeholders and rights-holders.
- Development of robust baselines of the appropriate scale, scope and depth
- Explicit recognition of uncertainties, gaps in information, and limitations of available methods for detecting and assessing threats.
- Evaluation of different mitigation options and the consequences of various courses of action and inaction; prioritising avoidance and minimisation of potential impacts to the maximum extent practicable.
- Application of well-accepted ways to add contingency when calculating biodiversity losses and gains in order to account for risks, and compensate for the time between losses occurring and gains being fully realised.
- An adaptive management approach involving the monitoring of mitigation and management actions, and evaluation of outcomes.

The Precautionary Principle is yet to gain unanimous support within UNCLOS yet is extremely necessary as the marine system is highly connected, causing hazardous effects of certain activities to spread out. Given the vulnerable nature and connectivity of the oceans, limited information and knowledge on marine biodiversity, ecosystem processes, and services, and poor understanding of the full effects of activities such as deep-sea mining in this environment, a risk based approach and application of the Precautionary Principle is essential.

In light of these constraints, when and if deep-sea mining proceeds, it must be approached in a precautionary and step-wise manner to integrate new and developing knowledge. Each step should be subject to explicit environmental management goals, monitoring protocols, and binding standards to avoid serious environmental harm and minimise loss of biodiversity (Niner *et al.*, 2018).

Although there are nearly 20 High Seas governance organisations, none has a comprehensive cross-sectoral mandate with regulatory authority and a focus on conservation in areas beyond national jurisdiction (Pew, 2017), (Figure 6). There is a huge gap in High Sea governance for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction.

If deep-seabed mining becomes a reality, a globally harmonised system for protecting the seabed will be needed (Wedding *et al.*, 2015). In common with many of the instruments applicable to their overlying waters, a harmonised system would need to take into account stressors such as ocean acidification, climate change and pollution, and key gaps in knowledge relating to marine biodiversity and ecosystem services and ocean processes. A harmonised approach could help to avoid fragmented, inconsistent approaches to regulating activities in different regions, though some level of systematic and permanent damage to ecosystems would be unavoidable. When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions (United Nations Oceans & Law of the Sea (UNCLOS), 2016). Conflicts could arise if a sovereign State does not agree with a harmonized system of ocean governance.

Figure 6: International organisations with regulatory authority to enact comprehensive conservation measures across multiple sectors on the High Seas include CITES, IMO and IWC – all oceans covered (not coloured). Credit: Pew Charitable Trusts 2017

BOX 10

Examples of regional arrangements to govern biodiversity in international waters

- Regional Fisheries Management Organizations (RFMOs), which have a duty to conserve all species associated with and dependent upon the fisheries that they seek to regulate. Membership in RFMOs includes fisheries nations, but although membership is encouraged, and includes most major players, it remains voluntary. If a nation does not join an RFMO, its flagged vessels may still operate in an RFMO region, although they will not be recognised by the RFMO or assigned quotas. The responsibilities of RFMOs are outlined in various international agreements, including the Food and Agriculture Organisation of the United Nations (FAO) Code of Conduct for Responsible Fisheries and the United Nations Fish Stocks Agreement, both adopted in 1995. Some RFMOs are moving towards taking an ecosystem approach to management, and some have enacted fisheries closures in areas beyond national jurisdiction in order to protect Vulnerable Marine Ecosystems.
- Regional seas agreements that were often formulated to prevent and control pollution but now have begun to protect areas within and beyond national jurisdiction in order to protect biodiversity, such as:
    - The Convention for the Protection of the Marine Environment of the North-East Atlantic – the ‘OSPAR Convention’ (OSPAR, 2019)
    - Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean.
    - The Nairobi Convention, part of UN Environment’s Regional Seas Programme. The programme aims to address the accelerating degradation of the world’s oceans and coastal areas through the sustainable management and use of the marine and coastal environment. It does this by engaging countries that share the western Indian Ocean in actions to protect their shared marine environment.
- Multilateral agreements such as the Noumea Convention for the Protection of the Natural Resources and Environment of the South Pacific Region, in which Parties have agreed to take all appropriate measures to prevent, reduce and control pollution in the Convention Area resulting directly or indirectly from exploration and exploitation of the seabed and its subsoil.
- The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which is applicable to the Antarctic marine living resources of the area south of 60° South latitude and to the Antarctic marine living resources of the area between that latitude and the Antarctic convergence which form part of Antarctic marine ecosystem (see also Box 6 in Section 2.4.5).

3.3 Operating in international waters

Discussions to establish the UNCLOS began in the early 1970s as an international treaty to manage the seas and was formally signed in 1982 (Box 11).

BOX 11

The International Seabed Authority (ISA)

The ISA was established in 1982 under the UNCLOS with the specific purpose to regulate and control activities related to seabed minerals in the area beyond national jurisdiction (the 'Area'). The ISA came into existence when UNCLOS entered into force in 1994. The ISA is comprised of an Assembly, a Council, and a Legal and Technical Commission, as well as a Finance Committee and a Secretariat. The Assembly, the supreme organ of the Authority, is composed of all States Parties to UNCLOS. Council consists of 36 members of the Authority (which are the same as States Parties) elected according to a complicated formula related to consumption and production of minerals and special interests, such as landlocked countries. The Legal and Technical Commission is currently composed of 30 individual members elected by the Council. While the Assembly and Council are open to observers, the Legal and Technical Commission holds its meetings in closed session, despite having been encouraged by Assembly to hold more open meetings to allow for greater transparency (Assembly resolution ISBA/23/A/13 -18 August 2017). In addition, the so-called Enterprise is empowered to conduct exploration and exploitation of seabed minerals on behalf of the international community but no steps have yet been taken to set the Enterprise into motion.

The ISA has entered into 30 contracts for exploration: 18 for polymetallic nodules in the Clarion-Clipperton Fracture Zone and Central Indian Ocean Basin, 8 for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and 5 contracts for cobalt-rich crusts in the Western Pacific Ocean (ISA, https://www.isa.org.jm/deep-seabedminerals- contractors. Accessed 2 April 2018). The ISA has developed regulations for exploration of the three main types of minerals, and is currently in the process of developing regulations for their exploitation. Measures developed in the ISA apply only to the Area: regulation on the continental shelf is for the coastal State. As stated in UNCLOS article 208.3: "Such laws, regulations and measures shall be no less effective than international rules, standards and recommended practices and procedures."

Management of seabed mining as currently organised and envisaged is fragmented – because it is partly under ISA jurisdiction and partly under State control – and lacks transparency in many respects (Lallier and Maes, 2016; Durden *et al.*, 2017, 2018). The Legal and Technical Commission of the ISA still holds its meetings in closed session, despite encouragement from the ISA Assembly to hold more open sessions and allow greater transparency. Workshops to develop policy are primarily run by invitation only. This contrasts with the relative openness of frameworks governing other aspects of maritime law, including the International Convention for the Prevention of Pollution from Ships (MARPOL) and the allied London Convention and Protocol (on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter), which have long traditions of active independent scrutiny by technical experts and observer organizations. Ardron et al (2019) suggest that accountability could be improved by giving the public and non-government organizations greater access to information and that seabed mining management could be improved through more effective reporting of activities, quality assurance, compliance and an independent panel to review decisions. As well as opening the Legal and Technical Commission to observers, implementation of an environmental committee, as discussed in the ISA Council in March 2018, would assist in better integration of science with policy considerations. A mechanism is still to be developed to assess environmental costs and detriment, social concerns and to integrate a dialog with stakeholders on the need for seabed mining. The ISA is currently developing exploitation regulations, which must ensure the effective protection of the marine environment from harmful effects (UNCLOS, article 145).

3.3.1 The role of the International Seabed Authority in promoting best practice

According to scientists within the MIDAS project, the International Seabed Authority can promote and encourage the use of best practice with regular engagement with the community of experts. Clear and transparent decision making, preferably with public review, will ensure that the community is made aware of all developments. If the International Seabed Authority is receptive and has a clear mechanism for engagement then the latest advances in technology and scientific research will likely be communicated. A possible way of ensuring that all current best practice is incorporated into International Seabed Authority guidelines is to have a regular review of approaches (possibly biannually) that encourages stakeholder participation. Another solution would be to provide a research funding mechanism that will attract submission of new ideas in the form of research grants. The funding mechanism could be supported by licensing funds and could focus on best practice development and in enhancing regional understanding and international cooperation between research institutions. The International Seabed Authority also needs to adopt a strong leadership position with regard to environmental issues, which will encourage nation states to adopt similar standards.

In its 25 years of existence, the International Seabed Authority has adopted regulations and guidance for exploration activities; in 2013 it began the development of regulations to govern the future exploitation of seabed minerals, starting with polymetallic nodules. The decisions made by the International Seabed Authority have wider relevance, since under UNCLOS (Article 2008) national laws and regulations for mining activities within national jurisdiction are to be “no less effective than” the international rules, standards, and recommended practices and procedures.

In the case of mining in the Area, mining companies need a State sponsor. The State sponsor has to exercise due diligence to ensure that the mining company complies with International Seabed Authority rules, regulations, standards and procedures. There is no specific guidance for this and at present relationships are developed on a case-by-case basis. There is a requirement, though, to follow Best Environmental Practice and for the sponsor to exercise a high degree of due diligence following a ruling in 2011 by the Seabed Disputes Chamber of International Tribunal for the Law of the Sea (ITLOS). The ruling is detailed in The Advisory Opinion of the ITLOS Seabed Disputes Chamber on the responsibilities and obligations of States sponsoring entities with respect to activities in the Area. The ruling stressed that “due diligence” includes the need for all States to ensure they have the administrative capacity to monitor, supervise and enforce their laws. No State is exempt from this requirement due to the need to avoid the potential rise of ‘sponsoring States of convenience’ applying weaker regulatory measures. This means that States may need to introduce new laws, administrative procedures and resources to regulate their enterprises to meet the expected standard. If laws are not enacted and enforced States may be held liable for damage including to the marine environment (Billett *et al.*, 2015).

Governance of seabed mining matters are further complicated by the different governance regimes in place for the exploration and exploitation of the seabed and its resources. A major advantage in developing standardised best practices for deep-seabed mining is that there is one principal global regulator. Unlike most deep-water industries, there is a higher potential for seabed mining to be carried out in areas beyond national jurisdiction than in national waters. This may in part be due to the governance and regulatory opportunities being more enabling in the Area than those in national waters.

The decisions to be taken include broad-scale/strategic decisions about the global approach to licensing exploration, standards and protocols for seeking operational permits, research and monitoring requirements, and benefit sharing. They also include more localised/tactical decisions about specific resource deposits and applications to exploit them. To make good decisions, it is important to understand the potential economic, social, and environmental impacts, benefits and costs of deep-seabed mining. To do this, information is required on the following:

- Geological/mineral resource availability
- Mining technologies and costs
- Economies/societies impacted directly by mining activities and indirectly via regional/global resource markets
- Environmental and ecosystem impacts of mining activity and any potential for post-mining restoration
- Counterfactual scenario – what will happen if seabed mining is delayed or mothballed? This includes consideration of alternative sources of resources, and alternatives to using them

Other principles endorsed by many States and enshrined in various legal structures and international agreements include the Precautionary Principle and the Polluter Pays Principle. Legitimacy also requires consultation over the trade-offs and uncertainties involved in resource management.

BOX 12

Controversies relating to the international seabed authority authorities

Concerns have been raised about the International Seabed Authority Legal and Technical Commission's recent decision making. In August 2018, the Chair, on behalf of the Commission, recommended that delegates approve a new contract to allow Poland to explore 3,900 square miles (10,000 square kilometres) of hydrothermal vent fields along the Mid-Atlantic Ridge in the Atlantic Ocean. There was no mention that the seabed to be potentially mined falls within what the CBD has identified as an Ecologically or Biologically Significant Marine Area (EBSA). This was questioned by the World Wildlife Fund and International Union for the Conservation of Nature (IUCN), stressing that the proposed contract was adjacent to the area to be explored for minerals lies the "Lost City," a unique hydrothermal vent field of 200 feet tall calcium carbonate chimneys that was discovered in 2000 and is now being considered by the United Nations as a possible World Heritage Site. No discussion ensued and the Commission unanimously approved the contract without comment and the Commission Chair pointed out that EBSAs currently do not impose a legal obligation to protect a designated area.

The Legal and Technical Commission must consider serious harm and adverse impacts to marine environment, which is highlighted by the lack of attention to EBSA in the latest claim.

3.3.2 Biodiversity Beyond National Jurisdiction

In August 2019 hundreds of delegates gathered at the United Nations headquarters in Manhattan to continue work on one of the most consequential ocean-based treaty negotiations in recent memory. It was the second of four planned intergovernmental conference sessions to establish a new, legally binding instrument for the conservation and sustainable use of biodiversity on the High Seas, in areas beyond national jurisdiction.

The conservation and sustainable use of 'Biodiversity Beyond National Jurisdiction' is increasingly attracting international attention, as scientific information, albeit insufficient, reveals the richness and vulnerability of such biodiversity, particularly around seamounts, hydrothermal vents, sponges, and cold-water corals, while concerns grow about the increasing anthropogenic pressures posed by existing and emerging activities, such as fishing, mining, marine pollution, and bioprospecting in the deep sea.

The UNCLOS sets forth the rights and obligations of states regarding the use of the oceans, their resources, and the protection of the marine and coastal environment. Although UNCLOS does not refer expressly to marine biodiversity, it is commonly regarded as establishing the legal framework for all activities in the oceans.

Following more than a decade of discussions convened under the United Nations General Assembly, the Assembly, in its resolution 72/249 of 24 December 2017, decided to convene an Intergovernmental Committee to elaborate the text of a legally binding instrument under UNCLOS on the conservation and sustainable use of Biodiversity Beyond National Jurisdiction, with a view to developing the instrument as soon as possible. Discussion are ongoing with a new Oceans Treaty proposed in 2020.

BOX 13

Examples of deep-seabed mining under national jurisdiction

The only deep-seabed mining project to date that has been granted a mining lease is within the territorial waters of Papua New Guinea and is principally governed by two items of national legislation: the Mining Act (1992) and the Environment Act (2000). The Mining Act declares all minerals to be owned by the national government and controls all exploration, processing and transport of minerals. The Environment Act is administered by the Department of Environment and Conservation (http://www.dec.gov.pg/legislation.html) and requires an Environmental Impact Statement prior to permits for mining being granted, with further conditions including installation of monitoring equipment, undertaking an environmental management program, baseline studies and a rehabilitation program.

An area where deep-seabed mining is still at the exploratory stage is within the New Zealand EEZ, which falls under two pieces of national legislation. The Crown Minerals Act 1991 legislates for minerals within the 12 nautical mile limit, but the potential sites for seafloor massive sulphides mining exists beyond this, yet still within the EEZ. The Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act (2012) manages the environmental effects of numerous activities, including seafloor massive sulphide mining, beyond the 12 nautical mile limit. The Act enacted in 2012, and regulations governing activities are still being developed (as of June 2013) (Boschen *et al.*, 2013).

Additional examples of national legislation frameworks and requirements are found in Annex 1.

3.4 Operating in national waters

According to UNCLOS, States are required to take all necessary actions to ensure the effective management of seabed mining activities (prospecting, exploration, mining and decommissioning) within their national jurisdiction and beyond.

Good practice marine policy for the mining industry should include many of the following characteristics (Kyngdon-McKay, 2014):

- Clearly established (and ideally quantitative) targets and thresholds for operations;
- A comprehensive listing of permitting requirements for marine operations;
- Comprehensive regulations for permitting, including undertaking an ESIA;
- Explicit monitoring, reporting and compliance requirements;
- Clearly identified regulating and enforcement bodies;
- Defined penalties and remediative actions in the event of non-compliance;
- A framework for the acquisition, management and relinquishment of concessions;
- Provision of detailed policy guidance and free access to information, ideally online;
- Identification and referral of proposals likely to have high environment or biodiversity impacts to independent government authorities for assessment;
- Linkages to national biodiversity strategy and priorities; and
- Emphasis on avoidance of environmental impacts over mitigation.

Companies at a minimum need to achieve compliance with the national policy and regulations in the countries they are operating. Good policy is advantageous for companies because it provides a clear set of rules with which to plan, cost and operate. It should also help with the identification and mitigation of key risks.

In reality, the level and complexity of policy varies greatly from country to country. In the most advanced cases multi-layered policy covers a wide range of marine activities and provides clear guidance for compliance. At the other end of the scale, policy may be fragmented or contradictory, or may not exist at all. Variation in the quality and coverage of policy creates a challenge for seabed mining– a company operating in each new country is likely to face a new set of challenges relating to policy. Therefore, a full legal review of existing policy and comparison with corporate policy and standards, is a priority for a company operating in a new location.

3.5 Influencing decision making for seabed mining

3.5.1 Guidance

Guidance consists of recommended, non-mandatory controls that help support standards and policies. Guidance is not usually a requirement, but rather strongly recommended as part of a good practice approach. Whilst guidance relating to good practice in impact mitigation and the management of biodiversity and ecosystem services has been produced for extractive sectors (Box 14), there is only guidance at a national scale. In South Africa seabed mining was included in the Mining and Biodiversity Guidelines. Historically the government of South Africa developed a guidance document and the mining industry developed a generic Environmental Management Programme to guide industry. Following this the legislation in South Africa changed so that the full Environmental Impact Assessment requirements are applied to seabed prospecting and mining in the same way as all other developments onshore. However, there is currently no guidance for deep-seabed mining, though the International Seabed Authority are working to develop guidance for deep-seabed mining, holding a workshop in Pretoria in 2019 for this purpose. Pew Charitable Trusts have been commissioned by the International Seabed Authority to develop a Good Practice Guidance for deep-seabed mining in direct response to the Regulations and Standards currently under development.

BOX 14

Relevant guidance for good practice biodiversity and ecosystem services management in extractive sectors

Good practice guidance and tools relating to assessment and mitigation of impacts on biodiversity and ecosystem services in general:

- Tools and guidance published by the Cross Sector Biodiversity Initiative (CSBI) including:
    - A cross-sector guide for implementing the Mitigation Hierarchy (2015)
    - Good practises for the collection of biodiversity baseline data (2015)
    - Timeline Tool (2013) – a tool to help identify milestones and key interdependencies between project development schedules, financing timelines and the actions required to apply the Mitigation Hierarchy effectively
- Good practice guidance for mining and biodiversity (International Council on Mining and Metals (ICMM), 2006)
- Mining & Biodiversity Guideline South African Business & Biodiversity Forum
- Ecosystem services guidance: Biodiversity and ecosystem services guide and checklists (IPIECA-OGP, 2011)
- Biodiversity and ecosystem services fundamentals. Guidance document for the oil and gas industry (IPIECA-OGP, 2016)
- Integrated mine closure: good practice guidance (ICMM, 2019)
- Making mining forest-smart: executive summary and principles (World Bank, 2019)

BOX 14 (cont.)

Relevant guidance for good practice biodiversity and ecosystem services management in extractive sectors

Resources specific to the marine environment:

- **The Pew Charitable Trusts website has a wealth of information and resources on seabed mining, with new material regularly uploaded: https://www.pewtrusts.org/en/projects/seabed-mining-project. The Pew Charitable Trusts is developing a Good Practice Guidance for seabed mining in direct response to the International Seabed Authority Regulations and Standards currently under development.**
- **Precautionary management of deep sea mining potential in Pacific Island countries. Draft for discussion (World Bank, 2016)**
- **Biodiversity and Ecosystem Services: Good Practice Guidance for Oil and Gas Operations in Marine Environments (FFI, 2017)**
- **Marine Geospatial Bibliography (IPIECA-IOGP Biodiversity and Ecosystem Services Working Group, 2013) – this is a free knowledge sharing platform that centralises reports, papers and environmental research relevant to oil and gas activities in marine environments.**
- **Reducing risks to western gray whales: Sakhalin Energy case study (December 2012)**
- **Blue Economy Development Framework (World Bank, 2016)**

3.5.2 Project-scale environmental management for deep-seabed mining

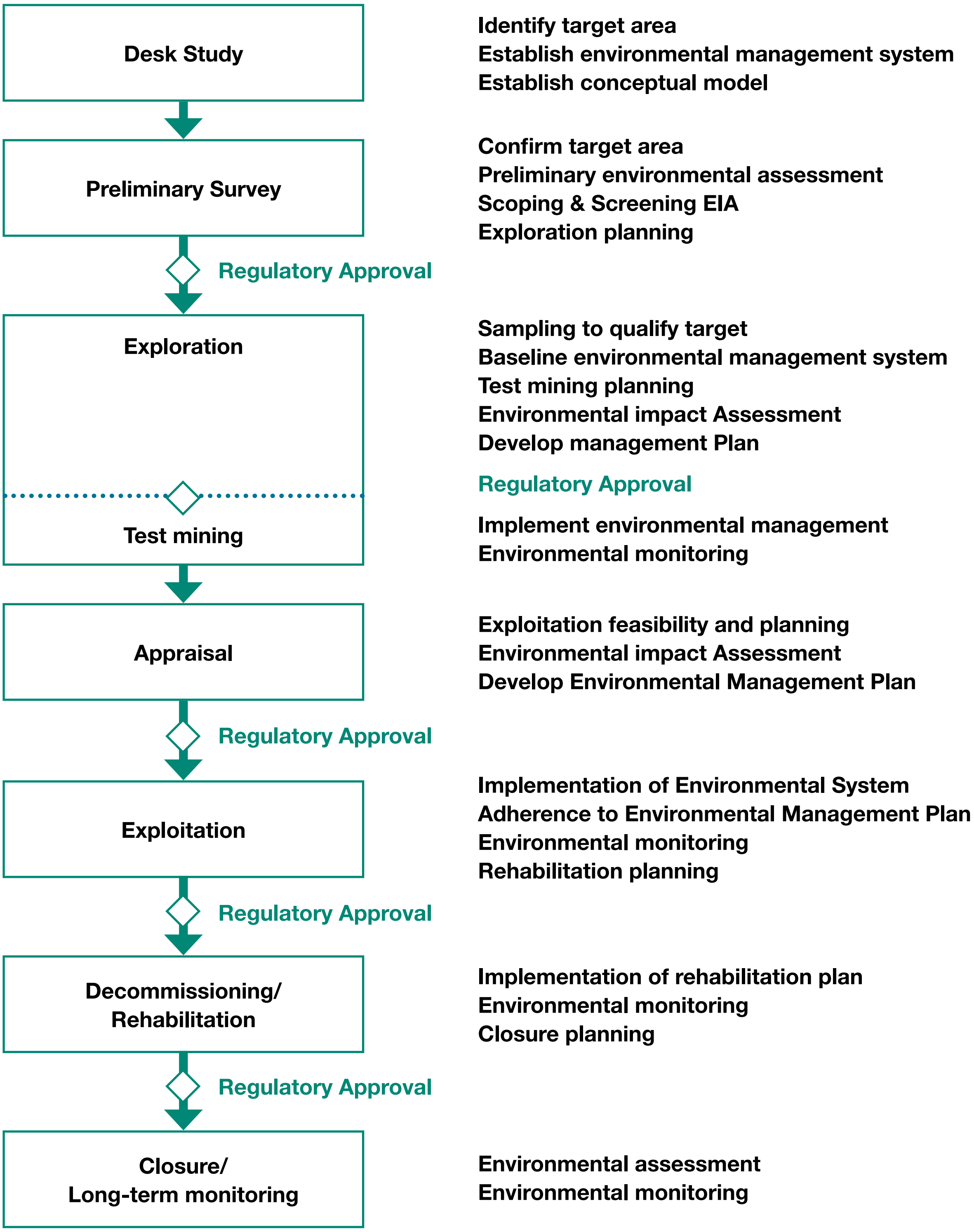
An EIA is required to obtain a permit to exploit seabed minerals. For deep-seabed mining, an EIA is required to obtain a title of either exploration or exploitation issued by the International Seabed Authority as they are considered to be both a direct obligation for States and a general obligation under customary international law (ITLOS, AO17, 2011, p. 50, para. 145). If properly conducted, EIAs can support the application of the Precautionary Principle during all stages of the EIA, as the objective of an EIA is to gather the maximum possible information on the project and the site it is due to take place in, while assessing the impacts and risks related to that project and identifying ways to mitigate them. Based on the resultant EIA document, decision makers will make the call: “is the risk too great?” So understanding risk is fundamental: risk to the environmental receptors, to society and to the ocean systems but not, in this case, the usual driver of financial risk (although this may result from other risks).

Durden *et al* (2018) consider that EIA frameworks should guide contractors on how to provide data during mining exploration, but the frameworks do not specify how such data would link to future exploitation. The authors stress that EIA data must influence decision making at the policy level.

Currently, EIAs do not always take into account the dynamic nature or interconnectivity of marine ecosystems, or that an ecosystem may be subject to multiple stressors. Conducting an EIA for seabed mining, particularly in deeper waters, is challenging because of the environmental conditions and uncertainties involved, which include a lack of environmental data at all spatial and temporal scales and the fact that mining technologies remain under development (Miller *et al*, 2018). Concerns have been raised that data collected by contractors vary in quality and consistency (Thompson *et al.*, 2018). If EIAs are to be used to predict the impacts of the proposed mining activity, then a standardised approach for their implementation and a method for assessing quality are required to be in place in time for the first mining applications to be considered.

Durden *et al.*, (2018) have developed a good practice framework to guide the environmental management of deep-seabed mining activities, including recommendations on regulatory oversight and review (see Figure 7 below). The scope is limited to the environmental management of the planning and execution of deep-seabed mining exploration, extraction and rehabilitation activities, and does not include transportation, port-based, on-shore or land-based activities (Durden *et al.*, 2018).

Figure 7: Flowchart depicting basic phases of a deep-seabed mining project, including environmental management steps (Credit: Durden *et al.*, 2018).



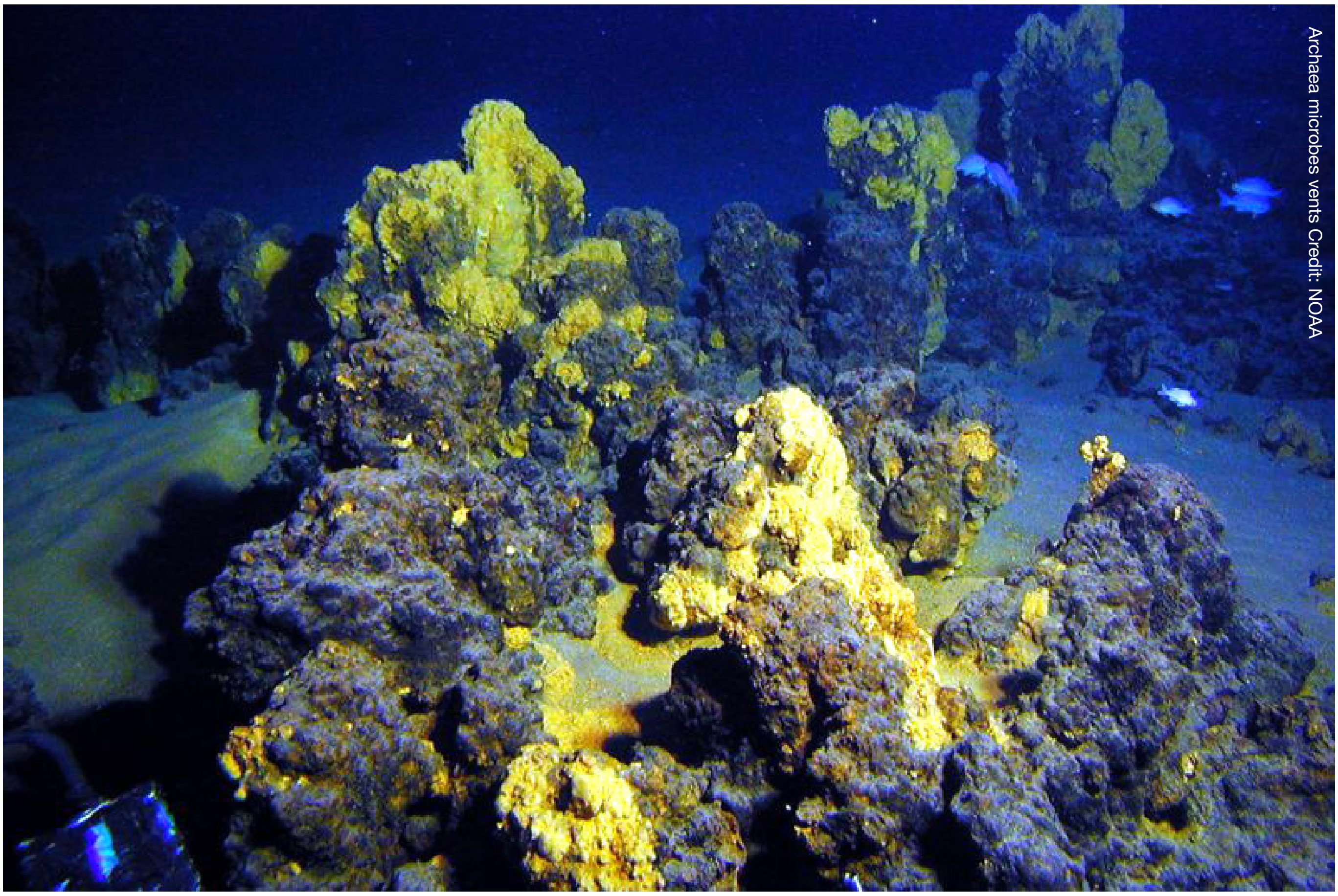
While informed by practices of other extractive industries, principles for the framework are specific to the deep-seabed mining context, including environmental, socioeconomic and legal/governance factors. These principles are described in Table 2 below:

Table 2: Principles of practice recommended by Durden *et al.*, 2018 for deep-seabed mining

Principle	Scope
1. The precautionary approach	Robust collection of baseline and monitoring data; full, transparent, and peer-reviewed EIAs; and staged reviews and assessments of detected impacts during test mining and commercial operations, all provide opportunities to adapt practices and management to ensure that precaution is prioritised. Decision making involving risk-benefit or cost-effectiveness tests for future actions, compared with alternatives, is recommended as a means to avoid potential harm, rather than simply assessing whether a "reasonable likelihood" of serious or irreversible harm exists
2. Mitigation of environmental Impacts	Application of the mitigation hierarchy in support of precautionary approach - prioritises the prevention or avoidance of impacts, followed by reduction of residual impacts, restoration and finally offsetting or compensation for the impacts. Following this hierarchy is widely regarded as good practice and is required by law in some jurisdictions. The ultimate goal of mitigation measures is to ensure no net loss of key environmental parameters. In deep-seabed mining there is likely to be emphasis on the avoidance and minimisation phases of the hierarchy, although restoration has been considered. 1) to ensure that environmental management is considered in the early planning stages of the project; and 2) that sufficient reviews of the planning, exploration, exploitation and monitoring activities are performed to ensure that avoidance and minimisation of impacts are applied in decision making in each phase, and to evaluate the effectiveness of the chosen mitigation and conservation actions taken.
3. Adaptation and adaptive management	Adaptation during the project to allow for industrial, scientific and policy developments to be incorporated into management strategy as they are acquired. This is particularly important in deep-seabed mining, where a substantial increase in available environmental data is anticipated (e.g. baseline study results, environmental conditions, faunal response to mining activities, etc.;), regulations are still incomplete, and mining technologies are under development. 'Adaptive management' involves the periodic re-evaluation and alteration of a project to accommodate current knowledge and techniques, and is thus an iterative process of deliberation. It is employed to reduce uncertainty and improve the long-term management of a project. However, adaptive management can be unsuitable for activities that quickly cause very serious or irreversible harm, where impacts must be measured on long-term scales, or where endangered species are critical to a complex and poorly understood community, concerns for deep-seabed mining. Anticipated developments include: 1) improvements to the understanding of the environment and impacts to it from mining, as well as changes to the mining plan at the project claim (arguably simply 'good management' practices); 2) improvements to the understanding of the environment, mining technologies and impacts at a greater spatial scale than the project (such as affecting other claims or the region); 3) altered environmental goals through the development and evolution of strategic and regional environmental management plans; 4) advances in the best available technology; 5) updates to deep-seabed mining environmental policy and regulations; and, 6) active experimentation, for example to test new technologies or to research mitigation options through a well-designed trial.

An important consideration in the environmental management of deep-seabed mining projects is time, an aspect deliberately omitted from the environmental management framework presented here. The appraisal phase is a bottleneck in project progression; this phase often requires years of work prior to the commencement of test mining or commercial extractive activities (e.g. seven years for the preparation, consultation and evaluation of the Trans-Tasman iron ore EIA in New Zealand).

Robust environmental management is dependent on the ability to recognise and act on threats to the ecosystem. Temporal scales and the timing of baseline and monitoring data collection must be scientifically relevant. Given the long timescales of some processes in the deep sea (years to decades, and longer), timelines for detecting and monitoring the impacts on such processes may conflict with timelines for project progression. Such mismatches in timescales must be considered by the contractor, regulator and stakeholders when developing regulations, assessing impacts, planning monitoring and mitigation actions, and determining whether active adaptive management is appropriate and, if so, how best to apply it (Durden *et al.*, 2018).



Archaea microbes vents Credit: NOAA

4 The Strategic Environmental Assessment (SEA) approach

This assessment covers seabed mining as defined in Section 2.2 and takes an approach that focuses on generic baselines and generic typologies of seabed mining rather than a project specific focus at a defined geographical location. It is therefore a generic assessment of issues and impacts and provides generic commentary on the likely outcomes of such ventures.

4.1 Documenting the state of the environment – baseline surveys

Initial characterisation of a seabed mining project is essential to inform the design of best practice environmental solutions. Seabed mining will potentially impact all levels of the marine environment, including the water surface (where plankton, nekton, neuston, marine mammals, turtles and birds, may be affected) and the seafloor, affecting the benthos including epi- and endobiota. In this section the focus is on seafloor-associated biodiversity since here the impacts are expected to be severe due to the removal and disturbance of the substrate. It's recognised that pelagic biodiversity is poorly understood and is likely to be important, too.

Figure 8 outlines the steps that are considered good practice when conducting seabed biodiversity surveys to establish a robust biodiversity and ecosystem services baseline.

Figure 8: Establishing a marine biodiversity and ecosystem services (BES) baseline

Establishing a marine BES baseline

Iterative, adaptive approach is required to respond to new information and meet evolving needs of the ESIA. Repetition of steps is often necessary

High-level screening

- Develop high-level picture of potentially sensitive and/or high value biodiversity and potential ecosystem services to inform further detailed assessment

Delineate the baseline study area

- Use ecologically meaningful boundaries
- Consider ecosystem services and dependencies
- Incorporate project activities and impacts

Scope the BES baseline

- Identify BES values for inclusion in the baseline in consultation with experts and stakeholders. Consider: habitats and species; ecological patterns and processes; oceanographic features; ecosystem service dependencies; protected areas and other sites important for BES; biophysical conditions
- Collate existing marine BES information and identify gaps
- Determine the scope, scale and depth of field assessment and studies

Conduct BES baseline assessment

- Involve experts and ensure best practice engagement with stakeholders
- Share ship and equipment time where possible
- Take into account specific challenges and considerations for establishing BES baseline in marine environment and factor costs into budgeting early in the project planning cycle

Develop baseline report

- Analyse and interpret all desk and field information
- Interpret results in consultation with key stakeholders
- Engage qualified experts to review baseline report
- Ensure all data are shared wherever possible
- If gaps still exist, consider further studies

Biodiversity assessment involves a survey or inventory of the biodiversity of an area. In very general terms, biodiversity refers to the variety of life but the term may target very different parts of the biosphere. Biodiversity may include all biological entities from molecules to ecosystems, and the entire taxonomical hierarchy from alleles to domain. It even includes varieties in interactions of life and the processes at all levels of these organisms (Gaston, Pressey and Margules, 2002). Biodiversity in this report mainly refers to the diversity of living organisms present in a system. However, since biodiversity can be also assessed by using molecular tools applied to the so called environmental DNA, which in the benthic systems is largely represented by extracellular DNA (i.e., DNA not associated to living biomass), biodiversity estimates in this case do not necessarily overlap with those based on approaches carried out on living organisms. Biodiversity can be expressed or estimated in different ways depending on the focus: from species richness, to evenness (equitability) or dominance indices, from (dis)similarities in community composition to the identification of indicator or key species/groups. It can have a taxonomical (morphological or molecular) focus (structural biodiversity) or rather emphasize on functional composition. Tools for biodiversity estimates also differ according to the spatial scale that is addressed, from local to regional or even global (alpha, beta, gamma,…) dimensions.

Monitoring programmes or environmental assessments would typically target specific groups, such as particular size classes (micro-, meio-, macro- or megafauna), specific taxa (nematodes, polychaetes, …), or functional groups (specific trophic levels, key species, habitat engineers,..). As an alternative, multi-taxon assessments would target more than one taxonomic group, likely across different size categories and including different trophic levels or functional guilds (Billet *et al.*, 2015).

The selection of methods for biodiversity assessment will also differ according to ecosystem characteristics. The focus of the MIDAS project was on four main ecosystems of interest for mining: 1) abyssal soft sediments covered with polymetallic nodules; 2) massive sulphide deposits as present near hydrothermally active sites; 3) cobalt-rich ferromanganese crusts as present on seamounts; and 4) methane hydrates present below soft sediments of passive and active margins.

In general, these four types of systems differ in substrate characteristics (hard versus soft), topography (flat versus rugged), spatial scale (< 1 square kilometre to > 1 million square kilometres), and temporal variability (diurnal to decadal cycles), in addition to other characteristics. Differences in these characteristics have significant consequences, in particular for sampling strategies and the selection of appropriate monitoring techniques.

In general, any biodiversity assessment can only report on species or groups that are present in the area but fail to resolve missing or absent species. This is especially the case for environments such as in the deep sea where many rare taxa are present. In this context, baseline information is largely unavailable, and has been identified as a priority before monitoring tools and methods can be put in place or recommended (MIDAS and Shirshov, 2016). Similar challenges will also be faced in the context of alluvial sediments in shallow waters where gold and diamonds are found, and phosphoratic sediments where phosphates are found. Rapid biodiversity assessment is an important technique in areas where information is limited or absent (Box 15).

Benthic coral assemblage Credit: NOAA

BOX 15
Rapid biodiversity assessment

Rapid biodiversity assessment is an important technique for terrestrial, freshwater, estuarine and marine system management, especially in areas where there is very little published or unpublished information (Patrick *et al.*, 2014). It is essentially a reconnaissance, a preliminary baseline inventory, which may lead to more detailed study and action depending on the results of the“recce”.

This process is well described in the guidelines on methods for rapid assessment of marine and coastal biodiversity provided by the CBD (Convention on Biological Diversity (CBD), 2004). These guidelines are directly applicable to marine ecosystems and include five general types of assessment:

- **Baseline inventory –** focuses on overall biological diversity rather than extensive or detailed information about specific taxa or habitats.
- **Species-specific assessment –** provides a rapid appraisal of the status of a particular species or taxonomic group in a given area.
- **Change assessment –** is undertaken to determine the effects of human activities or natural disturbances on the ecological integrity and associated biodiversity of an area.
- **Indicator assessment –** assumes that biological diversity, in terms of species and community diversity can inform us about water quality and overall health of particular ecosystems.
- **Resource assessment –** aims to determine the potential for sustainable use of biological resources in a given area.

The guidelines stress the importance of clearly establishing the purpose of the assessment as the basis for its design and implementation in each case. The scope of the assessment must be clearly defined.

For the rapid assessment of seabed biodiversity two types of approach are recommended:

1. Non-invasive, imaging-based techniques such as high-resolution video or photographic image surveys. This approach results in a high spatial or temporal resolution, but inevitably leads to a loss in taxonomic resolution. If observations have been sufficiently validated based on samples, organisms may be reliably identified to lowest taxonomic levels, but even then, cryptic diversity cannot be detected.
2. Referencing material of collected specimens where the present biodiversity is assessed through molecular and/or morphological techniques. The use of molecular techniques to extract and analyse DNA from water samples has become indispensable in sample-based biodiversity assessments since cryptic biodiversity can be relatively abundant, even in the deep sea. Another advantage of molecular techniques is that they are able to assess biodiversity of organisms that are too small or fragile to be identified based on morphological characteristics (e.g., prokaryotes, protists, and some meiofauna (animals between 32 and 300 microns in size) groups). Furthermore, molecular techniques offer the potential for speeding up the process of biodiversity assessment compared to morphology-based identification.

Typically, these techniques use genomic methods based on DNA and in some cases also analyses of protein composition to identify taxonomical units. In addition, molecular methods can be used to characterise functional diversity or identify the presence of certain trophic guilds, as reflected by the presence of corresponding metabolically relevant genes or the activity of metabolically relevant enzymes. These methods target functional genes (via DNA-based metagenomes), gene expression (e.g., RNA-based transcriptomics), and the identification of characteristic biomarkers or metabolites (e.g., proteomics, lipidomics, metabolomics, and other biochemical analysis). Detailed guidance is given in the Midas Report Tools for Rapid Biodiversity Assessment (MIDAS and Shirshov, 2016).

4.2 Impact assessment and mitigation planning

Impact assessment is the process of identifying the future consequences of a current or proposed action. In the context of a seabed mining operation, an impact assessment is commonly undertaken as part of the EIA/ESIA process but may also form part of a stand-alone risk assessment during operations.

Impact assessment requires the identification of direct, indirect, and cumulative impacts (i.e., placing the project in the context of resource use trends to ascertain how it contributes to impacts at seascape scale and/or across the sea-land interface). The context of seabed mining is generally premised by poor data, and inadequate knowledge of ecosystem function, composition, structure and the broader relationships with other features and actors in the seascape are poorly understood. The highly sensitive and unique ecological environment needs to be considered, coupled with the biophysical and geological patterns and processes underpinning the ecosystem function, composition and structure.

In terms of mining practice, there are three principal factors that will have major implications on the environmental impact of the mining development: i) the seafloor collection device, ii) the discharge point for particulate plumes, and iii) the spatial and temporal distribution of mining activities. These were all identified in a survey of deep-sea experts (Washburn *et al.*, 2019). In the case of the seafloor collector and the subsequent particulate processing, the environmental performance should be included as a key criterion for the design phase, preferably involving input from environmental experts.

Once impacts have been adequately described and quantified, the next stage is to devise and document appropriate mitigations that have a high level of confidence, designed to achieve overarching biodiversity and ecosystem services objectives. Best practice standards typical of other extractive sector activities in both terrestrial and marine environments demand a no net loss of net gain outcome for biodiversity as this objective. This objective drives the application of the mitigation hierarchy, as outlined in Box 2 (Section 1.4). The objective for mitigation management are usually driven by regulatory requirement (e.g. UNCLOS) and by Standards and Principles specified by a regulating authority (e.g. the International Seabed Authority or a national government) but could equally be imposed by sector or commodity standards driven by voluntary commitments to meet market demands for responsibly produced minerals. This risk and impact assessment is driven by the objective to achieve no harm. Mitigations are likely to be within the project area of influence, but could also tie into local, national and international biodiversity and ecosystem service management.

All mitigations should be designed through the framework of the mitigation hierarchy (see also Box 2 in Section 1.4). The avoidance of impacts is the first and most important step in the mitigation hierarchy. This includes explicit consideration of alternative locations or approaches with the spatial and temporal distribution of mining activities recognised as having a major influence on environmental impact.

Once all avoidance opportunities have been explored, the next step is to minimise those impacts that cannot be avoided. There are many potential procedural options for reducing mining impact, such as changing the pattern of mining activities, increasing spacing between mine tracks, changing the orientation of mining activities relative to prevailing currents, adjusting the timing of operations etc. MIDAS has made recommendations for environmental best practice that should be considered in the design criteria for potential projects (Billet *et al.*, 2015).

Once all possible minimisation measures have been applied, consideration should be given to restoring unavoidable impacts, according to good practice principles for restoration. Ecological restoration is the process by which a degraded ecosystem is assisted in recovering towards a pre-defined target state. A good practice restoration project will seek to restore key elements of biodiversity including species and habitats, the ecosystem functions that support them, such as primary production and nutrient cycling, and the ecosystem services that people rely upon (McDonald *et al.,* 2016). Thus, restoration projects can deliver environmental and social benefits. Restoration is complex, with many uncertainties and generally requires long timelines for results to be achieved. For these reasons it is important to develop a detailed plan that is guided by expert input and is socially acceptable to key stakeholders.

Biodiversity offsets are the last step in the mitigation hierarchy. They constitute measurable conservation gains, that seek to balance any significant biodiversity and ecosystem service losses that cannot be countered by avoiding or minimisng impacts, or remediating impacts through restoration. Given the lack of information on marine biodiversity and ecosystem services, especially in deep water, and uncertainties surrounding the definition of impacts and the effectiveness of mitigations for many marine ecosystems, offsetting is not currently considered practicable for deep-seabed mining (Section 13).

BOX 16

Considerations when defining the areas of interest for a seabed mining project

The term ‘area of influence’ is understood as “such area where significant environmental impacts caused by project performance are evident on physical, biotic and socioeconomic components, in each component of such environment.” Important factors to consider for defining the areas of influence of the project:

- **the proportion of the total area that will be affected, with respect to the whole water column/volume**
- **ensure good understanding (and consideration) of the influence of flow environments, including surface and subsurface currents in different seasons**
- **distance of coastal belts and inhabited areas from the areas of influence**
- **existence of fishing potential or any other commercial activity in the area of influence**

Finally, a baseline study area should incorporate project activities and impacts. This presents a major challenge when considering impacts such as sedimentation, for which there is minimal understanding of sediment transport through the water column in deeper water. Numerous complex modelling approaches exist to predict how a sediment could may move and settle, but the limitation is the lack of accurate input data in terms of water density, horizontal and vertical movements, temperature and salinity variations. In some conditions in deep water, sediment could remain suspended in the water column for years or even decades, which challenges any current modelling approach. Improving our understanding of physical conditions in deeper water habitats will help to better define input variables for modelling impacts. But conducting such research in different habitats and over meaningful timescales will require significant and sustained financial investment.

4.3 Informing decisions

The risk and impact assessment aims to provide an objective assessment of the current state of ecology within a project scenario, the likely impacts that will occur and the mitigations required to minimise impacts to the desired level. The assessment will form the basis of the formal response from the regulator to the proponent. The process needs to inform the following decisions:

- A ‘go’ or ‘no go’ decision for the project’s development
- If ‘go’, provide a clear plan for development based upon mitigation hierarchy
- Prescribe a plan for the long-term management of biodiversity
- Define the needs for long-term monitoring and evaluation

4.3.1 Monitoring

Project proponents (or deep-seabed mining Contractors in the Area) should carry out: a) thorough baseline surveys, b) monitoring of environmental impacts during mining and c) post-mining surveys to assess recovery. These steps should be integral in the EIA (Jones *et al*, 2019). Independent verification should be provided for each of these steps as well as a process to adjudicate when issues arise and a process to ensure compliance and financial penalty. It should be borne in mind that monitoring of recovery may need to be carried out over many tens of years. This information will be vital to assess how much future mining should be allowed. Mechanisms may therefore need to be set up that envisage the closure of the actual mining operations during this period.

Long term monitoring should be the responsibility of the project proponents. In the case of deep-seabed mining in the Area, monitoring should either become the responsibility of the sponsoring state or the International Seabed Authority itself. If it is to be the sponsoring state, bonds may need to be lodged to ensure compliance. If it is to be the International Seabed Authority, a levy may need to be charged per unit of mined ore or per lease area.

4.3.2 Data Sharing

The requirement to share environmental data acquisition plans in advance, pool effort, pool results and generally collaborate around the collection and interpretation and management of data will in general be helpful in the overall environmental management of the effects of extraction. However, it will also provide a visible demonstration by mining companies of compliance (as far as environmental data are concerned) to all parties including their peers.

The International Seabed Authority database ‘DeepData” (https://data.isa.org.jm/isa/map/) is one means of sharing information on deep-seabed mining. It holds centralised data of public and private information on marine mineral resources acquired from various institutions worldwide. The International Seabed Authority uses this data to standardise and evaluate data for quantitative mineral assessments. The integrated database system will be developed for use as a management and research tool that will be made accessible to authorised representatives of member States, scientists and researchers to further assist the Authority in its mandated work.

Catfish shark embryo Credit: NOAA

PART B

Cranchid-cockatoo squid Credit: NOAA

5. Biodiversity associated with seabed mining

The purpose of Part B is to define what is known about the marine environment from a biodiversity, ecosystem services and bio-physical perspective. This information is vital to assessing whether there is sufficient knowledge to develop a biodiversity and ecosystem services baseline that is adequate for the purpose of impact definition. This section first presents the various marine environments and associated biodiversity, then describes ecosystem services provided by oceans (and specifically those implicated in seabed mining) and finally discusses the fundamental geo-biological processes that enable functioning ecosystems and earth systems and are essential to the health and resilience of oceans.

Our current knowledge of the ocean is limited to the accessible coastal fringes and shallower zones, partly due to these area being historically utilised through commerce and trade. Coastal biodiversity and ecosystems are under extreme pressure from both terrestrial and marine activities, including farming, aquaculture, tourism, fishing and seabed mining.

The deep sea is often viewed as a vast, dark, remote, and inhospitable environment, yet the deep ocean and seafloor are crucial to our lives through the services that they provide. Our understanding of how the deep sea functions remains limited, but when treated synoptically, a diversity of supporting, provisioning, regulating and cultural services becomes apparent (Thurber *et al.*, 2014). The biological pump transports carbon from the atmosphere into deep-ocean water masses that are separated over prolonged periods, reducing the impact of anthropogenic carbon release. Microbial oxidation of methane keeps another potent greenhouse gas out of the atmosphere while trapping carbon in authigenic carbonates. Nutrient regeneration by all faunal size classes provides the elements necessary for fuelling surface productivity and fisheries, and microbial processes detoxify a diversity of compounds. Each of these processes occur on a very small scale, yet considering the vast area over which they occur they become important for the global functioning of the ocean. The deep sea also provides a wealth of resources, including fish stocks, enormous bioprospecting potential, and elements and energy reserves that are currently being extracted and will be increasingly important in the near future. Society benefits from the intrigue and mystery, the strange life forms, and the great unknown that has acted as a muse for inspiration and imagination since near the beginning of civilization. While many functions occur on the scale of microns to meters and timescales up to years, the derived services that result are only useful after centuries of integrated activity (Thurber *et al.*, 2014). This vast dark habitat, which covers the majority of the globe, harbours processes that directly impact humans in a variety of ways; however, the same traits that differentiate it from terrestrial or shallow marine systems also result in a greater need for integrated spatial and temporal understanding as it experiences increased use by society.

5.1 Defining the marine environment

Beyond coastal waters, the ocean is a vast, pristine and largely unexplored area, with a rich biodiversity. Even seemingly inhospitable environments in the deep sea have been found to support an array of highly specialised life forms that have evolved to thrive in such extreme conditions in the deep-sea. The ocean's biophysical systems support key processes in carbon sequestration which affect global carbon cycles and climate regulation.

Marine geosystems are as diverse and dynamic as terrestrial ones, but far more expansive.

Hotpots for biodiversity in the deep sea are often associated with deposits of rare minerals (such as cobalt, zinc and manganese) which may be associated with key geomorphologies such as hydrothermal vents and sea mounts.

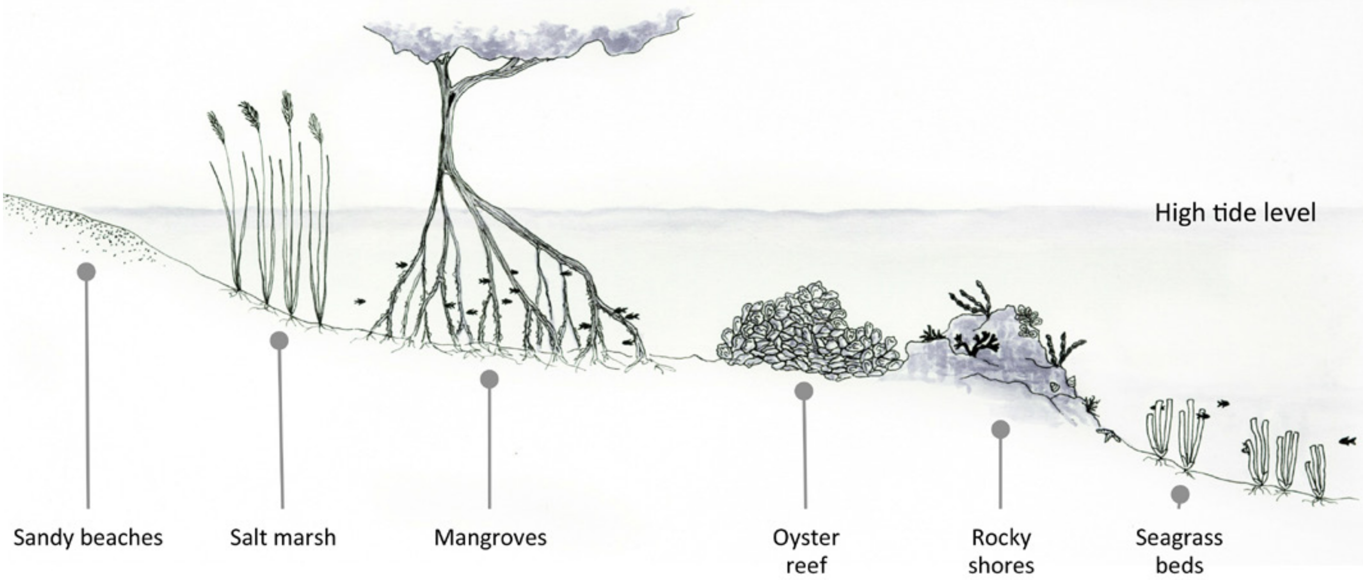
In the sections that follow, we consider estuarine, coastal, shallow water and deep-sea (oceanic) environments. The physical properties of habitats are presented along with an overview of known biodiversity and mineral associations. Estuarine and coastal habitats are considered here, even though near-shore mining is not. This is because impacts from seabed mining in both shallow and deep water could affect coastal habitats, and they therefore may be included in baseline characterisation and impact assessment for some seabed mining operations. Key gaps in knowledge are characterised at the end of section 6.

5.2 Estuarine habitats

An estuary is a partially enclosed body of water along the coast where freshwater from rivers and streams meets and mixes with salt water from the ocean. Estuaries and the lands surrounding them are places of transition from land to sea and freshwater to salt water (US EPA, 2012). Although influenced by the tides, they are protected from the full force of ocean waves, winds, and storms by such land forms as barrier islands or peninsulas. Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably-sized areas of forest, grassland, or agricultural land. The tidal, sheltered waters of estuaries also support unique communities of plants and animals especially adapted for life at the margin of the sea.

Many different habitat types are found in and around estuaries (Figure 9), including shallow open waters, freshwater and salt marshes[8], sandy beaches, mud and sand flats, rocky shores, oyster reefs, mangrove forests, and seagrass beds (Box 17).

Figure 9: Illustrated examples of different habitat types found in and around estuaries



Credit: Nicky Jenner/FFI

Estuaries can be associated with offshore alluvial gold, aggregate and phosphate occurence. Intertidal and estuarine habitats are vitally important to ocean health and are important habitats for a large number of species, including protected species.

BOX 17
Seagrass beds

Seagrass beds cover approximately 0.1–0.2% of the global ocean floor in both estuarine and inshore coastal environments (Duarte, 2002). Seagrass beds are a highly productive ecosystem and provide important ecological and economic functions including providing nursery habitat for fisheries (Jackson *et al.*, 2001) and acting to prevent coastal erosion and siltation of coral reefs (Stoddart and Scoffin, 1979; Fonseca, 1989). Loss of seagrass habitat from direct and indirect human impacts is estimated to be 33,000 square kilometres globally over the last two decades (Short and Wyllie-Echeverria, 1996). The primary cause of degradation and loss is reduction in water clarity, both from increased turbidity and increased nutrient loading and direct habitat disturbance or removal (Walker and McComb, 1992; Duarte, 2002).

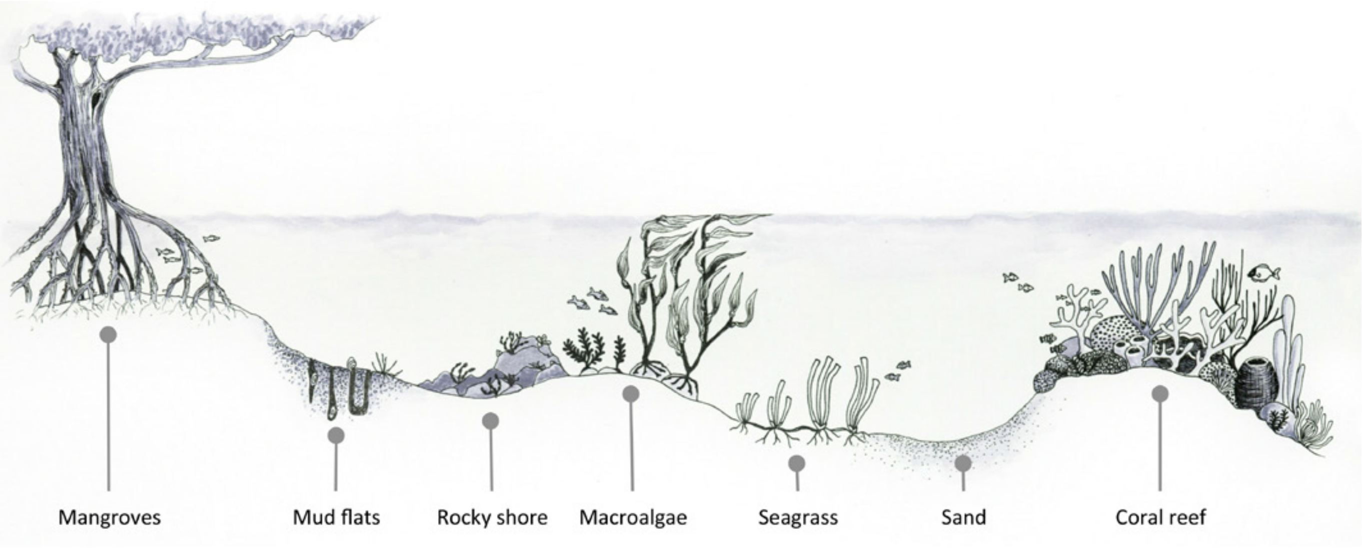
Freshwater and salt marshes habitats are not considered in the scope of this guidance

5.3 Shallow water coastal habitats

Coastal habitats are found in the area that extends from the high tide mark on the shoreline out to the edge of the continental shelf, in waters less than 200 metres depth. Coastal habitats can be associated with offshore diamond, alluvial gold, aggregate and phosphate extraction.

Coastal habitats in the inter-tidal zone may include coastal salt marshes, tidal mud flats, sandy beaches, mangroves, gravel/cobble beaches, rocky shores and armoured (bulkhead/rip-rap) shores. Near-shore demersal (bottom) habitats may include bare mud/sand flats, low and high profile hard substrate, seagrass beds, macroalgae forests, or coral reefs (Figure 10).

Figure 10: Illustrated examples of coastal habitats that may be affected by seabed mining



Credit: Nicky Jenner/FFI

5.4 Benthic Zone

The benthic zone is the ecological region at the lowest level of a body of water such as an ocean, including the sediment surface and some sub-surface layers. Organisms living in this zone are called benthos and include microorganisms (e.g., bacteria and fungi) as well as larger invertebrates, such as crustaceans and polychaetes. Organisms here generally live in close relationship with the substrate and many are permanently attached to the bottom. The benthic boundary layer, which includes the bottom layer of water and the uppermost layer of sediment directly influenced by the overlying water, is an integral part of the benthic zone, as it greatly influences the biological activity that takes place there. Examples of contact soil layers include sand bottoms, rocky outcrops, coral, and bay mud.

The benthic region of the ocean begins at the shore line (intertidal or littoral zone) and extends downward along the surface of the continental shelf out to sea. The continental shelf is a gently sloping benthic region that extends away from the land mass. At the continental shelf edge, usually about 200 meters deep, the gradient greatly increases and is known as the continental slope.

Benthos are the organisms that live in the benthic zone, and are different from those elsewhere in the water column. Many have adapted to live on the substrate (bottom). In their habitats they can be considered as dominant creatures, but they are often a source of prey for higher predators and form an essential link in foodwebs of ocean ecosystems (Alldredge and Silver, 1988).

Because light does not penetrate very deep into ocean water, the energy source for the benthic ecosystem is often organic matter from higher up in the water column that drifts down to the depths. This dead and decaying matter sustains the benthic food chain; most organisms in the benthic zone are scavengers or detritivores. Some microorganisms use chemosynthesis to produce biomass.

Benthic organisms can be divided into two categories based on whether they make their home on the ocean floor or a few centimetres into the ocean floor. Those living on the surface of the ocean floor are known as epifauna. Those who live burrowed into the ocean floor are known as infauna. Extremophiles, including piezophiles, which thrive in high pressures, may also live there (Fenchel, *et al* 2012).

Sources of food for benthic communities can derive from the water column above these habitats in the form of aggregations of detritus, inorganic matter, and living organisms. These aggregations are commonly referred to as marine snow, and are important for the deposition of organic matter, and bacterial communities. The amount of material sinking to the ocean floor can average 307,000 aggregates per square metre per day. This amount will vary on the depth of the benthos, and the degree of benthic-pelagic coupling. The benthos in a shallow region will have more available food than the benthos in the deep sea. Because of their reliance on it, microbes may become spatially dependent on detritus in the benthic zone. The microbes found in the benthic zone, specifically dinoflagellates and foraminifera, colonise quite rapidly on detritus matter while forming a symbiotic relationship with each other (Harris and Baker, 2012).

Modern seafloor mapping technologies have revealed linkages between seafloor geomorphology and benthic habitats, in which suites of benthic communities are associated with specific geomorphic settings. Examples include cold-water coral communities associated with seamounts and submarine canyons, kelp forests associated with inner shelf rocky reefs and rockfish associated with rocky escarpments on continental slopes.

Benthic macroinvertebrates have many important ecological functions, such as regulating the flow of materials and energy in marine ecosystems through their food web linkages. Because of this correlation between flow of energy and nutrients, benthic macroinvertebrates have the ability to influence food resources on fish and other organisms in marine ecosystems (Hemery and Henkel, 2015).

Demersal fish, also known as groundfish, live and feed on or near the bottom of the ocean. In coastal waters they are found on or near the continental shelf. Demersal fish are bottom feeders. Demersal fish can be divided into two main types: strictly benthic fish which can rest on the sea floor, and benthopelagic fish which can float in the water column just above the sea floor. Benthopelagic fish inhabit the water just above the bottom, feeding on benthos and zooplankton. The diversity of benthic life is scarcely known and more research is required to better understand the ecological patterns and processes and the composition and structure of benthic habitats. Beginning research is being made on benthic assemblages to see if they can be used as indicators of healthy aquatic ecosystems. Because the benthic system regulates energy in aquatic ecosystems, studies have been made of the mechanisms of the benthic zone in order to better understand the ecosystem.

All seabed minerals are associated with benthic habitats and ecosystems.

5.5 Continental Shelf

A continental shelf is a portion of a continent that is submerged under an area of relatively shallow water known as a shelf sea. This is the zone in which shallow water mining occurs or is proposed. The continental shelves are covered by terrigenous sediments; that is, those derived from erosion of the continents. However, little of the sediment is from current rivers; some 60–70% of the sediment on the world's shelves is relict sediment, deposited during the last ice age, when sea level was 100–120 metres lower than it is now.

Sediments usually become increasingly fine with distance from the coast; sand is limited to shallow, wave-agitated waters, while silt and clays are deposited in quieter, deep water far offshore. These accumulate 15–40 centimetres every millennium, much faster than deep-sea pelagic sediments.

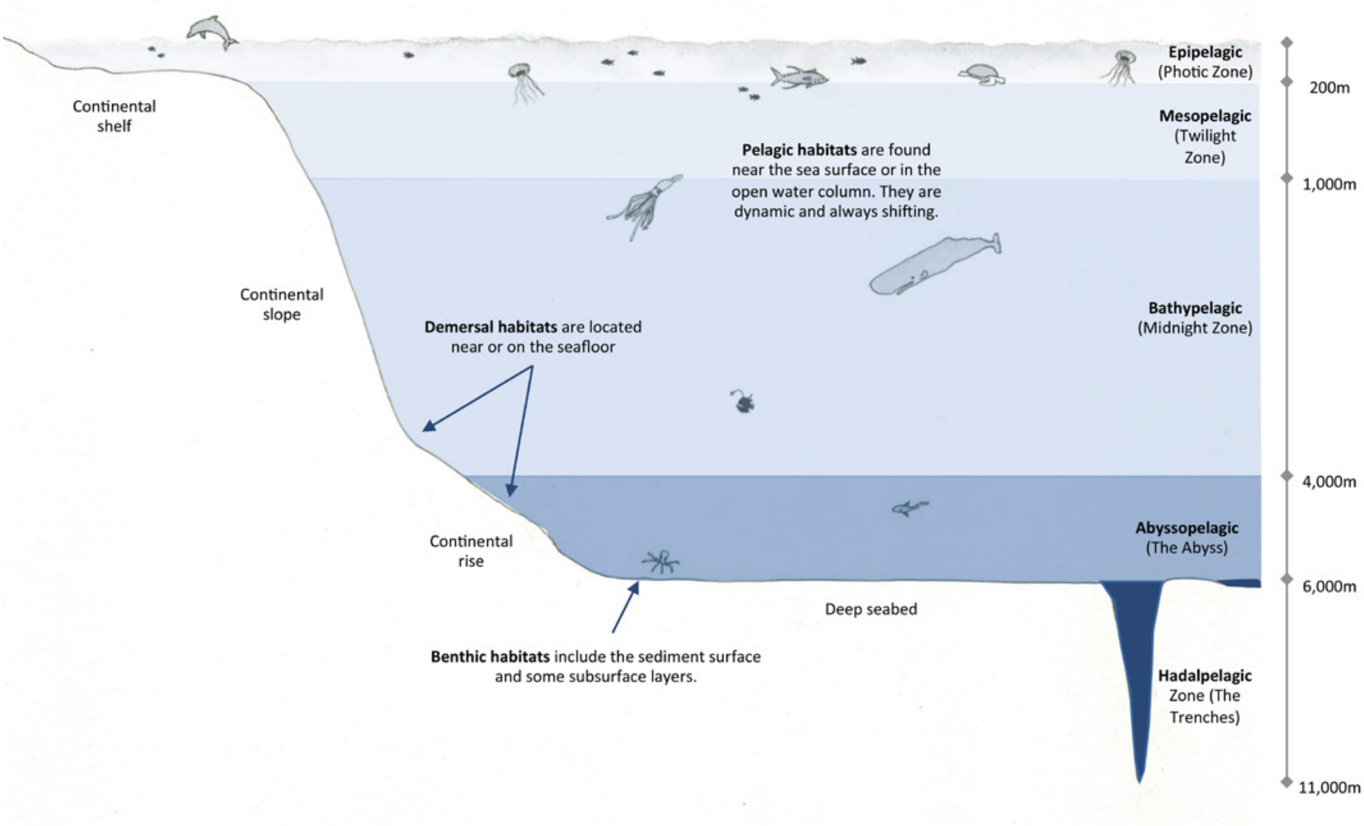
Shelf seas refer to the ocean waters on the continental shelf. Their motion is controlled by the combined influences of the tides, wind-forcing and brackish water formed from river inflows. These regions can often be biologically highly productive due to mixing caused by the shallower waters and the enhanced current speeds. Despite covering only about 8% of the Earth's ocean surface area, shelf seas support 15-20% of global primary productivity.

Continental shelves teem with life because of the sunlight available in shallow waters.

5.6 Oceanic (deep sea) habitats

Open ocean habitats are found in the deep ocean beyond the edge of the continental shelf, in waters of 200 – 11,000 metres depth. The ocean has been broadly divided into zones according to depth and oceanic habitats can be divided into pelagic, demersal and benthic habitats (Figure 11). Pelagic habitats are found near the surface or in the open water column, away from the bottom of the ocean. Pelagic habitats are dynamic, always shifting depending on the actions of ocean currents. Demersal habitats are near or on the bottom of the ocean. The benthic zone is the ecological region at the very bottom of the sea. It includes the sediment surface and some subsurface layers. Marine organisms living in this zone, such as clams and crabs, are called benthos. The demersal zone is just above the benthic zone and can be significantly affected by the seabed and the benthic ecosystem.

Figure 11: Marine zones by depth (metres below sea level) and broad habitat types (pelagic, demersal, benthic). Illustration not to scale



Credit: Nicky Jenner/FFI

Oceanic habitats include the pelagic ocean, vast abyssal plains, seamounts, mid-ocean ridges, trenches, canyons, cold seeps, hydrothermal vents and deep water coral systems. Deep-sea benthic habitats are generally poorly documented and understood. However, studies suggest that deep-sea biodiversity is essential for the sustainable functioning of the entire ocean (The Economics of Ecosystems and Biodiversity, 2012). This functional importance is further discussed in both the ecosystem services and biophysical processes sections below.

5.6.1 Pelagic Ocean

The pelagic zone consists of the water column of the open ocean. The pelagic zone occupies 1,330 million cubic kilometres (320 million cubic miles) with a mean depth of 3.68 kilometres (2.29 miles) and maximum depth of 11 kilometres (6.8 miles). The biomass of pelagic life decreases with increasing depth. It is affected by light intensity, pressure, temperature, salinity, the supply of dissolved oxygen and nutrients, and submarine topography.

The oceanic pelagic ecosystem is by far the largest on Earth and, although locally its assemblages may be as rich as many terrestrial ecosystems, its global diversity (at both a species and an ecosystem level) is low. The pelagic ecosystem is driven by primary production from phytoplankton. There are latitudinal trends in pelagic species diversity similar to those in many terrestrial taxa. High species richness in the oceans, however, tends to be associated with regions of low productivity that lack strong seasonality in the production cycle. The richest zones for species occur at the boundaries between different types of oceanic water where different species are mixed together, but the geographical locations of these boundaries are dynamic and can shift seasonally by hundreds of kilometres.

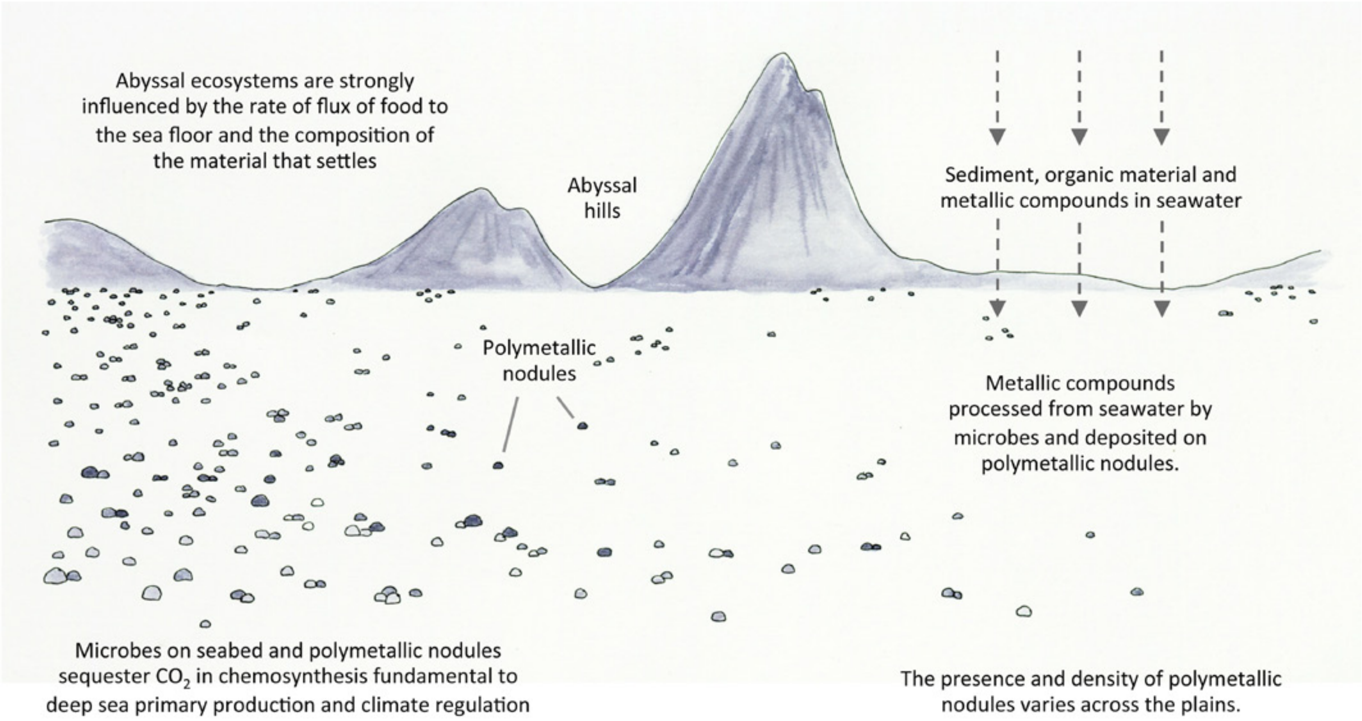
5.6.2 Abyssal Plains

An abyssal plain is an underwater plain on the deep ocean floor (Figure 12), usually found at depths between 3,000 metres (9,800 feet) and 6,000 metres (20,000 feet). Lying generally between the foot of a continental rise and a mid-ocean ridge, abyssal plains cover more than 50% of the Earth's surface. They are among the least explored regions on Earth and assumed to be largely flat and smooth, but with increasing evidence of spatial heterogeneity (Durden *et al.*, 2018). Abyssal plains are key geological elements of oceanic basins (the other elements being an elevated mid-ocean ridge and flanking abyssal hills).

The creation of the abyssal plain is the result of the spreading of the seafloor (plate tectonics) and the melting of the lower oceanic crust. Magma rises from above the asthenosphere (a layer of the upper mantle), and as this basaltic material reaches the surface at mid-ocean ridges, it forms new oceanic crust, which is constantly pulled sideways by spreading of the seafloor. Abyssal plains result from the blanketing of an originally uneven surface of oceanic crust by fine-grained sediments, mainly clay and silt. Much of this sediment is deposited by turbidity currents that have been channelled from the continental margins along submarine canyons into deeper water. The rest is composed chiefly of pelagic sediments. Metallic nodules are common in some areas of the plains, with varying concentrations of metals, including manganese, iron, nickel, cobalt, and copper.

Abyssal plains were not recognised as distinct physiographic features of the seafloor until the late 1940s and, until the 1980's, none had been studied on a systematic basis. They are poorly preserved in the sedimentary record, because they tend to be consumed by the subduction process[9].

Figure 12: Abyssal plains with polymetallic (manganese) nodules and associated processes. Illustration not to scale.



Credit: Nicky Jenner/FFI

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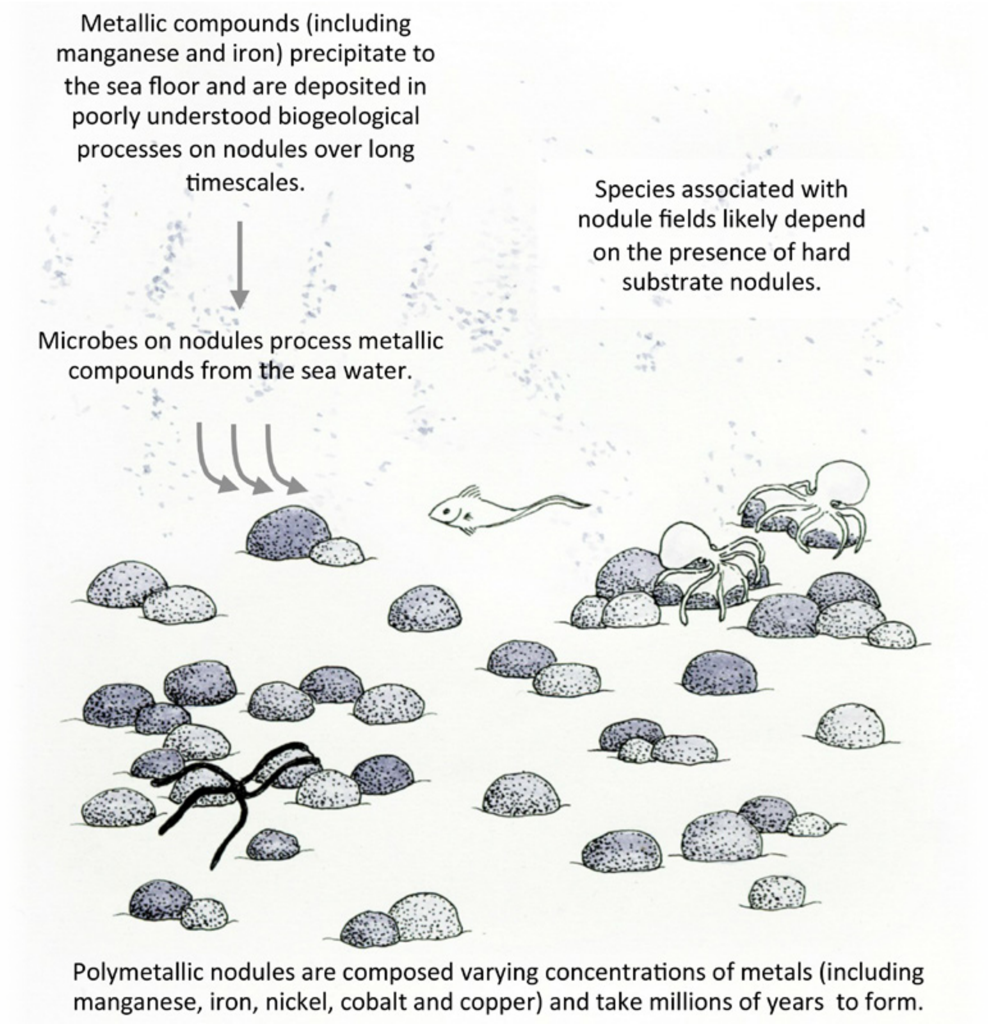
[9] Subduction - a geological process that takes place at convergent boundaries of tectonic plates where one plate moves under another and is forced to sink due to gravity into the mantle. Regions where this process occurs are known as subduction zones.

Figure 13: Polymetallic nodules associated with abyssal plains and processes contributing to their formation. Illustration not to scale.

References: Purser, *et al.*, (2016); Shiraishi, *et al.*, (2016); Vanreusel, *et al.*, (2016); Tully & Heidelberg (2019).



Credit: Nicky Jenner/FFI

Sediment-covered abyssal plains are less common in the Pacific Ocean than in other major ocean basins because sediments from turbidity currents are trapped in oceanic trenches that border the Pacific Ocean.

Though the plains were once assumed to be vast, desert-like habitats, research over the past decade or so shows that they teem with a wide variety of microbial life. An extremely high level of biodiversity exists on abyssal plains, with up to 2,000 species of bacteria, 250 species of protozoans, and 500 species of invertebrates (worms, crustaceans and molluscs), typically found at single abyssal sites. New species make up more than 80% of the thousands of seafloor invertebrate species collected at any abyssal station (Smith *et al.*, 2008), highlighting our heretofore poor understanding of abyssal diversity and evolution. They also exert significant influence upon ocean carbon cycling, dissolution of calcium carbonate, and atmospheric carbon dioxide concentrations over time scales of a hundred to a thousand years. The structure of abyssal ecosystems is strongly influenced by the rate of flux of food to the seafloor and the composition of the material that settles. Factors such as climate change, fishing practices, and ocean fertilization have a substantial effect on patterns of primary production in the euphotic (beyond penetration of sunlight) zone (Smith *et al.*, 2008). There is considerable local-scale variation in seabed communities, which may be partially driven by the terrain (Simon-Lledó *et al.*, 2019).

Polymetallic nodules are associated with abyssal plains (Figure 13; also see Section 11.3 for more information on the formation of nodules and their exploitation). These nodules are composed of iron and manganese which has precipitated from the ocean over long time scales. In some places nodules can be highly abundant over large areas, and in others they can be sparse or absent. Available evidence points to the importance of these polymetallic nodules for the persistence of deep-sea biota (Box 18). Nodule fields provide a hard substrate for various epifauna, such as sponges, and associated megafauna. Incirrate octopods, for example, are believed to utilise nodules and other seafloor structures to forage in seafloor sediments and brooding octopods have been recorded to use dead sponge stalks (Purser *et al.*, 2016). Insight into the fauna associated with nodules is crucial to support effective identification and mitigation of impacts (Vanreusel *et al.*, 2016).

BOX 18

Discovering the diverse biodiversity of abyssal plains in the Clarion Clipperton Fracture Zone

The Clipperton Fracture Zone is a geological submarine fracture zone of the Pacific Ocean, with a length of some 4,500 miles (7,240 kilometres). It is one of the five major lineations of the northern Pacific floor, south of the Clarion Fracture Zone, discovered by the Scripps Institution of Oceanography in 1950. The fracture, an unusually mountainous topographical feature, begins east-northeast of the Line Islands and ends in the Middle America Trench off the coast of Central America. It roughly forms a line on the same latitude as Kiribati and Clipperton Island.

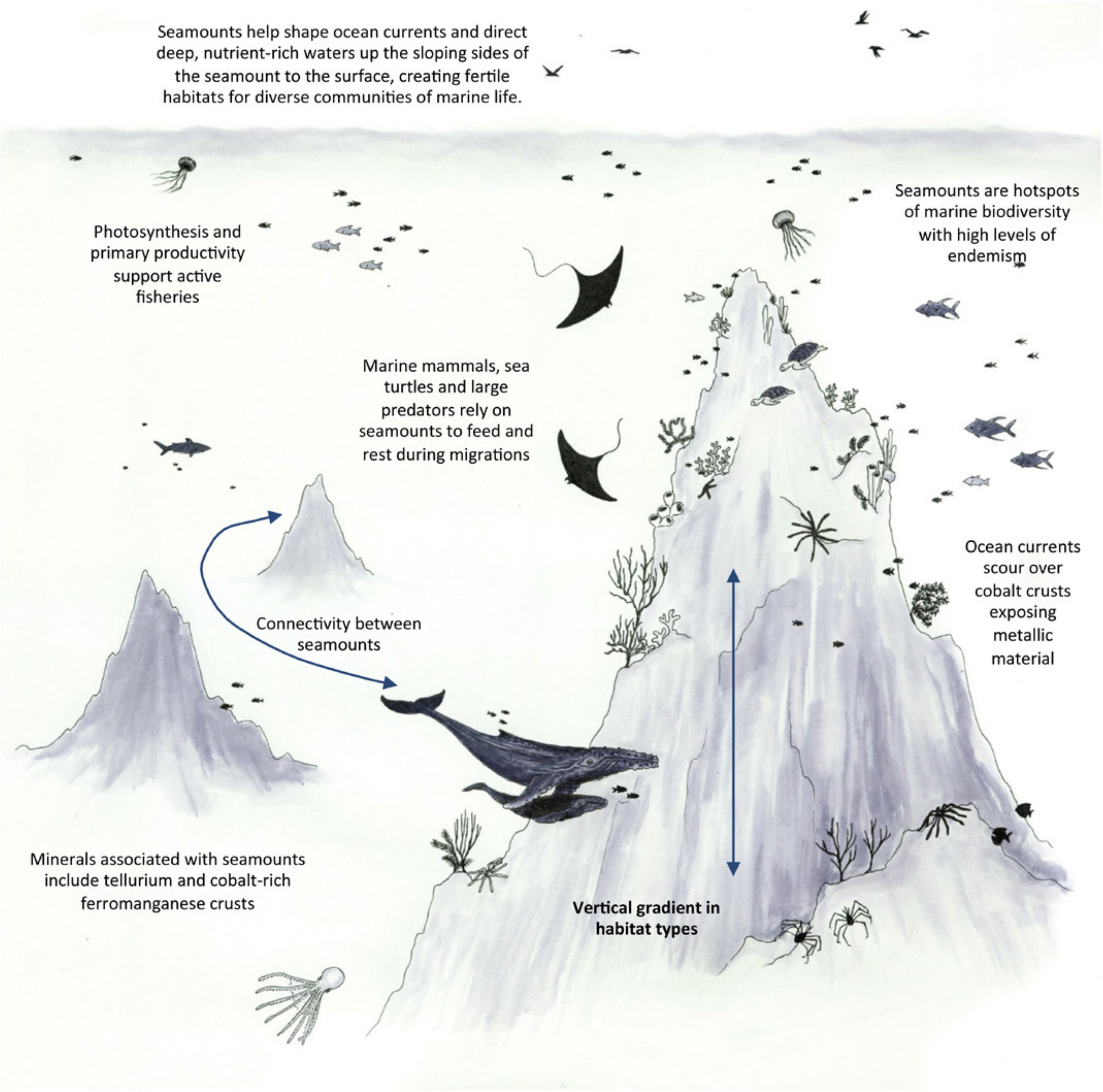
In 2016, the seafloor in the Clipperton Fracture Zone – an area being targeted for deep-seabed mining – was found to contain an abundance and diversity of life, with more than half of the species collected being new to science (Vanreusel et al., 2016). Data from recent surveys show that more animals live on the seafloor, and at high densities, in areas with higher nodule abundance whilst certain taxa were virtually absent from nodule-free areas (Simon-Lledó et al., 2019). Further, the majority of the megafaunal diversity also appears to be dependent on the polymetallic nodules themselves, and thus are likely to be negatively affected by mining impacts (Kristina M. Gjerde *et al.*, 2016; ISA and CCZ, 2019).

5.6.3 Seamounts

Seamounts are underwater mountains that rise hundreds or thousands of feet from the seafloor. They are generally extinct volcanoes that, while active, created piles of lava that sometimes break the ocean surface. In fact, the highest mountain on Earth is actually a seamount—Hawaii's Mauna Kea, a dormant volcano that is more than 9,100 metres (30,000 feet) tall measured from its base on the seafloor 5,500 metres (18,000 feet) beneath the surface.

Seamounts are commonly found near the boundaries of Earth's tectonic plates and mid-plate near 'hotspots'. At mid-ocean ridges, plates are spreading apart and magma rises to fill the gaps. Near subduction zones, plates collide, forcing ocean crust down toward Earth's hot interior, where this crustal material melts, forming magma that rises buoyantly back to the surface and erupts to create volcanoes and seamounts. Seamounts are also created at hotspots, isolated areas within tectonic plates where plumes of magma rise through the crust and erupt at the seafloor, often creating chains of volcanoes and seamounts, such as the Hawaiian Islands.

Figure 14: Seamounts and their associated finer scale habitats are hotpots of biodiversity in the ocean. Illustration not to scale.



Credit: Nicky Jenner/FFI

Scientists estimate there are at least 100,000 seamounts higher than 1,000 metres around the world. These provide hard foundations for deep-sea life to settle on and grow. In addition, seamounts rising into the ocean create obstacles that shape ocean currents and direct deep, nutrient-rich waters up the sloping sides of seamounts to the surface. These factors combine to make seamounts fertile habitats for diverse communities of marine life (Figure 14), including sponges, crabs, sea anemones, commercially important fish, and deep-sea corals. Unlike shallow-water corals, which rely on photosynthetic algae and sunlight to grow, deep-sea corals get energy from filtering organic material that falls from the surface.

Seamounts also attract an abundance of marine life and in some circumstances, seamounts can connect benthic and pelagic ecosystems. For example, fish and marine mammals are known to aggregate over seamounts, using them either for foraging or resting (Garrigue *et al.*, 2015; Morato *et al.*, 2015). Reisinger *et al.* (2015) tagged and tracked killer whales (Orcinus orca) and found that they spent time hunting over certain seamounts, suggesting that these oceanic features are a source of prey for these mammals. As well as supporting marine fauna including cetaceans, pinnipeds, and turtles for feeding, seamounts may be navigational features during migrations and as breeding grounds (Yesson *et al.*, 2011).

Seamounts are productive fishing grounds more than 80 commercial species worldwide. At the same time, coral mining and fish trawling, using nets that rake up everything in their paths, have created indelible scars in the spectacularly diverse and abundant seamount ecosystems. Deep-sea corals that thrive on and around seamounts host more than 1,300 different species of animals; some are unique to seamounts themselves and some live only on a specific species of coral. Until they were discovered in the year 2,000, these lush and intricate ecosystems were largely unknown, and scientists have only begun to learn about their ecological importance and their role in the evolution of life in the deep.

In particular, researchers have been investigating the interaction between seamounts and ocean currents and the role that this may play in creating isolated biological “hotspots” that act as critical locations for new species formation, endemism, and biodiversity.

Although they are typically hidden beneath the ocean (often making them a navigation hazard, particularly for submarines), seamounts are ubiquitous and fundamental geological features; studying them gives us insights into the forces that have shaped the face of our planet. Forged and altered by volcanic and tectonic processes that are intimately linked to the deep earth, they are also being targeted by mining companies that hope to harvest the minerals that often collect around seamounts as a result of hydrothermal activity. Minerals associated with seamounts include the scarce mineral tellurium and cobalt-rich ferromanganese crusts (Cuvelier *et al.*, 2019).

5.6.4 Mid-ocean ridges

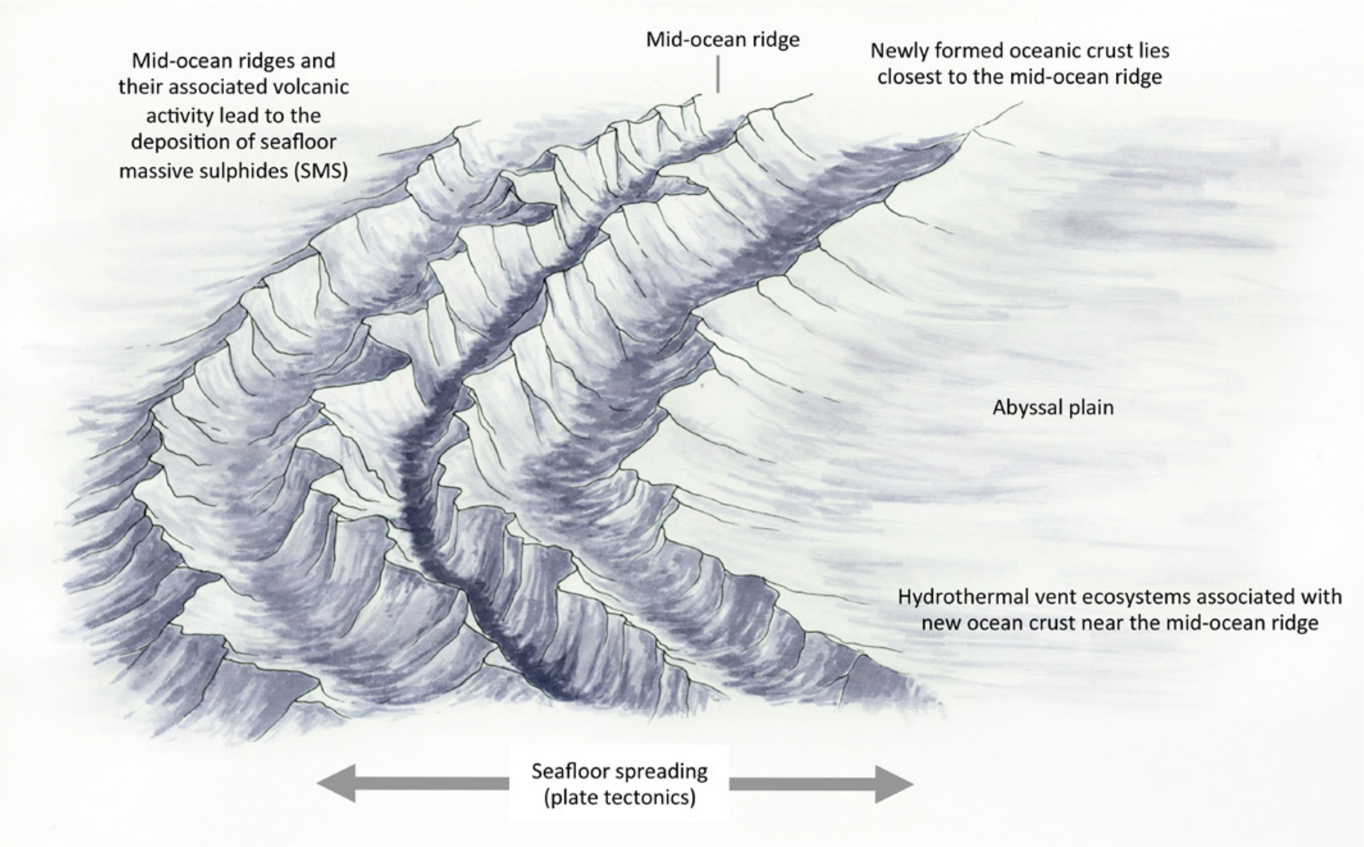
The mid-ocean ridge is a continuous range of undersea volcanic mountains that encircles the globe almost entirely underwater (Figure 15). It is a central feature of seafloor terrain that is more varied and more spectacular than almost anything found on dry land, and includes a collection of volcanic ridges, rifts, fault zones, and other geologic features.

At nearly 60,000 kilometres (37,000 miles) long, the mid-ocean ridge is the longest mountain range on Earth. It formed and evolves as a result of spreading in Earth’s lithosphere—the crust and upper mantle—at the divergent boundaries between tectonic plates. The vast majority of volcanic activity on the planet occurs along the mid-ocean ridge, and it is the place where the crust of the Earth is born. The material that erupts at spreading centres along the mid-ocean ridge is primarily basalt, the most common rock on Earth.

Because this spreading occurs on a sphere, the rate separation along the mid-ocean ridge varies around the globe. In places where spreading is fastest (more than 80 millimetres, or 3 inches, per year), the ridge has relatively gentle topography and is roughly dome-shaped in cross-section as a result of the many layers of lava that build up over time. At slow- and ultra-slow spreading centres, the ridge is much more rugged, and spreading is dominated more by tectonic processes rather than volcanism.

Mid-ocean ridges and vast, complex mountain ranges beneath the sea and thus have a variety of important values for biodiversity and ecosystem services. For example, major transform faults can provide pathways for the transfer of deep ocean water between deep ocean basins, important for nutrient and energy transfer as well as potentially larval movements (Dunn, *et al.*, 2018) . Mid-ocean ridges also harbour recognised genetic hybridisation zones which may foster evolution (Won *et al.*, 2003). Finally, hydrothermal vents may be found along mid-ocean ridges and these tend to be areas of very high biodiversity and specialisation – see overleaf.

Figure 15: Illustration of undersea volcanic mountain range of the mid-ocean ridge. Illustration not to scale.



Credit: Nicky Jenner/FFI

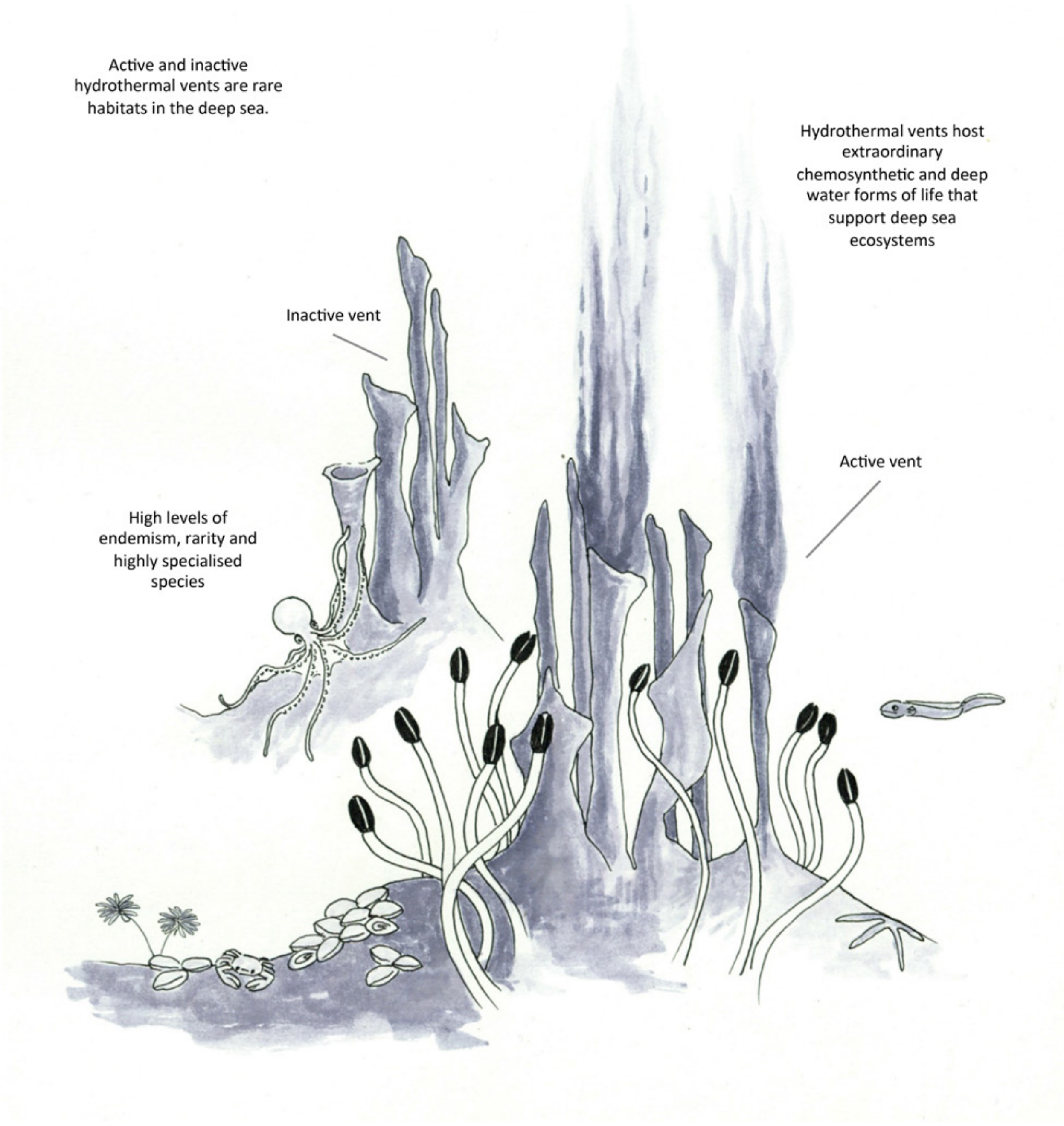
Mid-ocean ridges and their associated volcanic activity lead to the deposition of seafloor massive sulphides, where seawater reacts with host rock at high temperature, stripping the rock of metals such as zinc and copper. These are precipitated as seafloor massive sulphide deposits.

5.6.5 Hydrothermal vents

Hydrothermal vent ecosystems are localised areas of the seabed where heated and chemically modified seawater exits the seafloor as diffuse or focused flow and where microbial chemoautotrophs (organisms that derive their energy from chemical reactions and synthesise required organic compounds from carbon dioxide) are at the base of the food web (Van Dover, 2000). Most vent ecosystems tend to be linearly distributed on hard substrata (basalt) associated with new ocean crust along seafloor spreading centres, though there are sites where active vents on spreading centres are sediment-hosted (e.g., Guaymas Basin in the Gulf of California, Gorda Ridge in the northeast Pacific (Van Dover, 2000)). Vents are also associated with seamount volcanic systems such as the Loihi Seamount (Karl, Brittain and Tilbrook, 1989) and seamounts of the Kermadec Ridge (Clark and O’Shea, 2001).

Hydrothermal vents host extraordinary chemosynthetic and deep water forms of life and are centres of extremely high biodiversity with uniquely high ecological importance. Active vent fields are located in narrow corridors along the 60,000 kilometres-long path of the mid-ocean ridge axis, along 10,000 kilometres of back-arc spreading centres, and at many volcanoes belonging to the submerged portions of volcanic arcs. Globally, the active vent ecosystem is a rare habitat, comprising an estimated 50 square kilometres, or <0.00001% of the surface area of the planet – with the average size of a vent field a few square metres each.

Figure 16: Active and inactive hydrothermal vent systems and characteristic biodiversity. Illustration not to scale.



Credit: Nicky Jenner/FFI

While vent ecosystems are visually dominated by a few abundant species, many taxa at vents appear to be rare (comprising less than 5% of the total abundance in samples), and some are known from only one or a few collected specimens, even where sampling efforts have been extensive (Tsurumi and Tunnicliffe, 2003; Collins, Kennedy and Dover, 2012). Rarity is likely a consequence of multiple factors within vent ecosystems, including the scarcity of habitat, the high degree of specialization to narrow niches, the disjunct nature of the habitat, and limited sampling effort. Further attention is necessary to understand the functional role of rare species at vents and their vulnerability.

Vent ecosystems are typically dominated by benthic invertebrate taxa (e.g., vestimentiferan tubeworms, bathymodiolin mussels, vesicomyid clams, provannid snails, rimicarid shrimp, yeti crabs) that host symbiotic, chemoautotrophic microorganisms (Figure 16). These symbionts require a source of electron donors (e.g., sulphide in vent fluid), a source of electron acceptors (e.g., oxygen in seawater), and a source of inorganic carbon (e.g., carbon dioxide or methane in vent fluids, carbon dioxide in seawater). Vent areas play an important role in global trace element cycles (Box 19).

Total biomass of benthic organisms is typically very high at vents. Beyond the periphery of a vent field, living biomass is relatively inconspicuous, punctuated occasionally by solitary large anemones, gorgonian corals, or other megafaunal organisms. Diversity (species richness) at deep-sea hydrothermal vents is relatively low, dominated (thousands of individuals per cubic metre) by a small number of species (less than 10) and with a large percentage (25%) of rare taxa (Van Dover *et al.*, 2002). Cryptic taxa (morphologically similar, genetically distinct) and phenotypic plasticity (genetically similar, morphologically distinct) are typical. Species composition is often differentiated by habitat within a geographic region (e.g., species-abundance matrices of mussel beds are different from those of tubeworm aggregations) and varies substantively across ocean basins, with up to 11 biogeographic provinces recognised to date (Van Dover *et al.*, 2002; Moalic *et al.*, 2011; Rogers *et al.*, 2012). Vent communities differ widely among biogeographic regions with different vents within a region support different assemblages of species – i.e. very high levels of endemism and uniqueness.

BOX 19
Metal fixation at Vent Systems

The biological stabilisation of metal (e.g., iron, copper) from hydrothermal vents under dissolved or colloidal organic complexes for long-range export in the water column has been documented recently (Wu et al., 2011; Hawkes et al., 2013). Recent assessments of these iron sources indicate their significance for deep-water budgets at oceanic scales and underscore the possibility for fertilising surface waters through vertical mixing in particular regional settings and supporting long-range organic carbon transport to abyssal oceanic areas (German *et al.*, 2016).

Vent and seep areas hold important (yet largely unknown) implications for services to ecosystems and humanity (Le Bris *et al.*, 2017) because of their unique biodiversity and ecological functions in the Earth's biosphere, their geophysically-driven primary production sustained by chemosynthesis, their significance in global element cycles (i.e., iron), and their potential for natural products.

Minerals associated with hydrothermal vents include iron, copper, zinc and magnesium. A black smoker or deep-sea vent is a type of hydrothermal vent found on the seabed, typically in the bathyal zone, with largest frequency in depths from 2,500 metres to 3,000 metres. They appear as black, chimney-like structures that emit a cloud of black material. Black smokers typically emit particles with high levels of sulphur-bearing minerals, or sulphides. Black smokers are formed in fields hundreds of metres wide when superheated water from below Earth's crust comes through the ocean floor (water may attain temperatures above 400 °C). This water is rich in dissolved minerals from the crust, most notably sulphides. When it comes in contact with cold ocean water, many minerals precipitate, forming a black, chimney-like structure around each vent. The deposited metal sulphides can become massive sulphide ore deposits in time. Some black smokers on the Azores portion of the Mid Atlantic Ridge are extremely rich in metal content, such as Rainbow with 24,000 micrometre (μM) concentrations of iron.

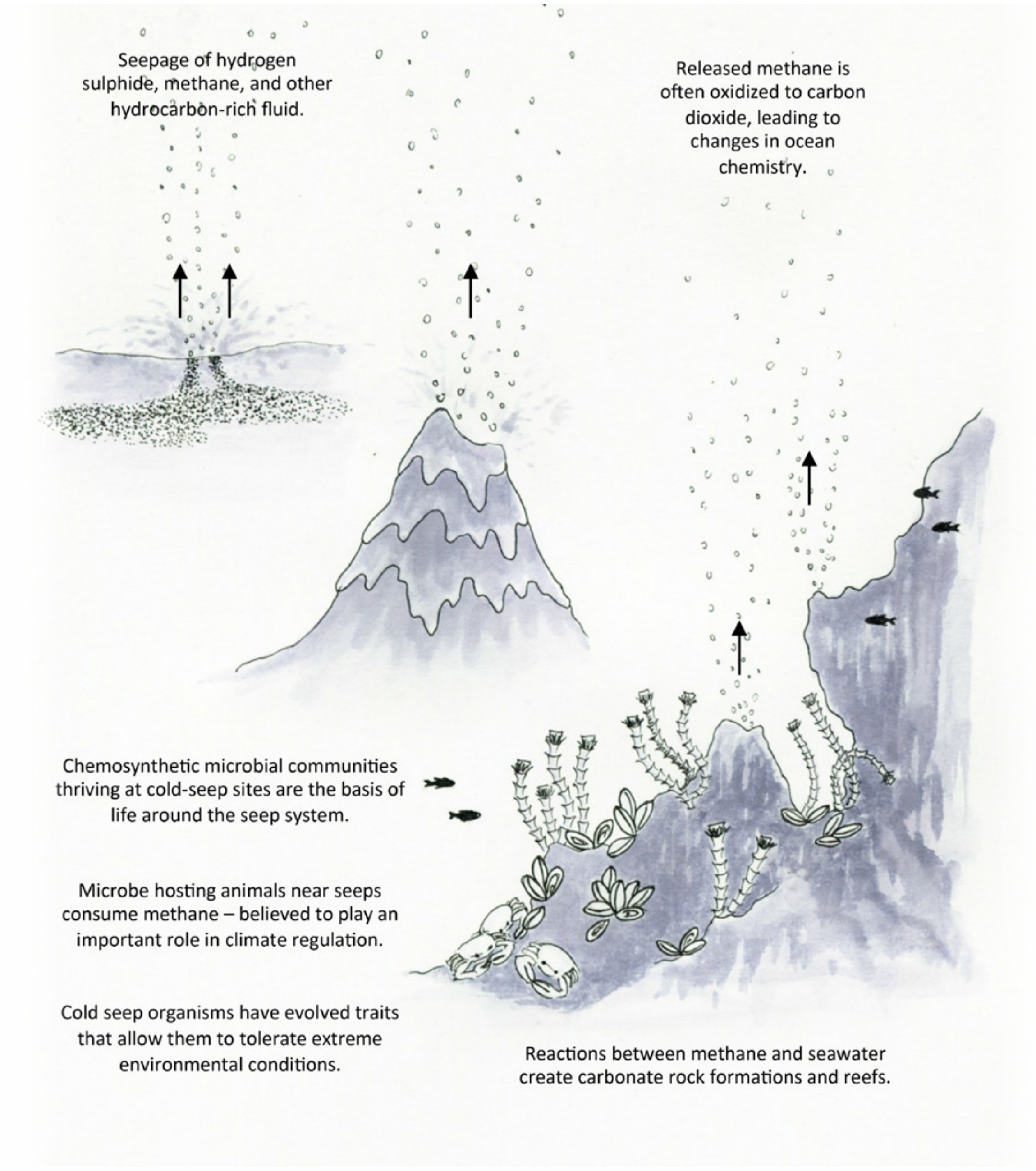
White smoker vents emit lighter-hued minerals, such as those containing barium, calcium and silicon. These vents also tend to have lower-temperature plumes probably because they are generally distant from their heat source (Colín-García *et al.*, 2016).

5.6.6 Cold seeps

Cold seeps are the areas of the ocean floor where hydrogen sulphide, methane, and other hydrocarbon-rich fluid seepage occur. Such seeps occur over fissures on the seafloor caused by tectonic activity. Fluid seepage out of those fissures gets diffused by sediment, and emerges over an area several hundred metres wide. Cold seeps constitute a biome supporting endemic species of animals and plants (Figure 17). These seeps develop unique topography over time, where reactions between methane and seawater create carbonate rock formations and reefs. These reactions may also be dependent on bacterial activity. Ikaite, a hydrous calcium carbonate, can be associated with oxidising methane at cold seeps.

Finding and understanding cold seeps is important because they have global significance for the transfer of methane and carbon from long-term storage in ocean-floor sediments into the ocean and atmosphere. Released methane is often oxidized to carbon dioxide, leading to changes in ocean chemistry, such as ocean acidification. Advanced technologies will expand opportunities for scientists to study how seeps in the deep ocean environment affect ocean chemistry.

Figure 17: Cold seep habitats support uniquely adapted chemosynthetic communities. Illustration not to scale.



Credit: Nicky Jenner/FFI

Both vent and seep ecosystems are made up of a mosaic of habitats covering wide ranges of potential physico-chemical constraints for organisms (e.g., in temperature, salinity, pH, and oxygen, carbon dioxide, hydrogen sulphide, ammonia and other inorganic volatiles, hydrocarbon and metal contents (Fischer *et al.*, 2007; Nakamura *et al.*, 2010; Levin and Sibuet, 2012). Some regions (e.g., Mariana Arc or Costa Rica margin) host both types of ecosystems, forming a continuum of habitats that supports species with affinities for vents or seeps (Watanabe *et al.*, 2010; Levin and Sibuet, 2012).

The chemosynthetic microbial communities thriving at cold-seep sites are the basis of life around the seep system. They are found within the seafloor sediment, as bacterial mats on the seafloor, within larger invertebrate organisms in the community and in the water column above the seep, and they act as the base of the food chain for an extensive and unique collection of organisms.

Cold-water or deep-sea corals growing on the carbonate precipitated from the microbial oxidation of methane are among the seep-related habitats, although they typically occur long after seepage activity has ceased.

Chemosynthetic ecosystems are linked with adjacent deep-sea ecosystems through dispersing larvae and juveniles, and through the export of local productivity to mobile fauna and surrounding deep-sea corals and other filter-feeding communities (Le Bris *et al.*, 2017), but the quantitative importance of their chemosynthetic production at the regional scale still remains to be appraised. At the global scale, a significant role of seep ecosystems is recognised in the regulation of methane fluxes, oxygen consumption and carbon storage from anaerobic methane oxidation by microbial consortia in sediments (Boetius and Wenzhöfer, 2013).

Deep-sea vents and seeps represent one of the most physically and chemically diverse biomes on Earth and have a strong potential for discovery of new species of eukaryotes and prokaryotes (Takai and Nakamura, 2011). The hydrothermal vent and cold seep animals have evolved traits that allow them to tolerate extreme environmental conditions. This makes these ecosystems a vast genomic repository of unique value to screen for highly specific metabolic pathways and processes. The vent and seep biota thus constitute a unique pool of potential for the provision of new biomaterials, medicines and genetic resources that has already led to a number of patents (Arrieta, Arnaud-Haond and Duarte, 2010; Thornburg, Mark Zabriskie and McPhail, 2010; Gjerde and Rulska-Domino, 2012). This great potential value to humankind is accounted for in the public awareness of potential threats and acceptability of deep-sea conservation programmes (Jobstvogt, Watson and Kenter, 2014).

Habitats indirectly related to hydrothermal venting include inactive polymetallic sulphide deposits and hydrothermal sediments (German and Von Damm, 2003).

5.6.7 Trenches

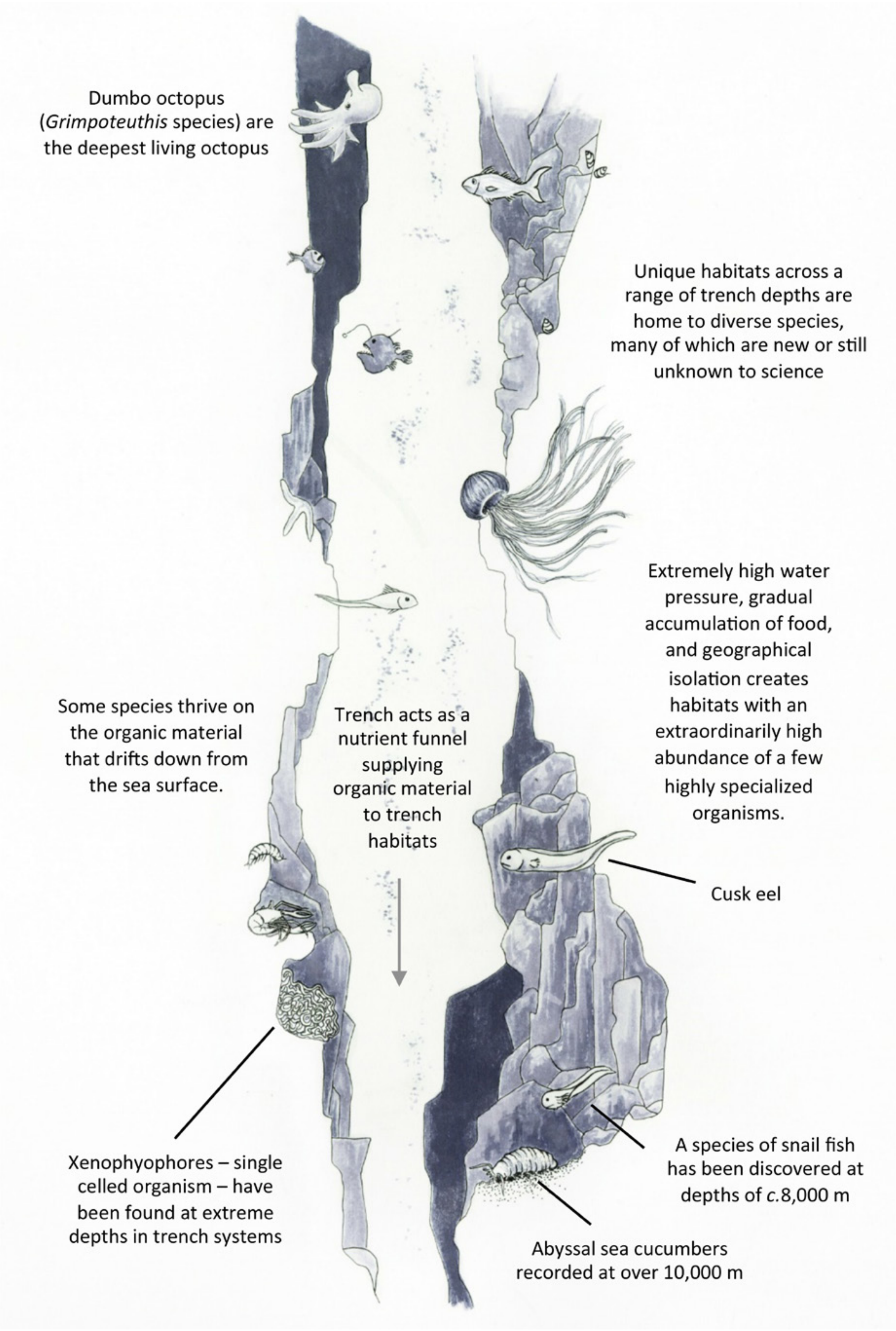
Ocean trenches are steep depressions in the deepest parts of the ocean where old ocean crust from one tectonic plate is pushed beneath another plate, raising mountains, causing earthquakes, and forming volcanoes on the seafloor and on land. With depths exceeding 6,000 metres (nearly 20,000 feet), trenches make up the world's "hadal zone," named for Hades, the Greek god of the underworld, and account for the deepest 45% of the global ocean. The deepest parts of a trench, however, represent only about 1% or less of its total area. The vast submarine slopes and steep walls of trenches make up much of the hadal zone, where unique habitats extending across a range of depths are home to diverse number of species, many of which are new or still unknown to science.

Trenches are formed by subduction, a geophysical process in which two or more of Earth's tectonic plates converge and the older, denser plate is pushed beneath the lighter plate and deep into the mantle, causing the seafloor and outermost crust (the lithosphere) to bend and form a steep, V-shaped depression. This process makes trenches dynamic geological features—they account for a significant part of Earth's seismic activity—and are frequently the site of large earthquakes, including some of the largest earthquakes on record. Subduction also generates an upwelling of molten crust that forms mountain ridges and volcanic islands parallel to the trench. Examples of these volcanic "arcs" can be seen in the Japanese Archipelago, the Aleutian Islands, and many other locations around the Pacific "Ring of Fire."

Trenches are long, narrow and very deep and, while most are in the Pacific Ocean, can be found around the world. The deepest trench in the world, the Mariana Trench located near the Mariana Islands, is 1,580 miles (2,528 km) long and averages just 43 miles (68.8 km) wide. It is home to the Challenger Deep, which, at 10,911 metres (35,797 feet), is the deepest part of the ocean. The Tonga, Kuril-Kamatcha, Philippine, and Kermadec Trenches all contain depths greater than 10,000 metres (33,000 feet).

Figure 18: Illustration depicting characteristic species found in or around oceanic trenches. Not to scale.

References: Thuy et al., (2012); NOAA Office of Ocean Exploration and Research 2016 Deepwater Exploration of the Marianas.



Credit: Nicky Jenner/FFI

The great depth of ocean trenches creates an environment with water pressures more than 1,000 times greater than the surface, constant temperatures just above freezing, and no light to sustain photosynthesis. While this may not seem like conditions suitable to life, the combination of extremely high pressure, the gradual accumulation of food along trench axes, and the geographical isolation of hadal systems are believed to have created habitats with an extraordinarily high abundance of a few highly specialised organisms (Figure 18).

Many of the organisms living in trenches have evolved surprising ways to survive in these unique environments. Recent discoveries in the hadal zone have revealed organisms with proteins and biomolecules suited to resisting the crushing hydrostatic pressure and others able to harness energy from the chemicals that leak out of hydrocarbon seeps and mud volcanoes on the seafloor. Other hadal species thrive on the organic material that that drifts down from the sea surface and is funnelled to the axis of the V-shaped trenches.

Because of their extreme depth, trenches present unique logistical and engineering challenges for the researchers who want to study them. Trench exploration to date has been extremely limited (only three humans have ever visited the seafloor below 6,000 metres) and much of what is known about trenches and the things that live there has been derived from two sampling campaigns in the 1950s (the Danish Galathea and the Soviet Vitjaz Expeditions) and from a handful of photographic expeditions and seafloor samples taken remotely from the deep with little knowledge of their precise location. Despite their scarcity, these initial attempts at studying trenches have hinted at the existence of previously unknown processes, species, and ecosystems.

5.6.8 Canyons

Deep-sea canyons are steep-sided valleys cut into the seafloor of the continental slope, sometimes extending well onto the continental shelf (Figure 19). These submarine canyons vary in size, shape, and morphological complexity; some were scoured by the flow of rivers during past low sea level periods, but most formed via other erosional processes, such as mud slides, debris flows, and turbidity currents.

Submarine canyons are major geologic features of continental margins that link the upper continental shelf to the abyssal plain. Results of the most recent surveys estimate approximately 9,000 canyons worldwide. Even with increased research activities in recent years, most canyons remain poorly known. These geologically and morphologically diverse environments support a wide variety of habitats. Some findings suggest that increased habitat heterogeneity in canyons is responsible for enhancing benthic biodiversity and creating biomass hotspots. Patterns of benthic community structure and productivity have been studied in relatively few submarine canyons.

Canyons support deep water coral communities, as well as a number of other sessile (or immobile) filter feeders, in addition to standard slope fauna. Taxonomic richness is also found to be higher in areas of exposed hard substrate. Therefore, canyons are unique in that they provide habitat for a variety of sessile taxa that are not found in other slope environments.

Several recent multidisciplinary projects focused on the study of canyons have considerably increased our understanding of their ecological role, the goods, and services they provide to human populations, and the impacts that human activities have on their overall ecological condition. Pressures from human activities include fishing, dumping of land-based mine tailings, and oil and gas extraction. Moreover, hydrodynamic processes of canyons enhance the down-canyon transport of litter. The effects of climate change may modify the intensity of currents. This potential hydrographic change is predicted to impact the structure and functioning of canyon communities as well as affect nutrient supply to the deep-ocean ecosystem (Fernandez-Arcaya *et al.*, 2017).

Figure 19: Submarine canyons and their importance in deep-sea productivity. Illustration not to scale

Credit: Nicky Jenner/FFI

Canyons have been described as “keystone structures” because of their role as relevant sources of goods and services to human populations. An increasing amount of data provides evidence of how canyons act benefiting and supporting fisheries (Yoklavich *et al.*, 2000) and enhance carbon sequestration and storage (Epping *et al.*, 2002; Canals *et al.*, 2006; Huvenne *et al.*, 2011). Canyon habitats also provide nursery (Sardà, Cartes and Company, 1994; Hoff, 2010; Fernandez-Arcaya *et al.*, 2017) and refuge sites for other marine life (Tyler *et al.*, 2009; De Leo *et al.*, 2010; Vetter *et al.*, 2010; Morris *et al.*, 2014), including vulnerable marine ecosystems and essential fish habitats such as cold-water corals and sponge fields (Schlacher *et al.*, 2007; Huvenne *et al.*, 2011; Davies *et al.*, 2014). Canyons have also been shown to provide habitat for spawning females of pelagic and benthic species of commercial interest (Lleonart and Farrugio, 2012). Other faunal components of marine ecosystems, including mammals and marine birds, also use canyons, for example, as feeding grounds (Abello *et al.*, 2004; García and Thomsen, 2008; Moors-Murphy, 2014; Roditi-Elasar *et al.*, 2019). Habitat diversity and specific abiotic characteristics enhance the occurrence of high levels of biodiversity(Santora *et al.*, 2018) in some canyons (Vetter and Dayton, 1999; De Leo *et al.*, 2010; McClain and Barry, 2010). Because of this biodiversity, canyons can be a rich source of genetic resources and chemical compounds (i.e., the use of canyon organisms in biotechnological, pharmaceutical, or industrial applications (Jobstvogt, Watson and Kenter, 2014).

The interplay between canyon topography and oceanic currents has profound consequences for the diversity, functioning, and dynamics of both pelagic and benthic communities. For example, currents funnelled through canyons likely enhance primary productivity (Ryan, Chavez and Bellingham, 2005) and drive sediment transport and associated particle-reactive substances toward deep environments (Puig, Palanques and Martín, 2014). Higher levels of primary productivity may lead to canyons being hotspots of faunal productivity in the deep sea (De Leo *et al.*, 2010). The highly variable seascapes within a canyon support diverse assemblages of species that play a wide variety of ecological roles, often across small spatial scales, giving rise to enhanced biodiversity, and ecosystem function (McClain and Barry, 2010). Given their local importance, canyons represent a relevant regional source of marine biodiversity and ecosystem function (Leduc *et al.*, 2013).

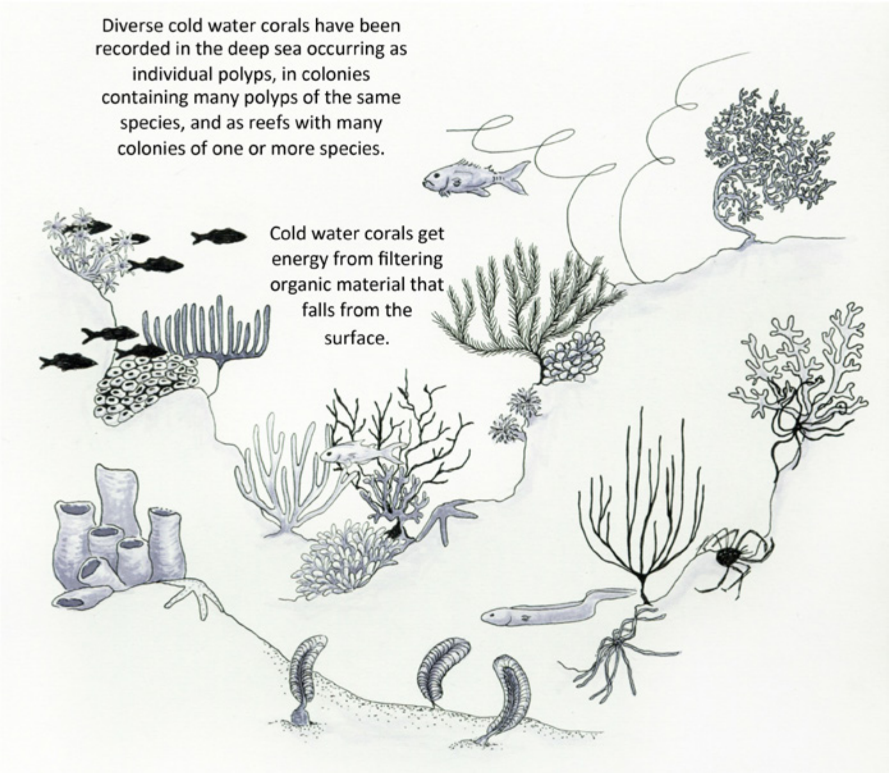
5.6.9 Deep water coral systems

Coral reef ecosystems are generally associated with coastal habitats in shallow tropical waters. Deep water corals are also found in deep-sea environments (Smithsonian Ocean, 2019). Deep- or cold-water corals are found in all of the world's oceans (Figure 20). They grow in rocky habitats on the seafloor as it slopes down into the deep oceans, on seamounts, and in submarine canyons. Most are found at depths greater than 200 metres (650 feet), but where surface waters are very cold, they can grow at much shallower depths.

Deep-sea species grow below the sunlit zone, so they feed on organic material and zooplankton, delivered to them by strong currents. Deep-sea black corals are among the oldest animals on Earth: one specimen has been dated at 4,265 years old. As they grow, corals incorporate ocean elements into their skeletons. This makes them archives of ocean conditions that long predate human records. They also can provide valuable insights into the likely effects of future changes in the oceans.

There is increasing concern and a broad scientific consensus that coral reef ecosystems are being rapidly degraded (Knowlton, 2001). Major anthropogenic impacts include mortality and reduced growth of the reef-building corals due to their high sensitivity to rising seawater temperatures, ocean acidification, water pollution from terrestrial runoff and dredging, destructive fishing, overfishing, and coastal development (De'ath *et al.*, 2012). For example, bottom trawling in the Atlantic Ocean is causing widespread destruction of deep water coral. Surveys have shown as many as half of the coral reefs found off the Norwegian coast are showing damage from bottom trawling.

Figure 20: Cold water corals come in diverse forms, colours and sizes. Illustration not to scale.



Credit: Nicky Jenner/FFI

5.6.10 Oxygen Minimum Zone

The Oxygen Minimum Zone (OMZ) (Childress and Sanders, 1990; Lalli and Parsons, 1993; Mann and Lazier, 2009; Seibel, 2011), sometimes referred to as the shadow zone, is the zone in which oxygen saturation in seawater in the ocean is at its lowest. This zone occurs at depths of about 200 to 1,500 metres (660 – 4,920 feet), depending on local circumstances.

OMZs are found worldwide, typically along the western coast of continents, in areas where an interplay of physical and biological processes concurrently lowers the oxygen concentration (biological processes) and restricts the water from mixing with surrounding waters (physical processes), creating a "pool" of water where oxygen concentrations fall from the normal range of 4–6 milligram per litre to below 2 milligrams per litre.

Surface ocean waters generally have oxygen concentrations close to equilibrium with the Earth's atmosphere. In general, colder waters hold more oxygen than warmer waters. As water moves out of the mixed layer into the thermocline, it is exposed to a rain of organic matter from above. Aerobic bacteria feed on this organic matter; oxygen is used as part of the bacterial metabolic process lowering its concentration within the water. Therefore, the concentration of oxygen in deep water is dependent on the amount of oxygen it had when it was at the surface minus depletion by deep-sea organisms.

Physical processes then constrain the mixing and isolate this low oxygen water from outside water. Vertical mixing is constrained due to the separation from the mixed layer by depth. Horizontal mixing is constrained by underwater topography (bathymetry) and boundaries formed by interactions with sub-tropical gyres and other major current systems. Low oxygen water may spread (by advection) from under areas of high productivity up to these physical boundaries to create a stagnant pool of water with no direct connection to the ocean surface even though (as in the Eastern Tropical North Pacific) there may be relatively little organic matter falling from the surface.

Despite the low oxygen conditions, organisms have evolved to live in and around OMZs. For those organisms, like the vampire squid, special adaptations are needed to either make do with lesser amounts of oxygen or to extract oxygen from the water more efficiently. For example, the giant red mysid (Gnathophausia ingens) have highly developed gills with large surface area and thin blood-to-water diffusion distance that enables effective removal of oxygen from the water (up to 90% oxygen removal from inhaled water) and an efficient circulatory system with high capacity and high blood concentration of a protein (hemocyanin) that readily binds oxygen.

Some classes of bacteria in the oxygen minimum zones use nitrate rather than oxygen, thus drawing down the concentrations of this important nutrient. This process is called denitrification. The oxygen minimum zones thus play an important role in regulating the productivity and ecological community structure of the global ocean. For example, giant bacterial mats floating in the oxygen minimum zone off the west coast of South America may play a key role in the region's extremely rich fisheries as bacterial mats the size of Uruguay have been found there. Existing Earth system models project considerable reductions in oxygen and other physico-chemical variables in the ocean due to ongoing climate change, with potential ramifications for ecosystems and people.

5.7 Microbes

In addition to the visible animal life associated with the seabed, diverse microscopic life also flourishes in these systems. This nearly invisible microbial life is responsible for the majority of the chemical cycling that occurs in these habitats, providing essential ecosystem services for, and underpinning ecosystem function of, shallow water and deep-sea environments (Thurber *et al.*, 2014).

Microbial life, particularly from the bacteria and archaea domains of life, represents a large and diverse genetic reservoir with mostly unexplored potential for medical and commercial applications. Despite the importance of the microscopic component of life to ecosystem services and the ecological function in the deep sea, this category has been somewhat overlooked in planning related to assessing and evaluating possible environmental impacts related to deep-seabed mining. Inclusion of microbial information (namely, community structure and biomass) into EIA recommendations only began in 2013 (International Seabed Authority, 2013). A recent expanded recommendation to include "diversity, abundance, biomass, community-level analysis, connectivity, trophic relationships, resilience, ecosystem function, and temporal variability" of microbial communities has since arisen in the 2018 draft regulations for exploitation (Ardron, Ruhl and Jones, 2018).

It must be emphasised that the majority of microbial life at hydrothermal vents has not been explored, despite increasing improvements in access to the deep ocean and new analytical tools (Xie *et al.*, 2011; Fortunato and Huber, 2016; Fortunato *et al.*, 2018). Therefore, many of the ecosystem services and patterns and processes of ecological function that microbes provide in these ecosystems are not yet known to science, and thus, the cultural heritage and educational services that active hydrothermal vents provide, both known and unknown, could be lost as a result of mining activities.

6. Understanding marine ecosystem services

6.1 Overview of marine ecosystem services

It is important for seabed mining projects to understand ecosystem services in order to avoid or mitigate impacts to services important both to ocean function and to those of local communities and to a seabed mining operation itself. Effectively managing ecosystem services through the life of an operation is a key component of ocean sustainability and important for managing operational and reputational risk.

Ecosystem services are the benefits that people derive from ecosystems (which are underpinned by inherent biodiversity values). Ecosystem services are generally classified as:

1. Provisioning services – goods or products obtained from ecosystems such as biological raw materials (limestone etc.) and food (fish, octopus, seaweed etc.)
2. Regulating services - benefits obtained from the regulation of ecosystem processes such as flood attenuation, climate regulation and waste attenuation.
3. Cultural services - nonmaterial benefits people obtain from ecosystems such as recreation, sense of place.
4. Supporting services - natural processes that maintain the other services such as primary production and nutrient cycling. In the deep ocean, these are most likely fundamental ecosystem function processes and those important to long term ocean health.

Marine ecosystems produce a vast array of goods and services to people, such as wild biotic stocks, and potential new biological and genetic resources supported by a variety of ecosystem services (Armstrong *et al.*, 2012; Barbier, 2017). These provisioning services are maintained by regulatory services that support many essential functions for the health of marine ecosystems. These services include, but are not limited to, food provisioning for organisms, nutrient cycling, and carbon sequestration (Armstrong *et al.*, 2012; Barbier, 2017; Le Gouvello *et al.*, 2017).

Marine ecosystem services are fundamentally important to humans, not only for the provision of livelihoods, but also in contributing to health and well-being. For example:

- 50% of global primary production occurs in the oceans
- The coastal boundary zone that surrounds the continents is the most productive part of the world ocean, yielding about 90% of marine fisheries catches. Overall, coastal and marine fisheries landings averaged 82.4 million tons per year during 1991–2000 (with a declining trend now largely attributed to overfishing) (Pauly *et al.*, 2005)
- Nearing 35 million jobs are directly linked to ocean fisheries, as well as the livelihoods of at least 300 million people (The Economics of Ecosystems and Biodiversity, 2012).
- Up to half a billion people are thought to depend economically on coral reefs ecosystems and 850 million people live within 100 kilometres of a coral reef.
- Many coastal communities have deep cultural and spiritual connections with the oceans
- Conservative estimates of the value of ecosystem services provided by seagrass beds are in the order of US$ 19,000 per hectare per year (Dewsbury, Bhat and Fourqurean, 2016) (Costanza *et al.*, 1997).
- Limited research has been undertaken in deep-sea environments however seamounts are known to be important to commercial fishing. Researchers in the Pacific have observed deep-sea species in the stomach contents of commercially important fish (The Economics of Ecosystems and Biodiversity, 2012).

- The buffering capacity of the deep sea plays a crucial role in mitigating the climatic changes caused by anthropogenic emissions: the biological carbon pump is very important in the global carbon cycle, transferring approximately 5-15 billion tons of carbon each year from the surface ocean to the oceans interior. This is around the same amount as the annual increase in carbon dioxide in the atmosphere driven by human fossil fuel use. Further, the deep-sea environment plays a key role in the cycling of other nutrients such as nitrogen, silica, phosphorus, hydrogen, and sulphur (Thurber *et al.*, 2014).

Ocean environments further provide a detailed record of past climates and marine environmental conditions. For example, marine sediment and nodules serve as a valuable resource for reconstructing past climate conditions as well as understanding and predicting future climate change.

6.1.1 The ecosystem services of the deep sea

A summary of deep ocean and seabed ecosystem services is provided in Table 3

Table 3: Some of the ecosystem services of the deep seabed (Orcutt et al., 2020)

Ecosystem Service	ES description	Baseline level of ES provision
Provisioning	Some benthic organisms are directly consumed by people (e.g. clams and oysters)	Utilisation of genetic resources from seep-sea vent systems
	Some benthic organisms are used as bait (e.g. worms and clams) or in other processes (e.g. may be crushed and used in industrial processes	
	Genetic material may be extracted from sediment dwelling bacteria or benthic organisms for pharmaceutical and research use	Utilisation of genetic resources from seep-sea vent systems
	Proteins or chemical compounds may be extracted from dwelling bacteria or benthic organisms for pharmaceutical and industrial use	Utilisation of mineral resources is limited today but potential exists for future mineral development
Provisioning	Benthic organisms and sediment dwelling bacteria influence climate processes: these organisms regulate some organic decomposition processes which influence carbon dioxide sequestration and the sediment itself may be a sink for organic (e.g. carbon-based) material	Deep-sea sediments act primarily as a carbon sink. The vents represent sources of heat and chemicals which support local increases in productivity and diversity
	Benthic organisms and sediment dwelling bacteria influence pollution attenuation processes: burying by the sediment itself may reduce the bioavailability of pollutants; sediments and sediment dwelling organisms regulate water purification processes	
	Sediment structure and the accumulation of sediment regulates accretion and erosion processes as well as storm surge and flood control	Sediment and sediment processes at the depths in question have almost no influence on erosion processes or storm surge protection (0)

Ecosystem Service	ES description	Baseline level of ES provision
Provisioning	Well-being may be derived by individuals simply because they know a health sediment community exists Well-being may be derived because the sediment exists and can be used in the process of generating human well-being, education, or scientific understanding	Given the remoteness and limited development of seabed resources, these values may be high relative to similar values held by individuals in more developed areas
Provisioning	Sediment dwelling organisms cycle energy, nutrients and organic matter within and between ecosystems. This energy cycling facilitates the production of future ecosystem services across multiple ecosystems. Three dimensional structures represent a feature around which organisms may aggregate while feeding and/or reproducing	The deep-sea acts primarily as a sink – energy and nutrients transport from deep-sea back into resources that provide provisioning or regulating services Nursery utilisation, association with vents and seamounts with thermal and chemical loading are all elevated relative to an undifferentiated deep seabed. However, few organisms that provide provisioning or regulating services benefit from these ES

Emerging discoveries highlighting the significance of deep-sea ecosystems in delivering global and localised benefits suggest that the "common heritage" of the seabed extends beyond its mineral resources to include substantial contributions to biodiversity and climate regulation - contributions that may be less quantifiable in terms of projected revenue, but indispensable to human life (Hunter, Singh and Aguon, 2018).

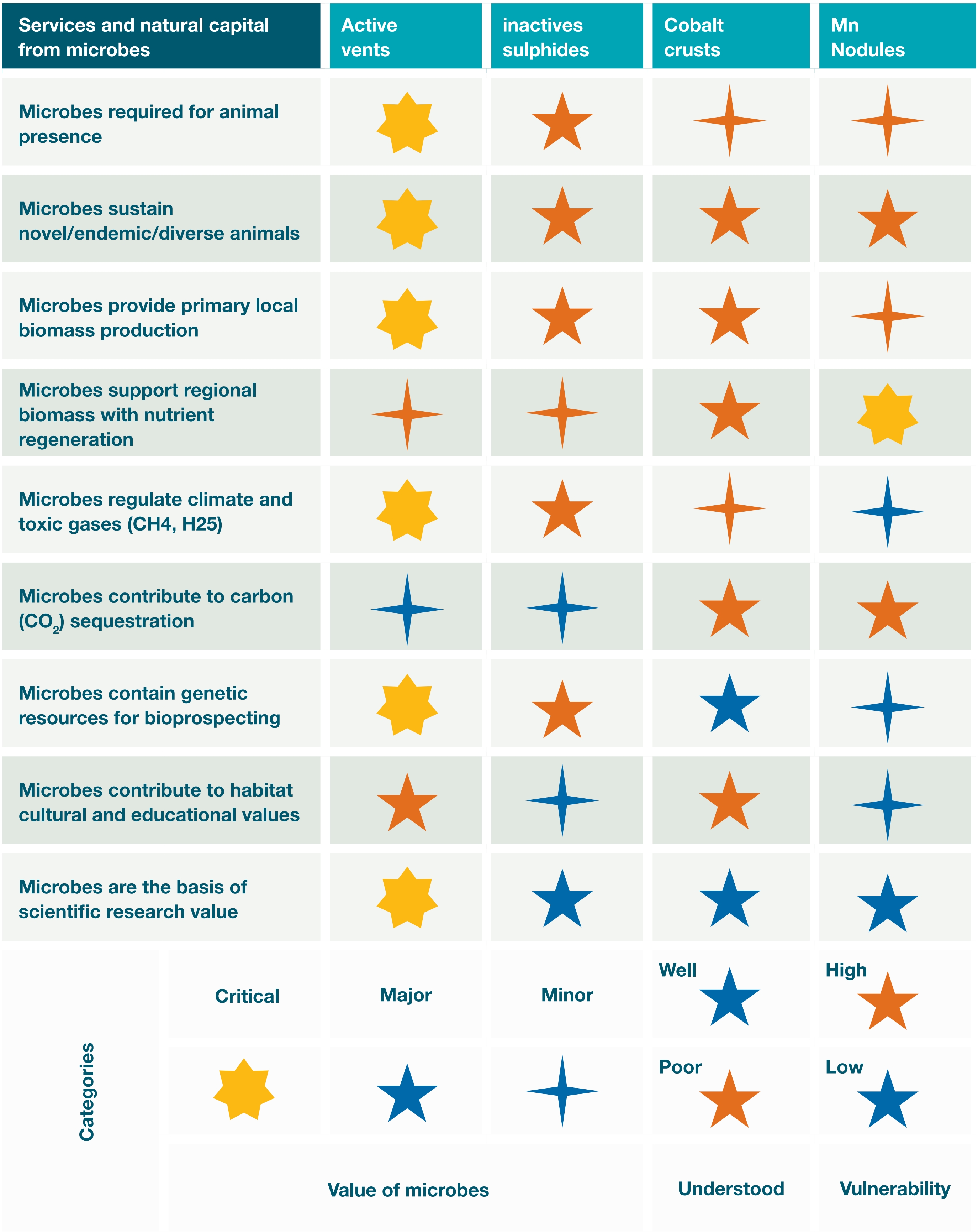
6.1.2 Importance of deep-sea microbial communities for ecosystem services

Diverse microscopic life also flourishes in the deep sea and underpins essential function and ecosystem services (Figure 21). This nearly invisible microbial life is responsible for the majority of the chemical cycling that occurs in these habitats, providing essential ecosystem services for deep-sea environments. Microbial life further represents a vast and diverse genetic reservoir with mostly unexplored potential for medical and commercial applications. In these ecosystems, the chemosynthetic microbial life is fundamental as the base of the food web. At hydrothermal vents, chemical reactions fuel highly productive chemosynthetic environments but in the low-temperature mineral deposits like ferromanganese nodules and cobalt crusts, chemosynthetic and biochemical processes also occur – maintaining the stasis of the oceans chemistry and ability to regulate e.g. climate and metal concentrations.

In 2018, a community of scientists met to define the microbial ecosystem services that should be considered when assessing potential impacts of deep-seabed mining, and to provide recommendations for how to evaluate these services (Orcutt *et al.*, 2020). The paper shows that the potential impacts of mining on microbial ecosystem services in the deep sea vary substantially, from minimal expected impact to complete loss of services that cannot be remedied by protected area offsets. The authors conclude by recommending that certain types of ecosystems should be "off limits" at least until initial characterizations can be performed, and that baseline assessments of microbial diversity, biomass, and biogeochemical function need to be considered in EIAs of all potential instances of deep-seabed mining.

Mineral resources on the seabed are also centrepieces of deep-sea ecosystems, functioning as refugia and stepping stones for animal biodiversity. For example, polymetallic crusts in the deep sea serve as hard substrate for the attachment of sessile animal communities such as sponges, or for egg-laying for mobile species like octopus which do not anchor in the soft sediment surrounding the deposits. As another example, unique animal communities have evolved to survive under the high temperature and extreme chemical conditions found at hydrothermal vents where massive sulphide deposits form from the interaction of these hot, mineral-rich fluids with surrounding cold seawater. Thus, these mineral deposits often host "hotspots" of animal life on the otherwise barren seafloor.

Figure 21: A qualitative assessment of the ecosystem services from microorganisms in deep-sea habitats with mineable resources. The size, outline, and shading of symbols reflects the value that microbes support in each system, how well microbial aspects of the ecosystem are understood, and the vulnerability of microbial aspects to mining impacts, respectively, per the legend (Orcutt et al, 2020).



Services and natural capital from microbes	Active vents	inactives sulphides	Cobalt crusts	Mn Nodules
Microbes required for animal presence	✹	★	✦	✦
Microbes sustain novel/endemic/diverse animals	✹	★	★	★
Microbes provide primary local biomass production	✹	★	★	✦
Microbes support regional biomass with nutrient regeneration	✦	✦	★	✹
Microbes regulate climate and toxic gases (CH4, H25)	✹	★	✦	✦
Microbes contribute to carbon (CO_2) sequestration	✦	✦	★	★
Microbes contain genetic resources for bioprospecting	✹	★	★	✦
Microbes contribute to habitat cultural and educational values	★	✦	★	✦
Microbes are the basis of scientific research value	✹	★	★	★

Categories	Critical	Major	Minor	Understood	Vulnerability
	✹	★	✦	Well ★	High ★
				Poor ★	Low ★
	Value of microbes			Understood	Vulnerability

6.1.3 Challenges for anticipating and mitigating impacts on ecosystem services

A key issue in the management of seabed exploitation is examining how ecosystem structure and ecological functions convert into benefits to society. The changes in the state of ecosystem components may be recoverable or reversible, determining the degree of impacts on ecosystems. Adequately estimating the potential state changes is thus essential for translating the impacts of seabed exploitation into losses to the ecosystem services. When extraction activities are prone to causing ecologically defined irreversible harm through species extinction or habitat destruction and the existence of ecosystem services in the future is threatened, the valuing of ecosystem services is highly relevant. However, a major challenge in this valuation is to quantify the marine ecosystem services in a comprehensive manner (Kaikkonen *et al.*, 2018).

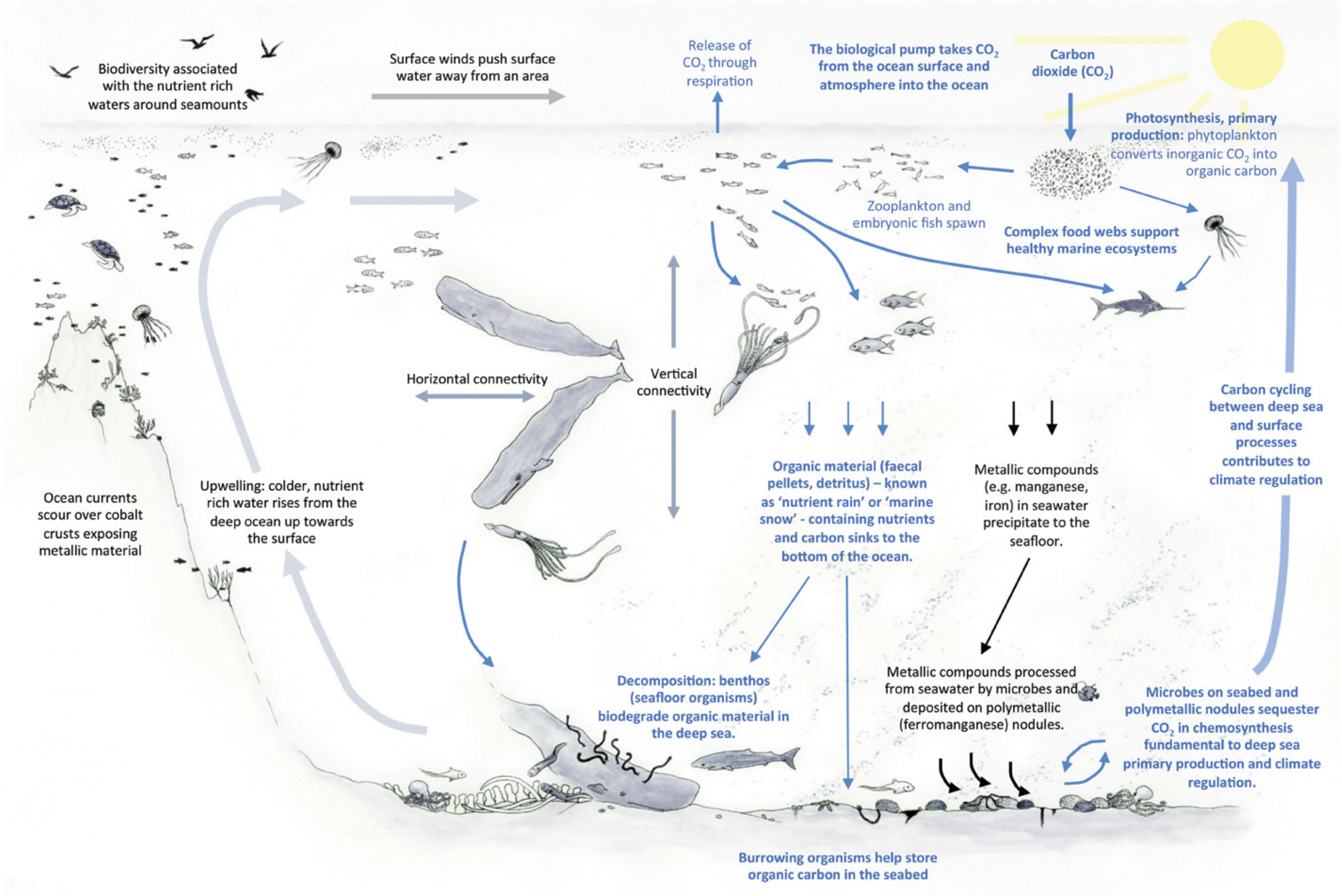
Unintentional trade-offs occur when decision-makers are ignorant of the interactions among ecosystem services or have incomplete knowledge of their functioning (Tilman *et al.*, 2001; Walker *et al.*, 2002). Ecosystem services trade-offs can be irreversible when the extraction of seabed resources destroys the habitats available for biodiversity maintenance, e.g. fish nursery grounds (Rodríguez *et al.*, 2006). Identification of the possible trade-offs allows decision-makers to better understand the long-term effects of only focusing on one ecosystem service or preferring one service over another (Rodríguez *et al.*, 2005). Understanding of the relationships among ecosystem services is thus essential for estimating the consequences of changes in one ecosystem service through linkages to other services.

6.2 Defining key biophysical processes of ocean geosystems

Marine geosystems are as diverse and dynamic as terrestrial ones, but far more expansive. Changes in ocean systems can have global repercussions because the oceans are connected to one another, and water masses from different seas mix (Redfield, 1958; Morel, Milligan and Saito, 2003; Sarmiento, Gruber and McElroy, 2007). There is a close relationship between biophysical processes that drive nutrient availability and connectivity that are essential to ecosystem health and function.

Productivity fuels life in the ocean, drives its chemical cycles, and lowers atmospheric carbon dioxide. Nutrient uptake and export interact with circulation to yield distinct ocean regimes. Several of the key ocean processes are summarised below and illustrated in Figure 22.

Figure 22: Illustration of oceanic processes including primary productivity and the biological pump, and connectivity. Illustration not to scale.



Credit: Nicky Jenner/FFI

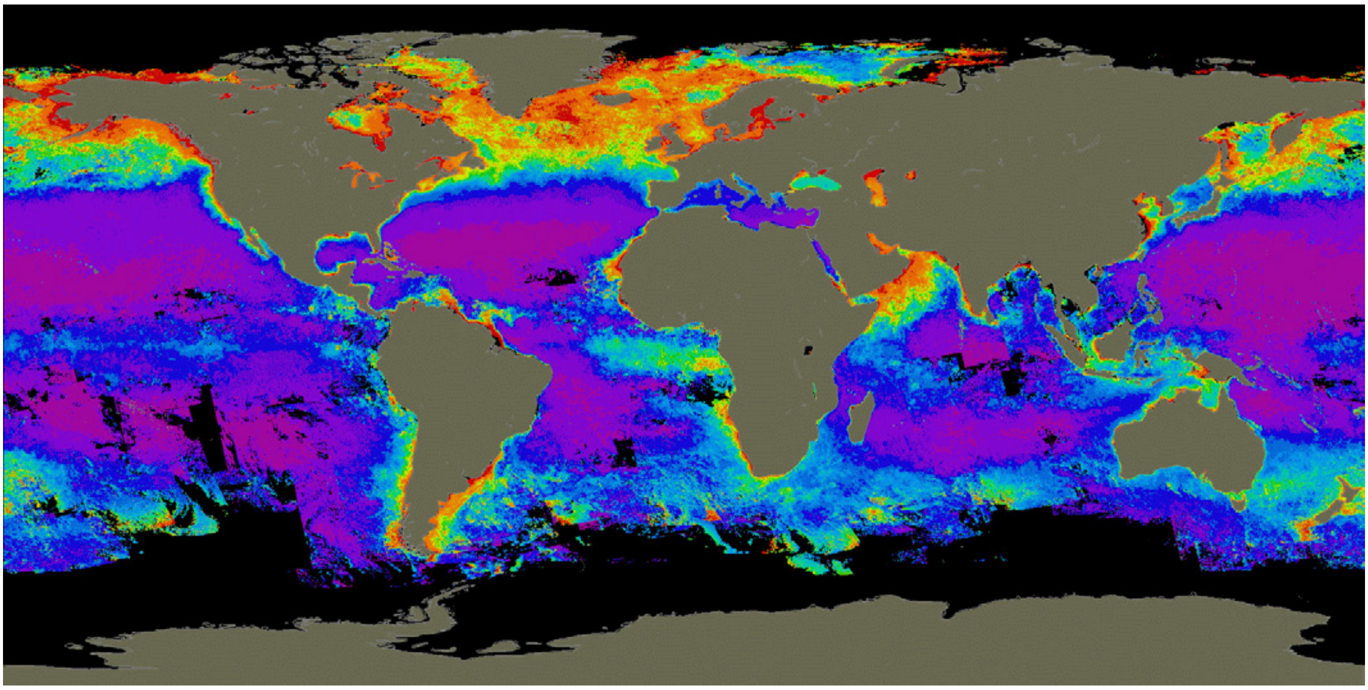
6.2.1 Primary Productivity

In marine environments, photosynthetic organisms – mostly phytoplankton (organisms that derive energy from the sun) are the most abundant form of life. Phytoplankton are "photoautotrophs," harvesting light to convert inorganic to organic carbon, and they supply this organic carbon to diverse "heterotrophs," organisms that obtain their energy solely from the respiration of organic matter. Open ocean heterotrophs include bacteria as well as more complex single- and multi-celled "zooplankton" (floating animals), "nekton" (swimming organisms, including fish and marine mammals), and the "benthos" (the seafloor community of organisms) (Sigman and Hain, 2012).

Because energy from light is required for photosynthesis (the conversion of carbon dioxide into cellular organic material using energy from the sun), photosynthetic organisms in oceans are restricted to shallow water areas where light can penetrate. This is called the photic zone. Light intensity diminishes rapidly with water depth, limiting the depths of the photic zone to less than ~100 metres. In addition, hydrogen is needed for photosynthesis.

However, photosynthetic organisms need more than just light, carbon dioxide, and water to survive. They also need nutrients: the two most important are nitrates and phosphates. Microbes in the soil on land absorb and convert atmospheric nitrogen (N^2) into nitrates (NO^3-), while phosphates are derived predominantly from the chemical weathering of continental rocks. Therefore, both nitrates and phosphates are provided as nutrients to photosynthetic organisms by run-off from land via riverine influx into the ocean. This contiguous relationship between terrestrial and marine systems is called allochthony and is fundamental to understanding the complexity of ocean systems and the importance of taking an ecosystem-based approach. For land plants, these nutrients are obtained from the soil. It's understandable then, that the most nutrient-rich waters on Earth are found very near to shorelines, where rivers dump nutrients into the oceans (Figure 23).

Figure 23: Primary productivity for June - September. Warmer colours represent higher primary productivity. Notice the intra-cratonic lakes that have high primary productivity. (Credit: NASA)



However, there is a secondary process for providing nutrients to the photic zone, and that's upwelling. Wind blowing across the surface of the ocean along continental coastlines, in addition to the Coriolis Effect (the deflection of seawater due to the rotation of the Earth) causes this typically warmer water to be displaced away from the coastline. Colder, nutrient-rich deep waters are then brought to the surface to replace the deflected surface waters. For example, upwelling and recycling of nutrients offshore Peru is related to prevailing winds pushing surface waters northward at the same time that the Coriolis Effect deflects it to the west, resulting in the upwelling of cold, nutrient-rich water. Upwelling occurs mainly in shallow (less than 200 metres) coastal waters and is the primary mechanism where deeper, nutrient-rich waters are brought into the photic zone. Areas where nutrients are provided through a combination of continental run-off and upwelling constitute only ~0.1% of the ocean area, but have a predominance of photosynthetic organisms due to the increased nutrient supply. This is called primary productivity, and it's the rate at which energy is converted by photosynthetic organisms to create organic substances. Areas of the photic zone that have higher nutrient supply tend to have increased primary productivity.

The worldwide distribution of modern organic-rich sediments doesn't correlate with zones with higher nutrients and primary productivity. For example, the coasts of Antarctica are thought to have some of the most nutrient-rich waters on Earth, yet the underlying sediments contain very little organic matter. This is due to the circulation of cold, oxygen-rich waters at the ocean bottom which inhibits the preservation of the organic matter once it has settled.

Most of the photosynthetic organisms that flourished in the photic zone will not be preserved at the ocean floor. The majority of these organisms will be degraded by other organisms during secondary production of organic matter or through chemical oxidation. The organic matter that actually makes it to the ocean bottom is generally a mixture of the remains of the primary producers (photosynthetic organisms and plants) and the faecal pellets produced by the organisms that feed off of the photosynthetic organisms. Consequently, the amount of organic matter that reaches the sediment–water interface is controlled by the depth of the water column, the amount of original photosynthetic organisms, and the quantity of secondary feeders. The deeper the water, the longer the time available for the secondary feeders to consume the photosynthetic organisms (biodegradation).

While our perceptions of life on Earth are skewed by our daily encounter with photosynthesis-supported life on land, the deep-sea is a fundamentally different environment where sunlight does not penetrate. In deep-sea environments, energy for life is also generated through chemosynthesis, where energy from inorganic chemical reactions is used to convert dissolved carbon dioxide into the organic molecules (sugars, fats, proteins, etc.) that are the building blocks of life. Hydrothermal vents offer a figurative buffet of chemical reactions that can fuel abundant chemosynthesis-driven microbial life. Similarly, in the low-temperature mineral deposits like ferromanganese nodules and cobalt crusts, chemosynthetic processes also occur (Orcutt *et al.*, 2020). In these ecosystems, the chemosynthetic microbial life can form the base of the food web. Thus, disruption to the supply of chemical energy sources can have consequences for the amount and type of life that can be supported.

6.2.1.1 Gaps in knowledge: the role of oceanic carbon cycling in climate regulation

The scale and rate of these novel carbon cycling processes happening on the seafloor may be very significant in terms of the carbon cycle. We do not yet know the fundamental biological and biochemical processes underpinning these processes, even though there is evidence that this is occurring at scales which may account for 10% of the carbon dioxide that the oceans remove each year. The implications of loss of this element of the carbon cycle in terms of climate regulation is poorly understood.

6.2.2 The biological pump

There are no accumulations of living biomass in the marine environment that compare with the forests and grasslands on land (Sarmiento and Bender, 1994). Nevertheless, ocean biology is responsible for the storage of more carbon away from the atmosphere than the terrestrial biosphere (Broecker, 1982). This is achieved by the sinking of organic matter out of the surface ocean and into the ocean interior where it is returned to dissolved inorganic carbon and dissolved nutrients by bacterial decomposition *(Error! Reference source not found.).* Oceanographers often refer to this process as the "biological pump," as it pumps carbon dioxide out of the ocean surface and atmosphere and into the voluminous deep ocean (Volk and Hoffert, 1985).

The organic detritus that makes it to the ocean bottom represents the remains of what didn't get eaten during its journey from the photic zone. Once the organic matter settles, it is once again subjected to biodegradation by benthic organisms (organisms that live at or near the sediment surface). Decomposition of organic material occurs rapidly by aerobic organisms at the basin floor. Deposit feeders (organisms that graze off the organic matter that has settled on the basin floor) and burrowing organisms (organisms that actively burrow through the sediment) make up the majority of organisms responsible for this further biodegradation.

At a global system level, primary productivity and nutrient cycling happens on a vast scale. Counter-intuitively, productivity in the Southern Ocean drives nutrients at the surface in the tropics. Deep water is upwelled into the Southern Ocean surface, where this nutrient-bearing water is pumped by the winds into the mid-depth ocean interior that supplies nutrients to the low latitude surface ocean (Palter *et al.*, 2010) (Figure 24). As a result, Southern Ocean circulation changes can affect ocean productivity on a global basis.

The overall strength the biological carbon pump is determined by: 1) the major nutrient content of the ocean, 2) the degree to which the major nutrients are consumed in surface waters, and 3) the carbon-to-major nutrient ratio of sinking organic matter. Calculations suggest that, in the context of the modern carbon cycle, if the biological pump were to stop, atmospheric carbon dioxide concentration would more than double over the course of roughly a thousand years (the time scale over which deep waters pass through the surface ocean) (Palter *et al.*, 2010). Conversely, a fully efficient biological carbon pump (one in which all nitrogen and phosphates supplied to surface waters are consumed and converted into exported organic matter) would lower carbon dioxide by more than half of its current concentration.

6.2.2.1 Gaps in knowledge: implications of disturbing geological and geochemical processes

Nutrients and minerals are important to consider in relation to seabed mining, as little is understood of the implications of releasing or disturbing the natural geological and geochemical processes that both control and influence the ocean's "budget".

6.2.3 Carbon dioxide and climate regulation

On the time scale of thousands of years, the chemistry of the ocean essentially sets the concentration of carbon dioxide in the atmosphere (Broecker, 1982). Ocean productivity affects atmospheric carbon dioxide by the export of both organic carbon and calcium carbonate $CaCO^3$ from the surface ocean to ocean depths; the former lowers atmospheric carbon dioxide, while the latter raises it more modestly (Archer, 2005; Sarmiento, Gruber and McElroy, 2007).

The biological carbon pump lowers atmospheric carbon dioxide directly by simply shuttling carbon out of surface waters, which causes carbon dioxide from the atmosphere to invade the surface ocean (Figure 24).

Scientists have discovered that microbes (e.g. bacteria) in the deepest parts of the seafloor are absorbing carbon dioxide and could be turning themselves into an additional food source for other deep-sea life. Bacteria living 4,000 metres below the ocean surface in the Clarion-Clipperton Fracture Zone are consuming carbon dioxide and turning it into biomass in a newly described chemosynthetic process. 200 million tonnes of carbon dioxide could be fixed into biomass each year by this process, equating to approximately 10% of the carbon dioxide that the oceans remove each year and is thus likely to be an important part of the deep-sea carbon cycle.

In addition to their rich biodiversity, hydrothermal vents and seeps constitute important sinks in which microorganisms specifically adapted to these environments consume and sequester carbon and methane, a greenhouse gas with roughly 25 to 50 times the potency of carbon dioxide. A 2016 study released by 14 universities and oceanographic institutions found carbon sequestration by hydrothermal vents and seeps to be even more "extensive in space and time than previously thought" (Levin *et al*, 2016) Indeed, one study author cautioned that the release of sequestered methane could be "a doomsday climatic event." Recent scientific breakthroughs have further revealed that most of the excess heat resulting from increased atmospheric greenhouse gas concentrations has been absorbed by the deep ocean, thereby significantly limiting climate change impacts on the ocean's surface and on land (Hunter, Singh and Aguon, 2018).

6.2.3.1 Gaps in knowledge

We do not yet know the fundamental biological and biochemical processes underpinning the biological pump, even though there is evidence that this is occurring as scales which may account for 10% of the carbon dioxide that the oceans remove each year. The implications of loss of this element of the carbon cycle in terms of climate regulation is poorly understood.

6.2.4 Phosphorus cycling

The ocean's phosphorous budget is largely controlled by geological and geochemical processes. Phosphorous enters the ocean by weathering, and it is removed through the sedimentary burial of organic phosphorous, phosphorous adsorbed onto iron oxides, phosphatic fossil material such as fish debris and shark teeth, and authigenic phosphate minerals (Froelich *et al.*, 1988). The residence time of phosphorous in the ocean has been estimated as 20,000 – 40,000 years (Ruttenberg and Berner, 1993). Inferences have been made that changes in the ocean phosphorous budget influence atmospheric carbon dioxide and on the transitions from ice ages to warm interglacials (Ren *et al.*, 2017).

6.2.4.1 Gaps in knowledge

There remain gaps in knowledge on the implications of phosphorus cycling in terms of ocean chemistry and the role of phosphorous in climate regulation and ocean health.

6.2.5 Nitrogen

The input/output budget of ocean nitrogen is largely biologically driven. Biologically available (or "fixed") nitrogen is brought into the ocean mostly by oceanic nitrogen "fixers" (cyanobacterial phytoplankton). Once fixed, the nitrogen is incorporated into the global ocean nitrogen cycle, which is dominated by the large reservoir of nitrate NO^3 stored in deep water. The upwelling or mixing of this nitrogen into the euphotic zone drives the export production across the global ocean. Fixed nitrogen is mainly lost from the ocean by "denitrification," when organic matter decomposes.

Nitrogen fixation requires two metals — iron and molybdenum — that could potentially limit the rate of this process and thus interfere with the nitrogen fixation feedback. It has been argued that the scarcity of iron in the modern ocean (see below) contributes to the widespread tendency toward nitrogen deficit in the global ocean by suppressing nitrogen fixation rates (Falkowski, 1997). More dramatically, it has been hypothesised that the long spell of slow evolution in life from 2.0 to 0.6 billion years ago was due to molybdenum limitation of nitrogen fixers, which slowed ocean productivity, organic carbon burial, and the build-up of oxygen in the atmosphere (Anbar and Knoll, 2002).

6.2.6 Iron

Iron is required for many phytoplankton functions, perhaps most importantly in the electron transport chain of photosynthesis. Iron has nutrient-like structure in the ocean, with extreme depletion in the surface waters of many regions leading to low primary production and ocean deserts. Iron input to the ocean system is fundamental for biodiversity, including biomass and species assemblages (structure and composition).

Iron enters the ocean mostly through dust deposition on the ocean surface, although ocean margins and hydrothermal vents are also substantial sources (Figure 24). Iron is consumed in surface water by phytoplankton and then put back into solution when sinking organic matter is remineralised at depth (Martin, Meng and Chia, 1989). Iron is also known to have an active internal cycle in the euphotic zone, involving both biological processes and reactions with light (Morel, Price and Hudson, 1991; Barbeau *et al.*, 2001). However — unlike carbon dioxide, nitrogen, phosphorous, or silicon — iron in the ocean water column precipitates and is scavenged by settling particles that transport it to the seabed, thus removing it from the ocean (Boyd and Ellwood, 2010).

6.2.6.1 Gaps in knowledge

There remain gaps in knowledge on the implications of iron cycling in terms of ocean chemistry and the role of iron in climate regulation and ocean health.

6.2.7 Silicon

Silicon — as $Si(OH)^4$ — is required by a number of phytoplankton and zooplankton groups for the construction of basic skeletons. Most important among these are the diatoms, a phytoplankton group that is pervasive throughout the global ocean and often dominant in temperate to polar waters. Diatoms are understood to be essential in the sinking flux of organic matter in oceans rather than primary productivity. While silicon is consumed in the construction of diatom shells, the sinking and subsequent dissolution returns the silicon to deep waters. A substantial fraction (~25% on average) reaches the abyssal seabed before it is dissolved (Tréguer and Rocha, 2013), and a significant fraction of this is buried.

6.2.8 Trace Metals

Trace metals (Quéroué, 2014) such as manganese (Mn), cobalt (Co), nickel (Ni), copper (Cu) and cadmium (Cd) also play key roles in many essential cellular cycles and may (co)-limit marine primary productivity (Morel and Price, 2003; Twining and Baines, 2013). Metals such as manganese (Peers and Price, 2004; Wolfe-Simon *et al.*, 2007) copper and nickel (Nuester *et al.*, 2012; Pörtner, 2012) are used in the formation of important enzymes for the defence of cells against harmful reactive oxygen compounds.

Manganese is also needed for the oxidation of water during photosynthesis (Sunda and Huntsman, 1995). Cobalt has important biological implications as it is at the centre of the vitamin B12, which is synthesised by bacteria and assimilated by eukaryotic phytoplankton (Croft *et al.*, 2005; Bertrand *et al.*, 2007). Nickel is required in urease, an enzyme that hydrolyses urea to provide nitrogen to algal cells (Morel, Price and Hudson, 1991; Morel and Price, 2003).

Copper limitation can be linked to iron limitation, because of its importance to the photosynthetic process (Peers and Price, 2006). Indication from a MIDAS in-situ weathering experiment deployed at the seafloor at the Arctic mid-ocean ridge show a positive correlation between the abundance of microorganisms on the mineral surfaces and the degree of weathering of metals such as iron, copper and zinc, suggesting that geo-microbiological processes play an important role in the degradation of sulphide minerals in seafloor massive sulphide deposits. This indicates that assessments of the potential environmental impact of mineral dissolution during deep-seabed mining activities should include biogeochemical processes in addition to abiotic geochemical leaching.

There is a strong parallel between the trace elements which are important to biological function in the oceans and those with economic value, as exemplified in Table 4 below.

Table 4: The use of trace metals: industrial/human use and the enzyme and enzyme cofactor containing trace metals and their biological function (Lavelle and Mohn, 2011) and basic internet search)

Mineral - Trace Metals		Human use	Biological system/ biogeological use - fundamental to basis of life biochemistry	
Nickel	**Ni**	Making Steel (46%), nonferrous alloys and superalloys (34%), electroplating (11%), coins, ceramics batteries, hard discs	Urease	Hydrolysis of urea into ammonia and carbon dioxide
			Superoxide dismutase	Splitting molecules of superoxide to hydrogen peroxide and oxygen - helps break down potentially harmful oxygen molecules in cells

Mineral - Trace Metals		Human use	Biological system/ biogeological use - fundamental to basis of life biochemistry	
Cobalt	**Co**	Alloys, magnets, batteries, catalysts, pigments & colouring, radio-isotopes, electro-plating	Vitamin B12 where cobalt is the central element in this vital, complex molecule	Carbon and hydrogen transfer reactions. Vitamin B12 is a nutrient that helps keep the body's nerve and blood cells healthy and helps make DNA, the genetic material in all cells
Copper	**Cu**	Electrical, telecom & electronic applications such as generators, transformers, motors, PCs, TVs, mobile phones (65%), automobile (7%), anti-bacterial agents& consumer products (coins, musical instruments, cookware	Plastocyanin - a copper-containing protein that acts as an intermediary in photosynthetic electron transport	Photosynthesis electron transport
			Cytochrome oxidase	Primarily known for its function in the mitochondria as a key participant in the life-supporting function of ATP synthesis - mitochondrial electron transport
			Ascorbate oxidase	Ascorbic acid oxidation and reduction - stimulates cell growth
			Superoxide dismutase	Splitting of superoxide to hydrogen peroxide and oxygen - an enzyme that helps break down potentially harmful oxygen molecules in cells
			Multi-copper ferroxides	High-affinity transmembrane iron transport essential to cellular function
Manganese	**Mn**	steel production (>85% of ore use for this), corrosive resistant alloys (cans), additive in unleaded gasoline, paint, dry cell and alkaline batteries, pigments, ceramic & glass industry	Oxygen-evolving enzymes	Oxidation of water during photosynthesis
			Superoxide dismutase	Splitting of superoxide to hydrogen peroxide and oxygen - helps break down potentially harmful oxygen molecules in cells
			Arginase	Catalyses urea during which the body disposes of harmful ammonia
			Phosphotranferase	Phosphorylation reactions - Phosphorylation plays critical roles in the regulation of many cellular processes including cell cycle, growth, apoptosis and signal transduction pathways. Phosphorylation is the most common mechanism of regulating protein function and transmitting signals throughout the cell

Mineral - Trace Metals		Human use	Biological system/ biogeological use - fundamental to basis of life biochemistry	
Iron	**Fe**	Pig iron, sponge iron, steel (>90%), alloys, automobiles, ships, trains, machines, buildings, glass	Cytochromes	Electron transport in photosynthesis and respiration enabling primary production
			Ferredoxin	Electron transport in photosynthesis and nitrogen Fixation enabling primary production
			Other Iron-Sulphide proteins	Electron transport in photosynthesis and respiration enabling primary production
			Nitrate and nitrite reductase	Conversion of nitrate to ammonia – fundamental to controlling metabolism of potentially toxic nitrates and nitrites. This process is vital to the recycling of nitrogen for microbial and plant growth, and animal health. Denitrification can negatively impact global warming through losses of nitrous oxide
			Chelatase	Porphyrin and phycobiliprotein synthesis – fundamental to photosynthesis and primary production via electron transport, light harvesting, oxygen transport and the assimilation of organic nitrogen and sulphur
			Nitrogenase	Nitrogen fixation
			Catalase	Conversion of hydrogen peroxide to water - It is a very important enzyme in protecting the cell from oxidative damage by reactive oxygen species
			Peroxidase	Reduction of reactive oxygen species - Its function is to break down hydrogen peroxide (H2O2), which is one of the toxins produced as a by-product of using oxygen for respiration.
			Superoxide dismutase	Disproportionation of superoxide to hydrogen peroxide and oxygen - an enzyme that helps break down potentially harmful oxygen molecules in cells

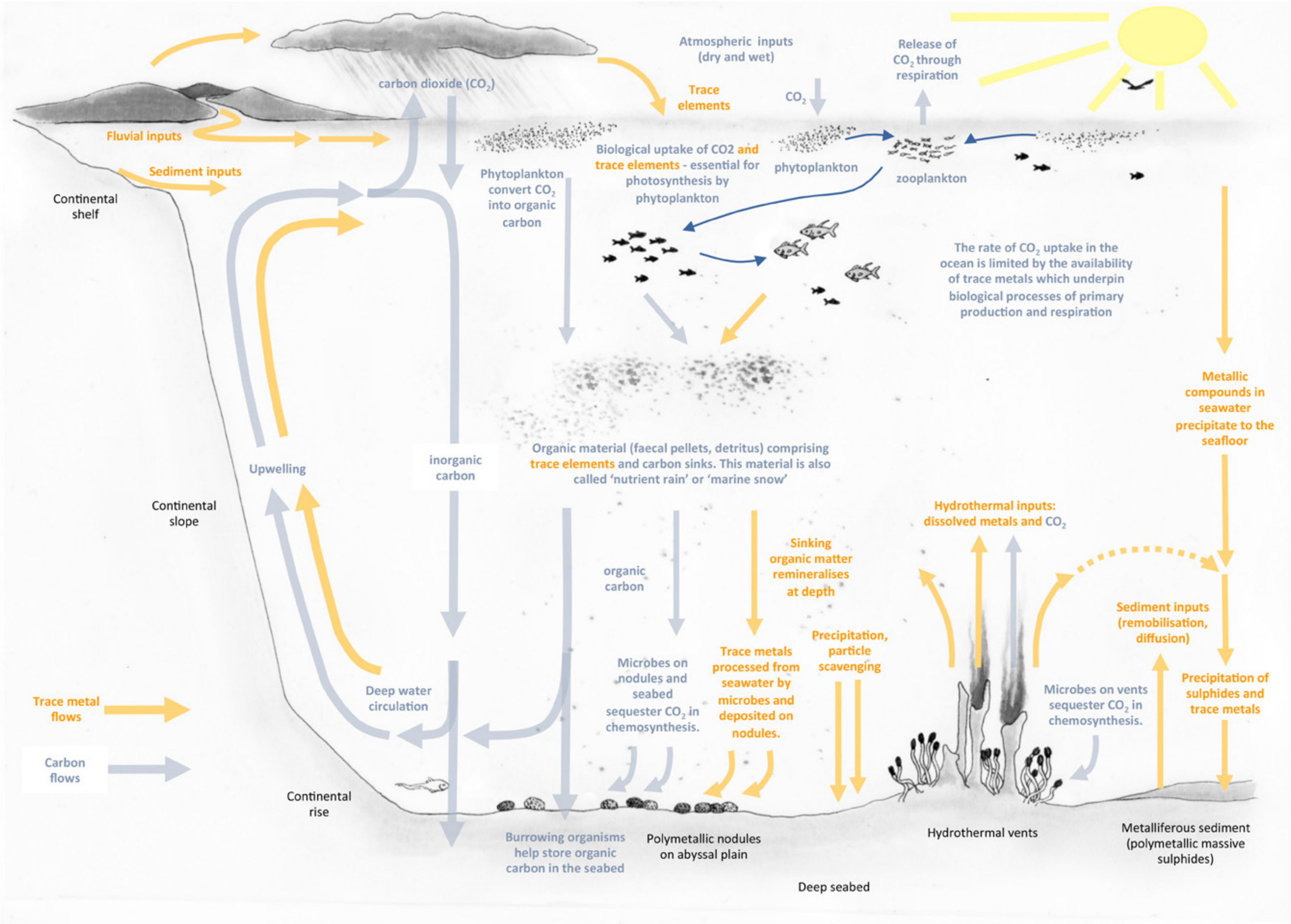
Mineral - Trace Metals		Human use	Biological system/ biogeological use - fundamental to basis of life biochemistry	
Cadmium	**Cd**	nickel-cadmium (Ni-Cd) rechargeable batteries & as a sacrificial corrosion-protection coating for iron and steel, batteries, alloys, coatings (electroplating), solar cells, plastic stabilizers, and pigments.	Carbonic anhydrase (can use zinc and cadmium)	Hydration and dehydration of carbon dioxide = fundamental to maintain acid-base balance in blood and other tissues, and to help transport carbon dioxide out of tissues. Essential to photosynthesis and the conversion of carbon dioxide to sugars.
Magnesium	**Mg**	Magnesium is the third most used metal in construction (after iron and aluminium). Nearly 70% of the world production of magnesium is used to make alloys, which have a very low density, comparatively high strength and excellent machinability	Chelatase	Porphyrin and phycobiliprotein synthesis – fundamental to photosynthesis and primary production via electron transport, light harvesting, oxygen transport and the assimilation of organic nitrogen and sulphur.
			Magnesium compounds	Needed for more than 300 biochemical reactions in the body. It helps to maintain normal nerve and muscle function, supports a healthy immune system, keeps the heartbeat steady, and helps bones remain strong. It also helps adjust blood glucose levels. It aids in the production of energy and protein

6.2.8.1 Particle scavenging

Trace metals are prone to passive adsorption onto particles and subsequent removal from the euphotic layer during sinking, a phenomenon known as scavenging. Manganese is one of the most susceptible metals to particle scavenging (Sunda and Huntsman, 1995). Manganese often exhibits scavenged type distributions with high concentrations in the euphotic layer due to photoreduction (Sunda and Huntsman, 1995), atmospheric inputs (Baker and Jickells, 2006; Wuttig *et al.*, 2013), and/or fluvial inputs (Aguilar-Islas and Bruland, 2006). However, manganese is insoluble in oxygenated water and is scavenged leading to a sharp decrease in subsurface concentrations (Sunda and Huntsman, 1995). Iron, cobalt and lead (Pb) are also subject to scavenging (Bruland and Lohan, 2003; Noble *et al.*, 2008, 2012). According to (Quéroué, 2014), nickel, copper, and cadmium are not scavenged, presumably due to their biological uptake and regeneration.

In simple terms, there is a relationship between the geophysical and biogeological processes that drive the trace element budgets on the planet (Figure 24). Interfering with them could cause consequences we cannot currently understand, and at timescales and over areas that may be difficult to comprehend.

Figure 24: The biological and nutrient pump of the oceans - Regulation of carbon dioxide and trace metals in the oceans. Illustration not to scale.
References: Boyd & Ellwood, 2010; Tully and Heidelberg, 2013; Quéroué 2015; Fumito *et al*., 2016.



Credit: Nicky Jenner/FFI

6.2.8.2 Gaps in knowledge

There remain gaps in knowledge on the implications of trace metal cycling in terms of ocean chemistry and maintenance of ecosystem function, and the role of trace metals in climate regulation and ocean health.

6.2.9 Human impacts on ocean productivity

Human activities can directly add significant quantities of major and trace nutrients to some regions of the coastal ocean, unambiguously impacting local productivity. While this enhanced productivity could theoretically benefit the upper trophic levels including fisheries, a host of effects lead to habitat disturbance. As an example, in the waters surrounding the Mississippi Delta and the Chesapeake Bay, the decomposition of the sedimented organic matter produced by nutrient-enhanced phytoplankton blooms lowers the oxygen content of subsurface waters, driving away fish and other complex organisms that require oxygenated water (Sigman and Hain, 2012).

The human impacts on open ocean productivity are likely to be complex. Global warming associated with the anthropogenic increase in greenhouse gases appears to be strengthening upper ocean stratification, reducing the nutrient supply from below and thus decreasing global ocean productivity (Behrenfeld *et al.*, 2006). At the same time, elevated carbon dioxide concentrations may have a fertilizing effect on some phytoplankton (carbon dioxide scarcity can restrict the rate of phytoplankton photosynthesis), while negatively impacting some organisms that produce calcium carbonate hard parts (seawater carbon dioxide concentration largely sets the saturation state of calcium carbonate and decreases under higher carbon dioxide) (Morel, Claustre and Gentili, 2010). Such changes may alter fisheries substantially, but the impacts are currently poorly understood.

The implications of nutrient mobilisation, reduction and transfer resulting from seabed mining operations is not yet well understood. However, there are likely to be impacts taking into account the discussion above. The implications of mobilisation and disturbance of these global nutrient budgets needs very precautionary consideration as the potential knock-on effects upon ocean health and ecosystem function could be considerable.

6.3 Ocean currents and connectivity

6.3.1 Ocean Currents

The world's surface ocean currents are driven by the sun. The heating of the Earth by the sun has produced semi-permanent pressure centres near the surface. When wind blows over the ocean around these pressure centres, surface waves are generated by transferring some of the wind's energy, in the form of momentum, from the air to the water. This constant push on the surface of the ocean is the force that forms the surface currents.

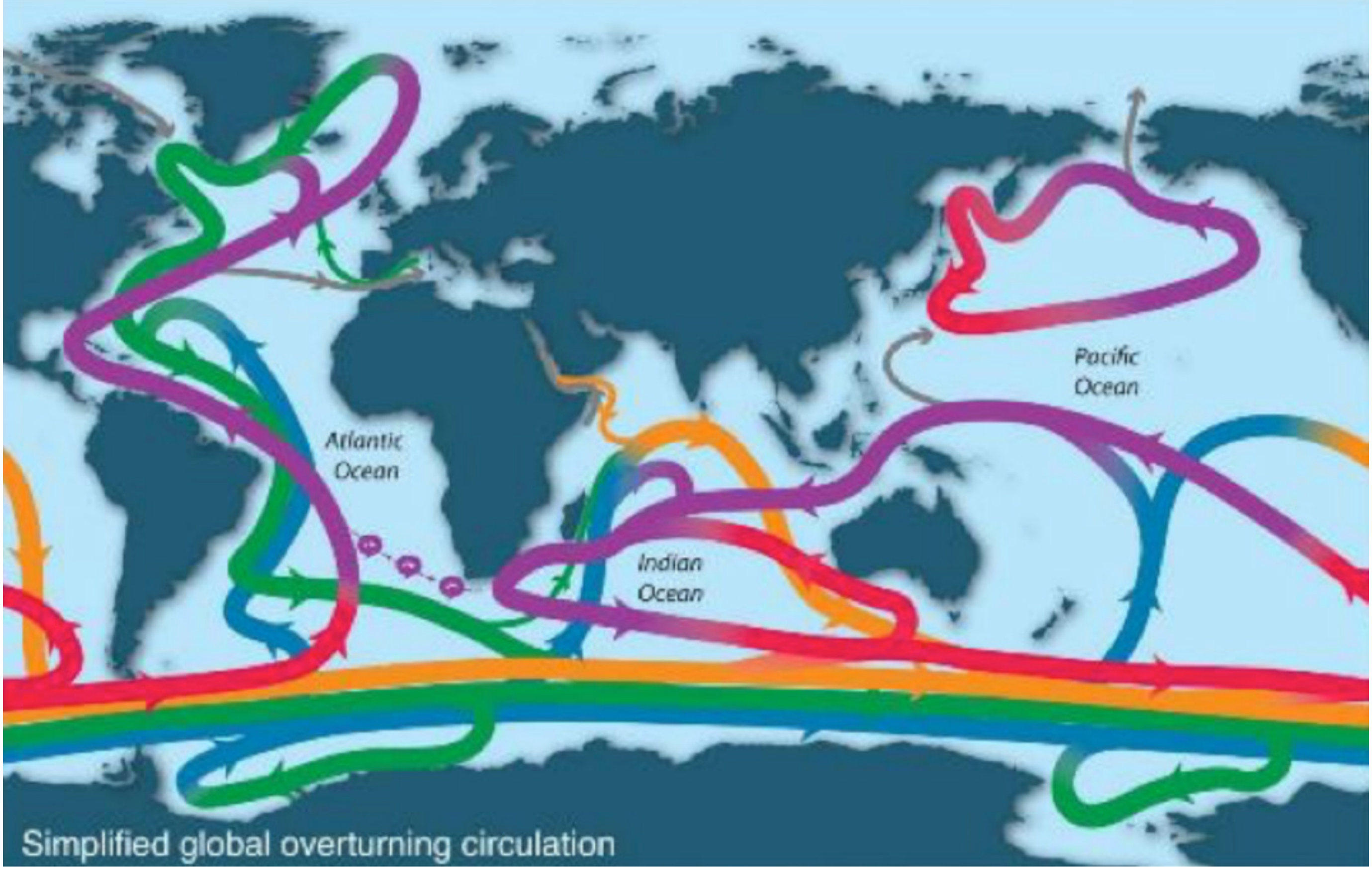
Along the west coasts of the continents, the currents flow toward the equator in both hemispheres. These are cold currents as they bring cool water from the Polar Regions into the tropical regions. The cold current off the west coast of the United States is called the California Current. Likewise, the opposite is true as well. Along the east coasts of the continents, the currents flow from the equator toward the poles. There are called warm current as they bring the warm tropical water north and south. The Gulf Stream, off the southeast United States coast, is one of the strongest currents known anywhere in the world, with water speeds up to 3 miles per hour (5 kilometres per hour). Ocean currents will have a huge impact on long-term weather any location will experience. For example, due to the Gulf Stream, the overall temperature of Norway and the British Isle is about 18°F (10°C) higher in the winter than other cities located at the same latitude.

While ocean currents are shallow-level circulations, there is global circulation which extends to the depths of the sea called the Great Ocean Conveyor (Figure 25). Also called the thermohaline circulation, it is driven by differences in the density of the sea water which is controlled by temperature (thermal) and salinity (haline).

In the northern Atlantic Ocean, as surface water flows north it cools considerably. When the water cools to a point where sea-ice forms, the “salts” are extracted (meaning sea-ice is fresh-water ice). The extracted “salts” make the water beneath the sea-ice denser causing it to sink to the ocean floor. This motion drives a slowly southward flowing deep-ocean current. The route of current is through the Atlantic Basin around South Africa and into the Indian Ocean and on past Australia into the Pacific Ocean Basin.

If the water is sinking in the North Atlantic Ocean then it must rise somewhere else. This upwelling is relatively widespread. However, water samples taken around the world indicate that most of the upwelling takes place in the North Pacific Ocean. It is estimated that once the water sinks in the North Atlantic Ocean that it takes 1,000-1,200 years before that deep, salty bottom water rises back to the upper levels of the ocean again.

Figure 25: Ocean waters circulate globally, rising in some regions and sinking in others. Credit: Talley, 2013. Warm colours indicate warm surface waters circulating to cooler deeper water returns.



6.3.2 Connectivity

Connectivity describes the interlinked nature of the ocean. Most ocean ecosystems have no obvious physical boundaries. Instead, they are defined by powerful currents that transport nutrients and small marine organisms, and by highly mobile species such as turtles, whales and tuna that can migrate across entire ocean basins for feeding and reproduction (Block *et al.*, 2011; Farley *et al.*, 2013). These horizontal and vertical movements connect the open ocean to coastal waters and the deep ocean and play an important role in maintaining healthy and productive ecosystems.

These physical flows and migratory movements link national waters and exclusive economic zones to areas beyond national jurisdiction. Connectivity in the ocean provides significant benefits to societies that depend upon or use the goods and services provided by ocean ecosystems. However, it also means that our interactions with the ocean do not occur in isolation, but instead the impacts we have in one place can have consequences elsewhere. Hence, efforts to sustainably manage our marine resources, even in national contexts, require explicit consideration of areas beyond national jurisdiction (Box 20).

BOX 20
Key messages from UNCLOS on ocean connectivity

Movements of currents and migratory animals connect all parts of the ocean, making conservation and sustainable use of biodiversity beyond national jurisdiction complex and dependent on interconnectivity. The relevance of connectivity for marine biodiversity has been recognised in the negotiations for a new international legally binding instrument under the UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. The negotiations are evolving around four topics which make up the 'package', adopted by the fourth meeting the Ad Hoc Open-ended Informal Working group on 'Biodiversity Beyond National Jurisdiction'. These topics are now part of the discussions in the Intergovernmental Conference (IGC) for the new Implementing Agreement:

- **Area-based management tools;**
- **Environmental impact assessments;**
- **Technology transfer and capacity building;**
- **Marine genetic resources.**

Under the new instrument, the following provide potential starting points:

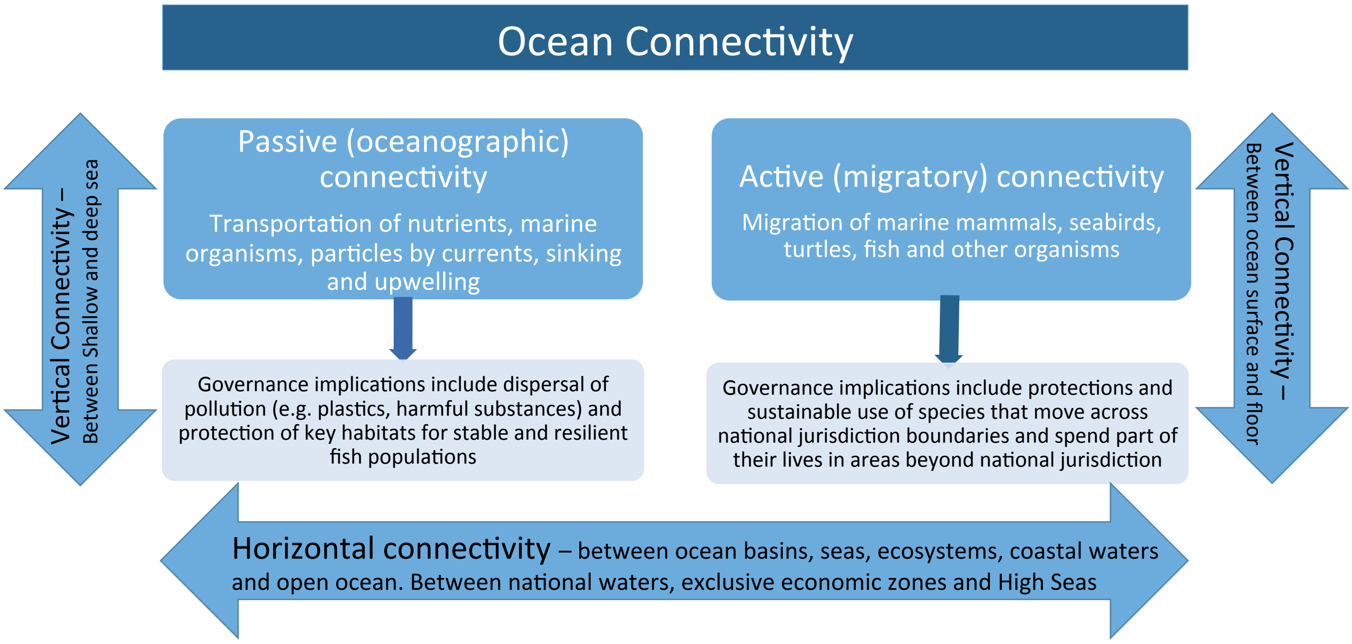
- **Movements of biodiversity, including migratory species, can be integrated in planning and implementation of area-based management tools.**
- **Potential impacts from distant and localized activities are mobile and can be considered, given the highly connected nature of the marine environment.**
- **EIAs can account for transboundary ecosystems and the connectivity generated by migratory species.**
- **Technology transfer and capacity building can have a role in strengthening monitoring of connectivity and making connectivity information available and accessible for decision making.**

In the marine realm, movement between ecosystems is largely unobstructed by obvious physical boundaries. As a result, all parts of the global ocean are interconnected. There are two types of connectivity in the ocean: passive and active (Figure 26).

Passive connectivity: marine organisms and other materials are transported across the ocean without active movement. Passive connectivity, also described as oceanographic connectivity, refers to the transportation of material such as nutrients, small marine organisms and other particles by ocean currents and processes such as sinking and upwelling. An example of passive connectivity is the dispersal of fish larvae, which are carried across large distances by ocean currents. Regional studies from the Coral Triangle and the Caribbean show that the passive movement of larvae connects fish populations between different coral reefs in the two regions (Treml and Halpin, 2012; Schill *et al.*, 2015). This passive movement of larvae between the reefs plays an important role in maintaining fish populations and healthy, functioning reefs.

Active connectivity: marine animals migrate between different parts of the ocean. Active connectivity, also described as migratory connectivity, describes the movement of marine animals across the ocean and up and down through the water column. Marine mammals, seabirds, turtles and fish can travel great distances to reach specific feeding or breeding areas, moving between coastal waters and the open ocean. Many of these migratory species, including those of economic importance, spend some part of their lives in the open ocean beyond national jurisdiction (Lascelles *et al.*, 2014). Another example of active connectivity is the daily vertical movement of fish and other marine organisms to the surface or to shallow waters at night to feed and back into deeper waters during the day. This daily movement represents the largest animal migration on Earth (Hays, 2003).

Figure 26. Illustrates the broad categories of ecological connectivity: Passive and active forms of movement and the horizontal and vertical dimensions of connectivity (Credit: Harrison *et al.*, 2018).



6.3.3 Movement across ecological and jurisdictional boundaries

Movement in the ocean can occur horizontally, connecting different ocean basins and seas, and linking coastal waters with the open ocean. Movement also occurs vertically, connecting the deep sea and shallow waters. Both happen at multiple scales – local, regional, global – and across jurisdictional boundaries as currents and migratory species move through the High Seas, Exclusive Economic Zones and national waters (Harrison *et al.*, 2018). Likewise, nutrients and particles can sink through the water column in the High Seas and be deposited on the extended continental shelf under the jurisdiction of a specific country.

6.3.4 Implications of currents and connectivity for marine biodiversity and management

The dispersal of individuals among marine populations is of great importance to metapopulation dynamics, population persistence, and species expansion. Understanding this connectivity between distant populations is key to their effective conservation and management. For many marine species, population connectivity is determined largely by ocean currents transporting larvae and juveniles between distant patches of suitable habitat (Treml *et al.*, 2008). This is important, too, when considering the risks and impacts of dispersion of potential contaminants, altered fluid dynamics and nutrient balances produced by seabed mining processes.

6.3.4.1 Connectivity and dispersal at vents on mid-ocean ridges.

In order to evaluate connectivity, an important unknown in deep ocean ecosystems, information about dispersal is required (Thurnherr *et al.*, 2020).

Dispersal in the ocean is strongly dependent on the relevant temporal and spatial scales. On time scales of weeks to months, which are important in the context of larval dispersal, advection (larval transport) by large-scale flows does not typically dominate dispersion (Van Dover *et al.*, 2002). As a result the net dispersion in the ocean can be in directions other than the direction of the mean flows, including upstream.

To illustrate these points, consider dispersal patterns near the Lucky Strike hydrothermal vent field located near the base of a topographic peak in the rift valley of the Mid Atlantic Ridge near 37°N. Year-long current metre records obtained near the vent field in 1994/95 and in 2001/02 both reveal southward mean flow. The apparently reasonable inference that the hydrothermal material (including larvae) from Lucky Strike is dispersed predominantly southward along the rift valley is entirely wrong, however, because the mean flow averaged across the entire width of the rift valley is consistently to the north, as was determined by detailed oceanographic surveys carried out in 2006 and 2010, as well as from year-long current-metre measurements collected at more representative locations between 2006 and 2007. The southward mean flow observed on the earlier moorings is, in fact, part of a <5km-wide cyclonic circulation around the topographic high next to the vents (for additional details, see Thurnherr *et al.*, 2008).

The influence of large ocean-wide current and eddies is also important:

In the eastern part of the Central Tropical Pacific/Clarion Clipperton Zone, at an average water depth of ~4,100 metres, tidal energy contributes only one third to abyssal current variability over smooth topography. Aleynik (Aleynik *et al.,* 2017) show that there are a number of energy controlling factors implicating sediment movement and dispersal in the deep oceans: (i) near-inertial oscillations, induced by wind and geostrophic shear, which are nearly as energetic as (ii) tidal contributions, and (iii) mesoscale ocean eddies, generated 3,500 kilometres away under the influence of the Central American Gap Winds. The remotely-generated eddies occasionally dominate the near-bed current regime, causing resuspension of fine-grained deep-sea muds. This implies that resuspension of deep-sea sediments might be a regular, natural process, however this likely simply creates niche habitats in the ocean where species adapt to these conditions.

6.3.4.2 Implications of currents and connectivity for seabed mining

Acknowledging the complex nature of ocean currents and connectivity, and related implications for marine biodiversity, is fundamental to managing risks and impacts of seabed mining – relating to, for example, the transfer of contaminants and sediments that might arise from seabed mining. Similarly, the lack of dispersion and dilution due to the absence of ocean mixing can exacerbate the impacts when localised. The consequences of disruption of physical ocean systems from human activities through the introduction of energy causing alteration of water dynamics, densities, turbidity, nutrient compositions etc. are poorly understood and require further study.

7. Gap analysis: assessing baseline studies against good practice

Preceding sections (5 and 6) explored existing, available information on biodiversity and ecosystem services that would be needed to inform the baseline. Here, we consider the extent to which there is sufficient knowledge to develop a biodiversity and ecosystem services baseline that is adequate for the purpose of impact definition. In the following sections we assess the ability of existing and future seabed exploration and mining operations to meet the standards of a good practice baseline for biodiversity. Gaps are identified for each stage of the baseline process.

7.1 High level screening

There is limited information available online for assessing deepsea marine biodiversity, ecosystem services and biophysical processes. A desktop screening exercise would usually aim to produce a high-level list of biodiversity concerns to take forward into a more detailed scoping exercise. Knowledge on marine biodiversity is varied, and tends to decrease significantly in deeper water (see Box 21). Some information can be gleaned from sources such as Integrated Biodiversity Action Tool (IBAT), the UNEP-WCMC Ocean Data Viewer, international research collaborations such as MIDAS, and Regional, national and local biodiversity action plans, where they exist. However, given the paucity of information available on biodiversity for deeper water systems, it is very likely that a scoping exercise for deep-seabed mining would not adequately identify key biodiversity values.

Ecosystem services are complex and poorly represented however there is an increasing body of science that is underpinning the description and importance of ecosystem services and complex ecosystem function in the oceans.

Biophysical processes, as described above, need to form the basis of understanding of ecological function and ocean health, and require additional knowledge and scientific research to underpin decision making on risk and impact assessment.

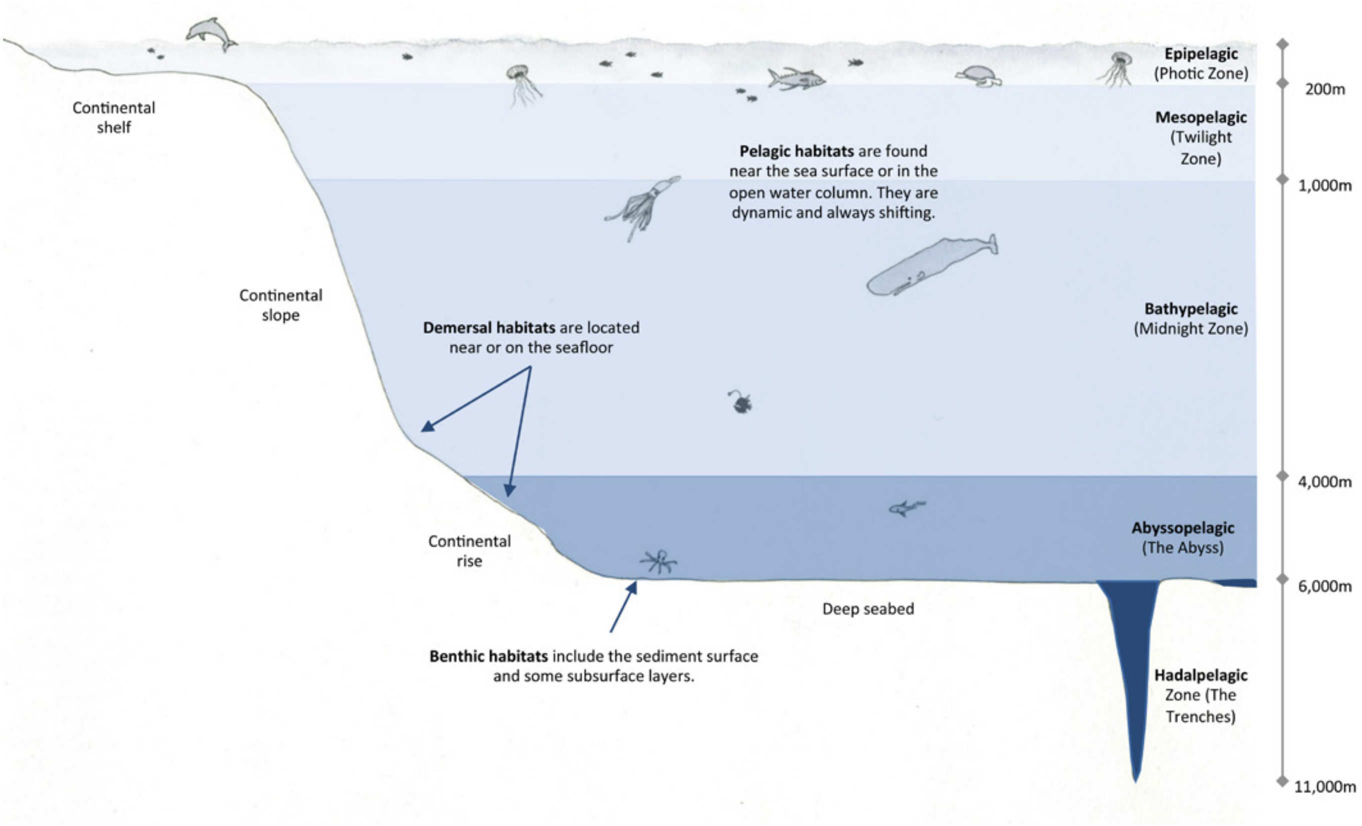
7.2 Delineating the baseline study area

When delineating the baseline study area, good practice dictates that one must use ecologically meaningful boundaries. There are two significant gaps in attempting to apply this approach in deeper water. First, ecologically meaningful boundaries are difficult to establish. It may be possible to delineate boundaries in an estuarine or coastal system where a hard boundary with land or deep water (e.g. edge of continental shelf) occurs, but even for estuaries the input and outflow of rivers to an estuarine system makes it far from discrete. When one considers deep water habitats, with a continuous water column and the potential for both vertical and horizontal currents, defining meaningful boundaries for biodiversity becomes almost impossible. Improving our knowledge of deep-water ecology, connectivity and currents will help to better define boundaries, but even with significantly more information, it is unlikely that discrete and meaningful boundaries could be drawn.

Baseline studies must consider ecosystem services and dependencies. In coastal environments, some success has been had with defining a range of ecosystem services, from the most tangible provisioning services such as seafood and seaweed fertilizers, to regulating services such as storm protection from coral reefs and mangroves, and cultural services including recreation and ceremonial values. However, the processes underlying these systems are rarely well understood. Even for common species such as the Atlantic salmon and the European lobster, which support lucrative international fisheries, the secrets of their breeding cycle have only recently been unlocked.

In deeper water, our knowledge of marine ecology is considerably lower. Further, the global scale bio-physical processes that drive the interaction between ocean and atmosphere, and are responsible for carbon sequestration and oxygen production, have only recently been defined. We currently have little idea of the amplitude of these cycles, or their sensitivity to change, so they can only be described in abstract and subjective terms. As previously, improving our knowledge of ecosystem function and services through research will enable a better definition of them in project baselines, but where a paucity of data exists, a precautionary approach should be applied (Box 20).

Figure 27: Marine zones and habitats



Credit: Nicky Jenner/FFI

7.3 Scoping the biodiversity and ecosystem services baseline study

Good practice indicates that scoping should identify biodiversity and ecosystem services values for inclusion in the baseline in consultation with experts and other stakeholders, considering high value species and habitats, protected areas, ecological processes, ecosystem services, biophysical conditions. The procedure is to collate existing marine biodiversity and ecosystem services information, and identify any gaps in knowledge that exist. These knowledge gaps determine the scope, scale and depth of field assessments and studies.

The process of scoping a baseline study for a seabed mining operation will encounter similar constraints to the screening exercise, in that knowledge on marine biodiversity is varied, and tends to decrease significantly in deeper water (see Box 21). This poor distribution of knowledge is even more important at the scoping stage, when any existing information needs to be acquired and assimilated into the baseline. As demonstrated in Box 21, the type and level of information available from open source studies varies greatly, and in reality, only a proportion of studies contain data that is suitable and available for inclusion in baseline. Online resources will provide protected area boundaries (e.g. the World Database on Protected Areas, WDPA) but these may need to be verified locally.

In the case of deep-seabed mining in the Area, it would be important to ascertain the level of protection allocated to the zone of interest to ensure avoidance of areas of particular environmental interest or those set aside as protected areas.

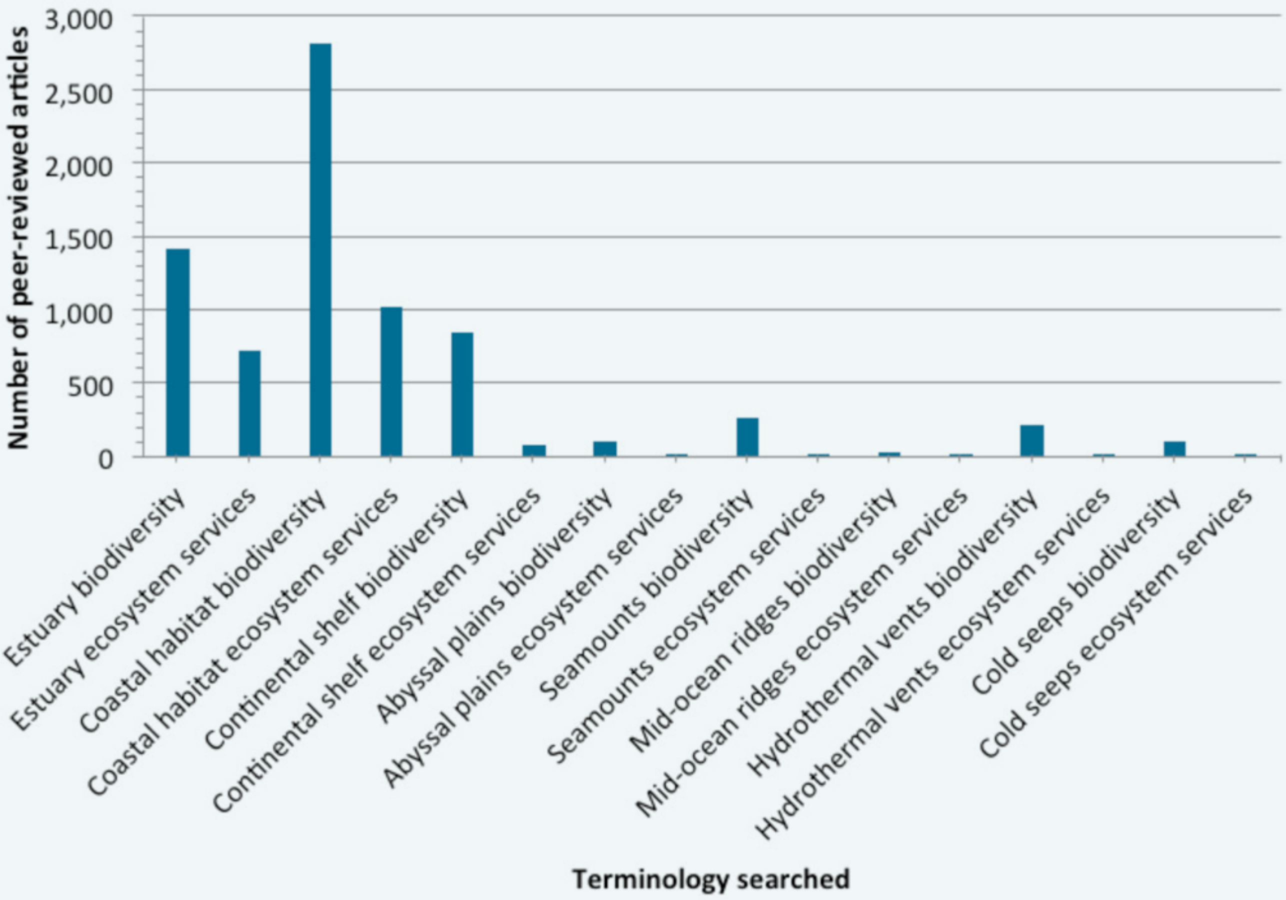
The International Seabed Authority is orchestrating the development of Regional Environmental Management Plans for areas within the Area to essentially provide a zoning allocation for mining and other uses, including protection and set aside of some areas (Box 22).

BOX 21

Investigation of research information available on biodiversity and ecosystem services for different marine habitats

It is well documented that our knowledge of marine biodiversity and ecosystem services decreases with increasing ocean depth. This study aimed to drill deeper into the distribution of studies by assessing the number of studies per main habitat type. A Web of Science search was conducted using key words of 'habitat type', 'habitat type + biodiversity' and 'habitat type + ecosystem services'. The results indicate that first, shallow water habitats contain far more studies than deep water habitats. Second, coastal habitat + biodiversity yielded the greatest number of studies – more than 2,800 in total. In all habitats, the studies on biodiversity outnumbered those for ecosystem services. The lowest number of studies returned was one – for mid-ocean ridges + ecosystem services

Graph showing the number of Web of Science peer-reviewed articles relating to shallow to deep sea ecosystem services and biodiversity



BOX 22

Regional environmental management planning for deep-seabed mining

Aims of regional environmental management planning:

1. to review and analyse seafloor and water column ecosystem data from the northern mid-Atlantic ridge (MAR);
2. to synthesise environmental data, faunal distribution, faunal dispersal capabilities and distances, genetic connectivity, patterns of biodiversity, community structure, ecosystem function, and ecological proxy variables along and across the northern MAR;
3. to review current exploration activity within contract areas and distribution of resources (polymetallic sulphides) along the northern MAR;
4. to describe potential areas that could be vulnerable to exploitation of mineral resources in the Area and would require enhanced management measures; and
5. to describe potential areas in the Area that could be reserved from exploitation in order to achieve effective protection of the marine environment, including through the designation of areas of particular environmental interests (APEIs).

The regional management planning process draws on data and knowledge contributions covering:

- biodiversity (e.g. species/taxon richness and evenness);
- community structure (e.g. abundance/diversity of different components of the biota, species/Operational Taxonomic Unit structure);
- biogeography (e.g. species range, degree of species overlap, community similarity);
- genetic connectivity (e.g. shared haplotypes, spatial scales of genetic connectivity);
- ecosystem functions and drivers (e.g. carbon cycling, nutrient fluxes, methane/hydrogen sulphide metabolism, geomorphology, slopes);
- habitat modelling (e.g. habitat diversity) ; and
- distribution of hydrothermal systems/polymetallic sulphides along the northern MAR.

The scoping process is likely to identify a lot of information that is unavailable. For example, threatened species which were identified in screening, but for which little or no range or ecological data exists for the area of interest; ecosystem services that have been identified but not studied; biophysical processes that are suspected but poorly understood. Any significant gaps in knowledge will require studies to be commissioned as part of the baseline process.

7.4 Conducting a biodiversity and ecosystem services baseline assessment

A good practice baseline project will engage subject experts to help plan, execute and interpret baseline studies. The great constraint for conducting baseline studies in deep water is likely to be resources – funding, equipment and expertise. Biological and physical studies in deep water are very expensive for manned equipment in deeper water. Such costs are difficult for individual companies to bear, so this resource gap may be addressed through partnerships: sharing ship and equipment time where possible; establishing partnerships with research organisations; developing joint studies wherever possible.

In addition to cost, weather conditions and sea state may greatly reduce the time available for deployment in certain areas, especially in deeper water where the passage to safe waters may be long.

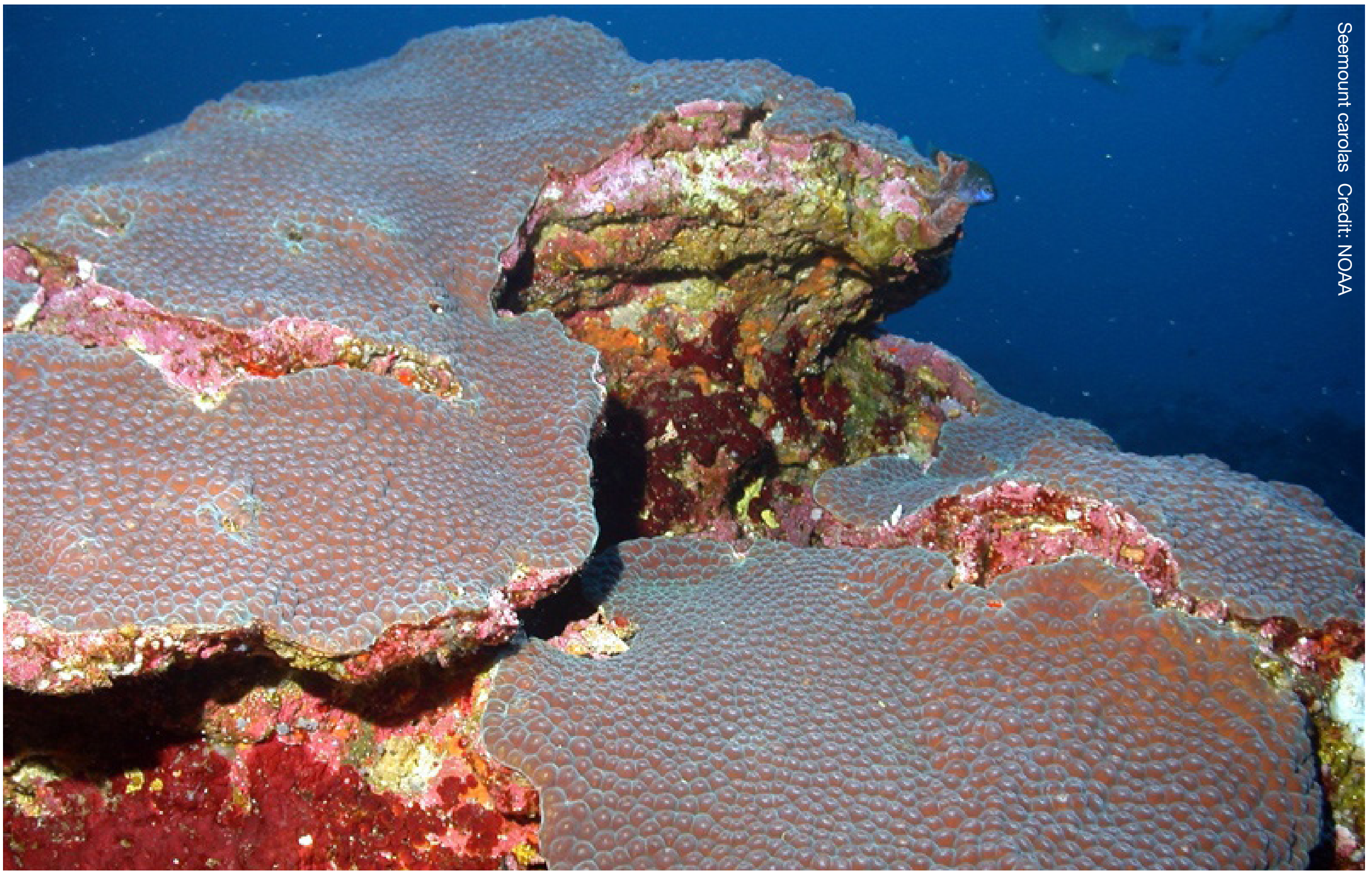
Good practice requires that ecological processes are incorporated into baseline studies. This will necessitate the engagement of an EIA/ESIA consultant who understands ecological processes and has experience of measuring them. Again, costs may be significant where field work is required, so combining studies and planning to utilise primary data from other baseline studies should reduce costs.

7.5 Develop baseline report

A good practice baseline report will analyse and interpre*t al*l desk and field information and interpret results in consultation with key stakeholders. As for previous steps in the baseline process, expertise may be limited and difficult to engage. The greatest challenge for the report writing process may be the persistence of significant gaps and uncertainties, which either require the application of a precautionary approach, or the commissioning of further studies.

Given the significant deficiency in biodiversity and ecosystem services and biophysical knowledge for the oceans, sharing data on an open source platform would be considered a key component of good practice for baseline studies. ISA have developed DeepData for this purpose which contains some useful information.

There are significant data gaps relating to the understanding and scientific knowledge of the biodiversity, ecosystem patterns and processes and the function of the ocean, and for deep-sea ecosystems in particular. Whilst scientists agree that the oceans play a fundamental role in the maintenance of earth systems, additional work is needed to understand the implications of disruption of these systems and the large scale impacts derived from mining, marine plastics, over-fishing. The deep-sea biome performs vital functions such as acting as “a major sink for carbon dioxide” while circulating chemicals around the globe, depositing and generating vital nutrients to ocean and shoreline ecosystems and sustaining rich populations of diverse flora and fauna (Kirkham, Gjerde and Wilson, 2020).



Seemount carolas Credit: NOAA

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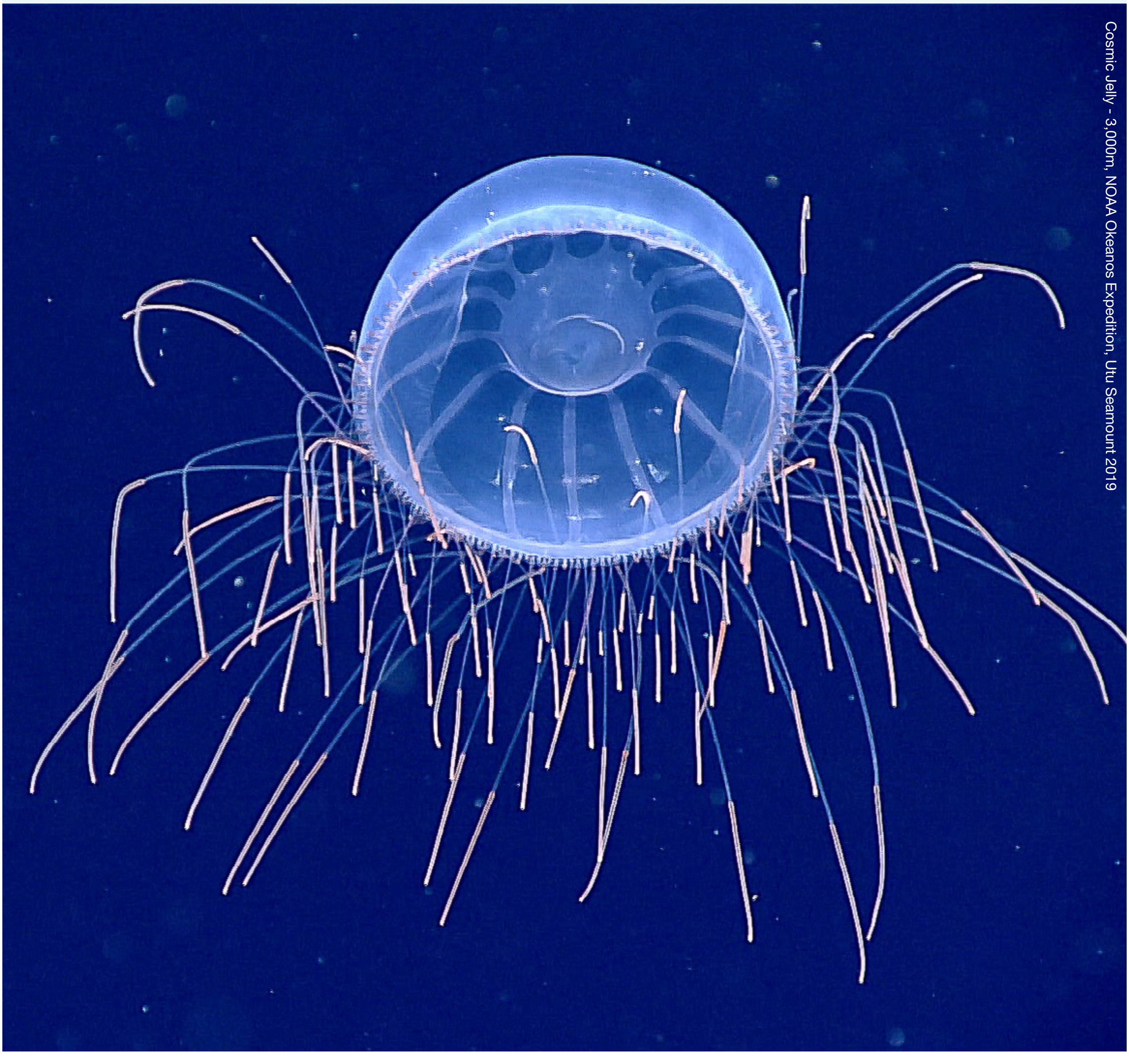


Cosmic Jelly - 3,000m, NOAA Okeanos Expedition, Utu Seamount 2019

8. Risk and impact assessment of seabed mining

Determining the environmental risks and impacts of mineral extraction depends on the knowledge, information and data available. The ocean remains our least explored and also our largest environment on the planet. It follows that a considerable level of knowledge will be required to assess and manage sustainably exploitation of resources found in the ocean, and particularly in the deep sea.

In this section we present the impacts associated with seabed mining. First, the generalised impacts associated with different stages in the project cycle are summarised (Section 9). We then undertake a more thorough risk and impacts assessment of existing and proposed seabed mining operations to determine whether and to what degree good practice impact assessment and the mitigation hierarchy framework can be effectively applied to the main forms of seabed mining. The assessment considers different types of resource and associated mining practices first for seabed mining in shallow waters (Section 10), and then for deep-seabed mining (Section 11). The seabed mining types addressed in the risk and impact assessment are listed in Table 5 below.

By understanding how mining activities impact on biodiversity and the potential options for mitigation, contractors can apply specific measures to help to avoid and mitigate anticipated impacts and reduce their net impact on biodiversity.

Table 5: Summary of resource deposits of interest to the seabed mining industry

Type of mineral deposit	Mean water depth (metres)	Resources found	Habitat type
Aggregates	<100 (Shallow)	Aggregates, sand	Alluvial deposits on continental shelf
Diamonds	<180 (Shallow)	Diamonds	Unconsolidated sediments on continental shelf
Phosphate nodules	180-400 (Deep)	Phosphate	Deposits on continental shelf
Manganese crusts	800 – 2,400 (Deep)	Mainly cobalt, some vanadium, molybdenum and platinum	Seamounts
Sulphide deposits	1,400 – 3,700 (Deep)	Copper, lead and zinc some gold and silver	Hydrothermal vents
Polymetallic nodules	4,000 – 6,000 (Deep)	Nickel, copper, cobalt, and manganese	Abyssal plain

9. Impacts and the project cycle

Mining companies and contractors operating in marine environments can have impacts on biodiversity and ecosystem services at all stages of the project lifecycle.

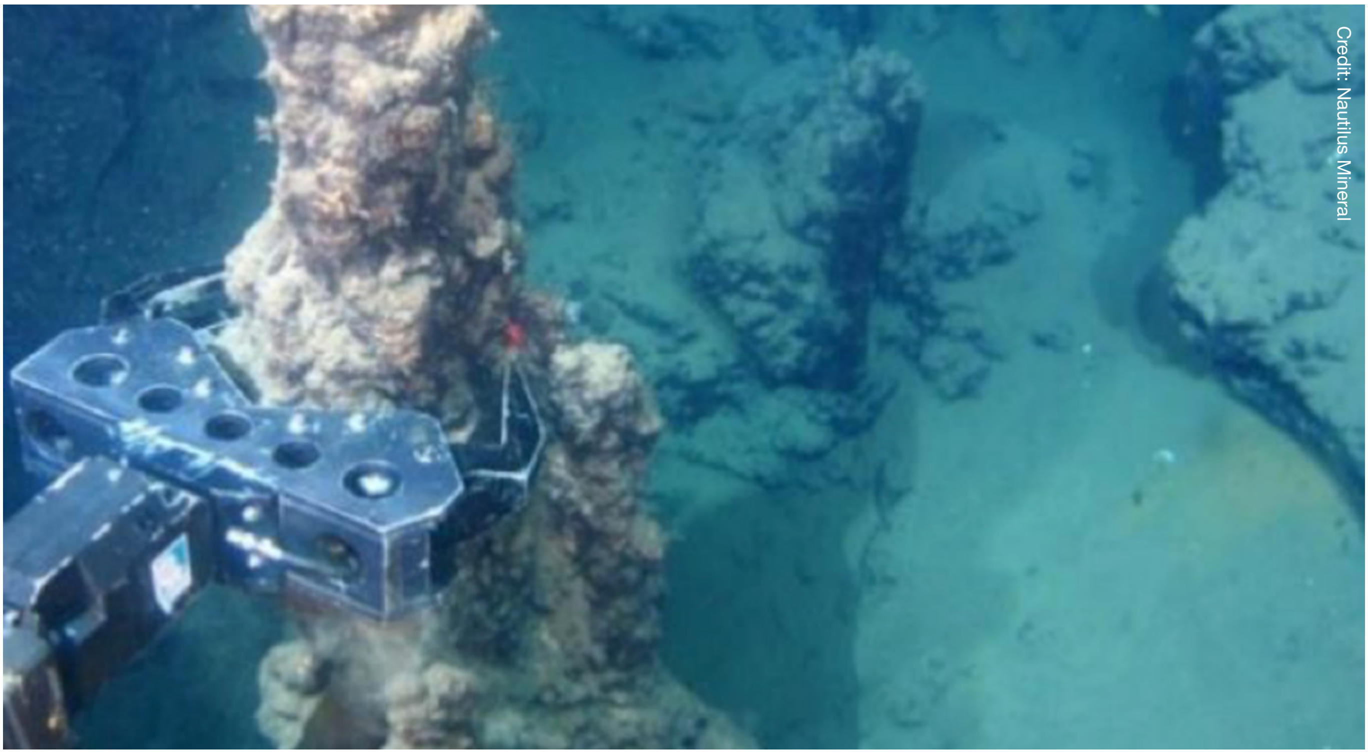
Some impacts occur across all mining types and/or at all phases throughout the project lifecycle, from exploration surveys through to closure, whilst others can be exclusive to particular types of mining and/or project phases. For deep-seabed mining, according to the International Seabed Authority (2012), the production stage is likely to have a high intensity of direct impact, a local scale of spatial activity (around 10,000 square kilometres) and an activity duration of years. This is likely to be less spatially extensive for shallow seabed mining. The probability of an accidental event causing environmental damage is reportedly small, although the persistence of impact following mining activity could continue for decades in the absence of effective mitigation or restoration activities (International Seabed Authority, 2012).

This section describes the project cycle and what impacts a seabed mining project can have on biodiversity, according to both the type of seabed mining taking place and the project phase, and what mitigation opportunities exist to reduce these impacts. Project phases are categorised as follows:

- Exploration/prospecting surveys
- Exploration/prospecting sampling
- Site development
- Production/operations
- Decommissioning

9.1 Exploration surveys and sampling

Figure 28: Grab sample of deep-sea thermal vent chimney during exploration



Credit: Nautilus Mineral

Exploration activities for seabed mining are taking place for seabed mining in shallow and deep waters and these activities generally are not expected to cause serious environmental harm (Maxwell, Ban and Morgan, 2014). For deep-seabed mining, it is only exploration activities that are currently ongoing as there are no deep-seabed mining projects yet in operation. Over-sampling and both unintentional and intentional damage to sulphide structures are among the impacts to vent ecosystems resulting from exploration and scientific research. The major prospecting and exploration activities included here typically fall within the realm of oceanographic research, though explorers for commercial manganese nodule deposits have refined and modified many procedures to fit their particular goals, their basic methods and backgrounds stem directly from the well-developed disciplines of geological, physical, and biological oceanography. Specific field techniques and associated potential impacts are listed in Table 6.

These techniques are initially employed to find the best mine sites and to map their extent. Such activities would probably continue throughout the life of the mine and are done to inform potential mining areas in all but the last year or so of mining. After the mineral resources are mapped, the same techniques would be used at higher spatial densities but at lower overall levels of effort to delineate the actual path to be traversed by the mining device. The United States government has determined that these activities are not expected to cause serious environmental harm (Lavelle and Mohn, 2011).

Table 6: Prospecting and exploration techniques

Prospecting and exploration field techniques	Potential Impacts associated with activity
• Gravity and magnetometric observations and measurements	• Light – impacts to ecosystems evolved in darkness and utilising bioluminescence; light on surface causing behaviour change or attracting species e.g. squid, or medusa which migrate diurnally between deep and shallow waters • Noise – impacts affecting behaviour (feeding, breeding and movement) of macro-organisms and megafauna • Potential impact to microorganisms sensitive to magnetic pulses/influences
• Bottom and sub bottom acoustic profiling or imaging without the use of explosives	• Noise – impacts affecting behaviour (feeding, breeding and movement) of deep-sea organisms • Potential fragmentation of habitats and loss of connectivity through noise generation
• Mineral or sediment sampling of a limited nature such as those using either core, grab, or basket samplers	• Loss of habitat • Degradation of habitat • Loss of individuals
• Water and biotic sampling	• Nominal or no measurable impacts anticipated
• Meteorological observations and measurements, including the settling of instruments	• No measurable impact anticipated

Prospecting and exploration field techniques	Potential Impacts associated with activity
• Hydrographic and oceanographic observations and measurements, including the setting of instruments	• Temporary impacts of noise and light as outlined above
• Sampling by box core, small-diameter core, or grab sampler, to determine seabed geological or geotechnical properties	• Measurable but nominal impact anticipated
• Television and still photographic observation and measurements	• No measurable impact beyond temporary disturbance to e.g. behaviour and feeding
• Shipboard mineral assaying and analysis for polymetallic nodules and phosphates	• Noise of ship (dynamic positioning equipment) • Light of ships • No measurable impact anticipated
• Positioning systems, including bottom transponders and surface and subsurface buoys for deep-seabed mining	• Noise impacts to species causing fragmentation of habitat/loss of habitat • Nominal impact anticipated

9.2 Site development

Site development and construction for deep-seabed mining will involve geophysical studies, and the likely construction and development of support infrastructure. Concurrently, high levels of surface vessel movements, subsurface operations, reservoir and production engineering, mine design and construction, surface facilities and risk assessment will be required. This phase has impacts and risks similar to those of full operational phase, below. Prototype mining system would be necessary to develop adequate operational control, to demonstrate system reliability, and to acquire sufficient ore for pilot scale metallurgical processing tests.

9.3 Production/operations

The production/operations phase commences following the completion of the field development phase and may last 10 to 30 years depending on the resource.

9.3.1 Seabed mining in shallow waters

In this phase, seabed minerals are extracted using a variety of methods, including dredging (aggregates), discriminate or selective extraction using remote crawlers and shovels (e.g. diamonds); suction of benthic materials from the sea floor using a suction dredge (sand and aggregates); or draghead, dredger and grinders for phosphates. The operations require mining vehicles and corresponding launch & recovery systems, vessel conversion, ore processing, transportation, separation and ancillary ore handling equipment. At the basis of each mining operation lies the mineral which is sought. The mineral determines the mining operation, processing operation, and the economics of the project. continuous power supply and adequate storage space for mineral products would be required on the platform, as the mining sites lie several thousand kilometres (500 – 1,000 kilometres) away from possible landing sites for these ores, involving 1-10 days of travel time (at 10 knots speed) for the transport vessels besides loading / unloading time (for ores, spares, fuel, manpower and provisions) during each visit to the mining platform. Vessels are sometimes serviced by helicopter.

Aggregate and diamond extraction in waters <200 metres depth are dealt with in more detail in Section 10.

Alluvial mining involves the recovery of target resources (e.g. gold and iron sands – not dealt with here) from alluvial material such as sand, silt and clay. It tends to occur in shallower waters of <200 metres depth along the continental shelf.

Alluvial mining typically involves some form of seabed dredger or miner and suction of the sediment to the ocean's surface for processing (Figure 29).

9.3.2 Deep-seabed mining

In this phase, mining systems collect target material from the seafloor, which will then be transported via a lifting mechanism to bring them to the surface through up to 6 kilometres of water column, as well as handling equipment on the mining platform.

Mining of deep-sea mineral deposits have several technological challenges in terms of extreme operating conditions such as those found at operating depths of between 1 and 6 kilometres, including distance from shore (>1,000 kilometres), high pressure (100-500 bars) and low temperatures (0-100°), as well as physical forces like currents, waves, and weather. These conditions have implications for mining methods and associated technological requirements. As with shallow water mining, continuous power supply and adequate storage space for mineral products would be required on the platform, as the mining sites lie several thousand kilometres (2,000 – 6,000 kilometres) away from possible landing sites for these ores, involving 5-15 days of travel time (at 10 knots speed) for the transport vessels besides loading / unloading time (for ores, spares, fuel, manpower and provisions) during each visit to the mining platform.

Development of deep-seabed mining technology is in different stages, with a number of crawlers and lifting mechanisms being tested by the Contractors (Table 7), however, the real challenge lies in up scaling and integrating different subsystems and making them work on a sustained basis continuously for 300 days per year under extreme conditions, such as meteorological factors (rainfall, winds, cyclones), hydrographic conditions (high pressure, low temperature, currents, lack of natural light); coupled with seafloor environment (undulating topography, variable sediment thickness and compactness, and heterogeneous distribution of deposits).

To overcome these, the application of new technology to nodule mining, such as three-dimensional sensing, autonomous navigation, robotic manipulators and vehicles for the extreme environment of space missions (Jasiobedzki and Jakola, 2007) could provide some of the solutions. Similarly, advances in floating platforms, availability of riser hardware for deep-water and harsh environments, sub-sea power systems and pumps required for mining (Sharma, 2017); as well as the advantages of flexible risers in connecting pumps and power cables, reduced top tension for surface vessel, ability to retrieve and reinstall, and easy handling in severe weather conditions (Sharma, 2017) could provide the much required technological support for development of sub-sea mining systems.

Whereas considerable research and analyses have been carried out on the collector and riser systems (Chung, 2003), very few studies have been conducted on the mining platform and ore handling and transfer at sea. These studies (Amann, 1982; Ford *et al.*, 1987; Herrouin *et al.*, 1989) have proposed possible designs, dimensions, weight, production capacity, and power generation required on the platform to support a deep-seabed mining activity. This sector (mining platform and ore transfer) will have to depend on existing infrastructure available for offshore oil and gas production and bulk carriers to be modified into mining platforms and transport vessels.

Table 7: Status of deep-seabed mining and processing technology - after (Herrouin *et al.*,1989; Miller *et al.*, 2018)

Contractor	Mining Technology	Processing Technology
Belgium	Development of Pantania II nodule collector (crawler with riser), tested at 4,500 metres depth in Clarion Clipperton Zone	
France	Model studies on self- propelled miner with hydraulic recovery system	Tested pyro and hydrometallurgical processes for Nickel, Copper, Cobalt
Japan	Passive nodule collector tested At ~2,200 metres depth; Field pilots	Developed a process to recover Nickel, Copper, Cobalt
India	(a) Design includes flexible riser and multiple crawlers (b) Crawler tested at ~1,000 metres depth in the sea	(a) Tested 3 possible routes (b) Pilot plant set up for 500 kg / day for Nickel, Copper, Cobalt
China	(a) Includes rigid riser with self-propelled miner (b) Tried different concepts of collector and lifting mechanisms	Developed a process to recover Manganese, Nickel, Copper, Cobalt, and Molybdenum
South Korea	(a) Design includes flexible riser system with self-propelled miner (b) Developed 1/20 scale test miner (c) field trials	Not known
Russia	Collector and mining subsystems in trial stage	Recovered Manganese, Nickel, Copper and Cobalt from nodules
IOM	Conceptual design includes nodule collector, buffer, vertical lift system.	Not known
Germany	Considering innovative concepts for mining	Not known
Belgium	Collector and mining subsystems in trial stage; Considering innovative concepts for mining	Considering different options for processing
UK	Considering innovative concepts for mining	Considering different options for processing

Whereas, the mining activity is likely to have an impact on environment; the reverse (i.e. impact of environment on mining activity) should also be considered because the prevailing environmental conditions at the mine site would play a major role in the design and performance of different sub-systems of the mining system. The major parameters contributing to this will be the atmospheric conditions, hydrographic conditions, seafloor topography, nodule characteristics and associated substrates (Table 8).

Table 8: Influence of environmental conditions on mining systems design and operation

	Conditions (key parameters)	Influence on mining system
1	Atmospheric (wind, rainfall, cyclone)	Will determine actual fair weather conditions for operating the mining system during different seasons of the year.
2	Hydrographic (waves, currents, temperature, pressure)	Will influence operations on the platform including mineral-handling and mining system deployment at the surface; and stability of riser system in the water column.
3	Topographic (relief, macro and microtopography, slope angles)	Will have a bearing on the manoeuvrability and stability of the mining device on the seafloor.
4	Nodule characteristics (grade, size, abundance, morphology, distribution pattern)	Important for designing the mechanism for collection, crushing as well as screening of nodules at the seafloor from un-wanted material before pumping the nodules to the surface.
5	Associated substrates (sediment-size, composition, engineering properties; rock outcrops – extent, elevation)	Will affect the mobility and efficiency of the collector device to be able to operate without sinking (or getting stuck) in the sediment and be able to avoid the rock outcrops for its safety.

9.4 Decommissioning

All projects must consider decommissioning or a closure/abandonment plan as part of the environmental management of the project. Closure of Operations and Abandonment includes all the activities related to the closure of a main facility and its installations at the end of the estimated useful life and the activities related to the proper abandonment of the installations and the rehabilitation of the site. As compared to the oil and gas industry, with its complex seabed infrastructure, marine mining operations are likely to be less complex to decommission.

The main sources of impact relate to the decommissioning of umbilicals and use of explosives leading to the disturbance of the benthic environment and the decommissioning of subsea facilities, some of which may be embedded in the seafloor, causing disturbance to the seafloor.

10 . Seabed mining in shallow waters: impacts and mitigations

As with terrestrial mining, there are likely to be considerable impacts of seabed mining upon biodiversity and ecosystem services. However, these impacts are not yet fully articulated nor fully understood. This section provides an assessment of impacts for the main types of seabed mining that are currently in operation or proposed for shallow waters.

The section is ordered topically by type of mining and resource being exploited. For each resource, the current approach to mining is explored, recognising this is a fast-moving sector with rapid technological development. The potential impacts to marine biodiversity and ecosystem services are summarised, and gaps in knowledge assessed. Mitigations (both proven and potential) are identified and assessed for applicability and appropriateness. We focus upon avoidance and minimisation measures here. The occurrence or potential for restoration and offsetting are noted in the context of applying the mitigation hierarchy. Restoration and biodiversity offsets/compensation are further described in Section 13.

In the sections that follow, seabed mining for aggregates and diamonds are discussed. These are all well-established mining enterprises that have operated for nearly three decades (in the case of marine-based diamond extraction) and so information relating to mining approaches and impacts are well established. In addition, being shallow water operations, reasonable information relating to biodiversity and ecosystem services is also available in many cases. This contrasts with seabed mining in deep water, where the mining approaches are yet to be finalised, and information on biodiversity and ecosystem services in deep water is limited. Seabed mining in shallow waters thus provides a useful starting point for assessing the data needs, approach and likely gaps relating to mining in deep water. Gold is not specifically included in this assessment but the associated risks and impacts are aligned to those for aggregates and diamond mining in shallower substrates.

For ease of reference, information is provided for each type of resource in turn according to the following structure. First, the general locations and methods used to exploit target resource are presented, followed by a summary of the main impacts and, in turn, the main mitigation options. The impacts and mitigation options are assessed in more detail in the impact and mitigation tables that follow. At the end of each sub-section, a summary of gaps in knowledge and concerns relating to undertaking an impact assessment are presented.

Presenting information in this way for each mining type and resource leads to repetition, as impacts and mitigations can be similar for different mining types. However, it is necessary to present the fullest picture possible for every type of mining, to ensure each sub-section is stand-alone.

10.1 Alluvial aggregate mining: impacts and mitigations

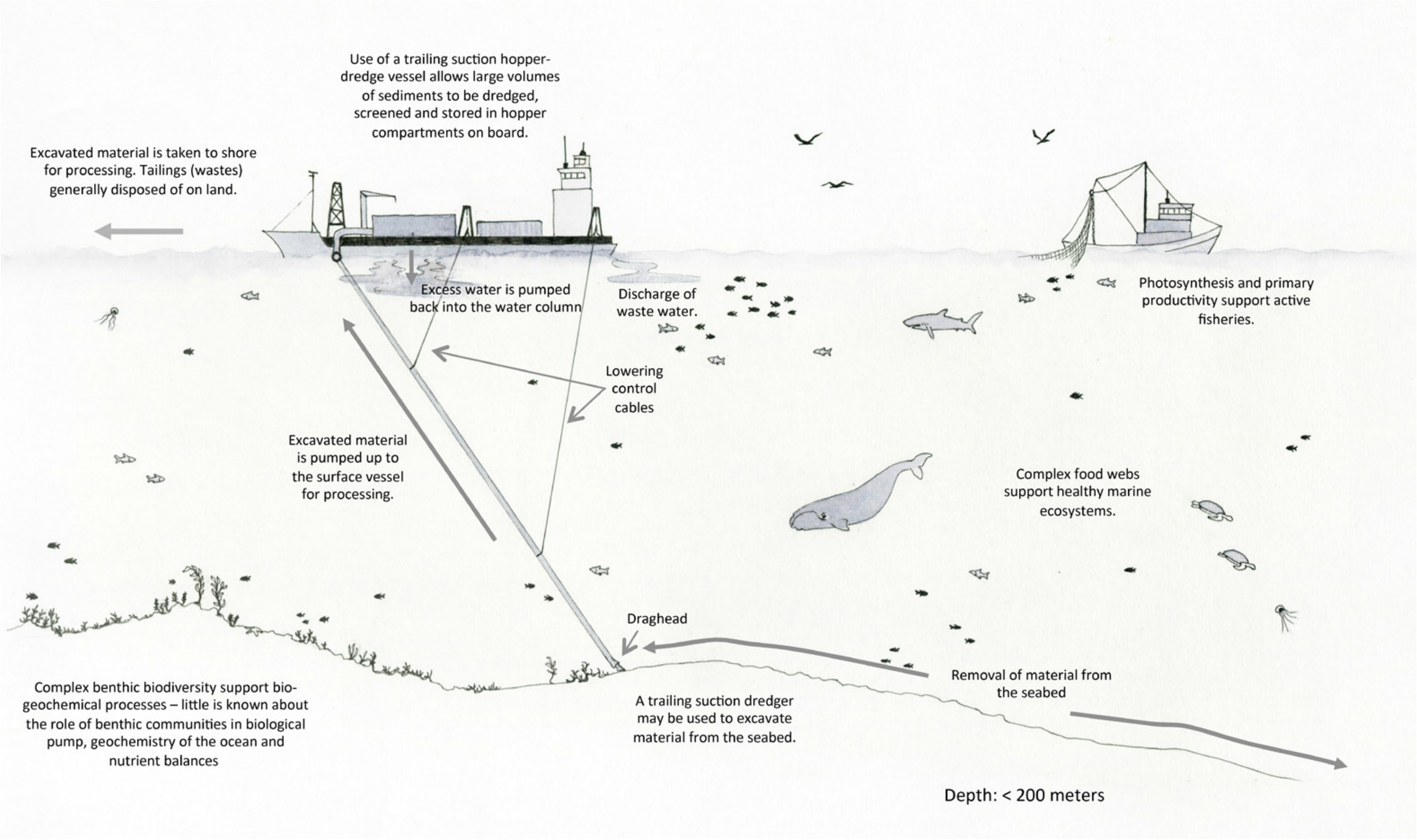
For offshore alluvial aggregate mining, this report refers readers to existing best practice guidance and specifically to the Coastal Impact Study Best Practice Guidance which was developed by the British Marine Aggregate Producers Association and The Crown Estate from well-established approaches to assessing coastal impacts. Definition, impacts and good practice mitigation is described for alluvial aggregate mining and the guidance seeks to establish best practice for the British marine aggregate industry and advises on the scope, standards and transparency that are expected. It is designed to be a valuable reference providing mutual benefit to all stakeholders and consultees, including dredging companies, consultants, government regulators and agencies, local authorities, NGOs, other seabed and coastal users and the public. Both defended and natural coastlines are considered through this process (Newell and Woodcock, 2013). Given the existence of national and internationally relevant guidance for the mining of alluvial aggregates, we do not conduct a full risk and impact assessment here. Instead we briefly summarise the mining process, main risks and impacts and mitigation options, and gaps in knowledge.

10.1.1 Exploitation of alluvial aggregates

Alluvial resources have been removed from the primary (usually mother rock) source by natural erosive action over millions of years, and are eventually deposited in a riverbed, the shoreline where the river meets the sea, or on the ocean floor. Aggregates such as gravel and sand are mined in shallow waters typically <200 metres depth along the continental shelf and in multiple locations globally.

The mining of aggregates from the seabed typically involves some form of seabed dredger or miner and suction of the sediment to the ocean's surface for processing (Figure 29). Technologies such as the Trailing Suction Hopper-Dredge are utilised allowing large volumes of sediments to be dredged, stored in hopper compartments on board, and transferred to another vessel or onshore for further processing. Trailing Suction Hopper-Dredge vessels have the ability to dredge seafloor sediments at a rate of >100,000 square metres per day (MMC, 2007). All materials are taken to shore for processing, with tailings (wastes) generally disposed of on land (note: there are terrestrial-based social and environmental impacts related to this that are not dealt with in this report).

Figure 29: Mining of alluvial aggregates in shallow waters. Illustration not to scale.



Credit: Nicky Jenner/FFI

10.1.2 Risks and impacts of alluvial aggregate mining

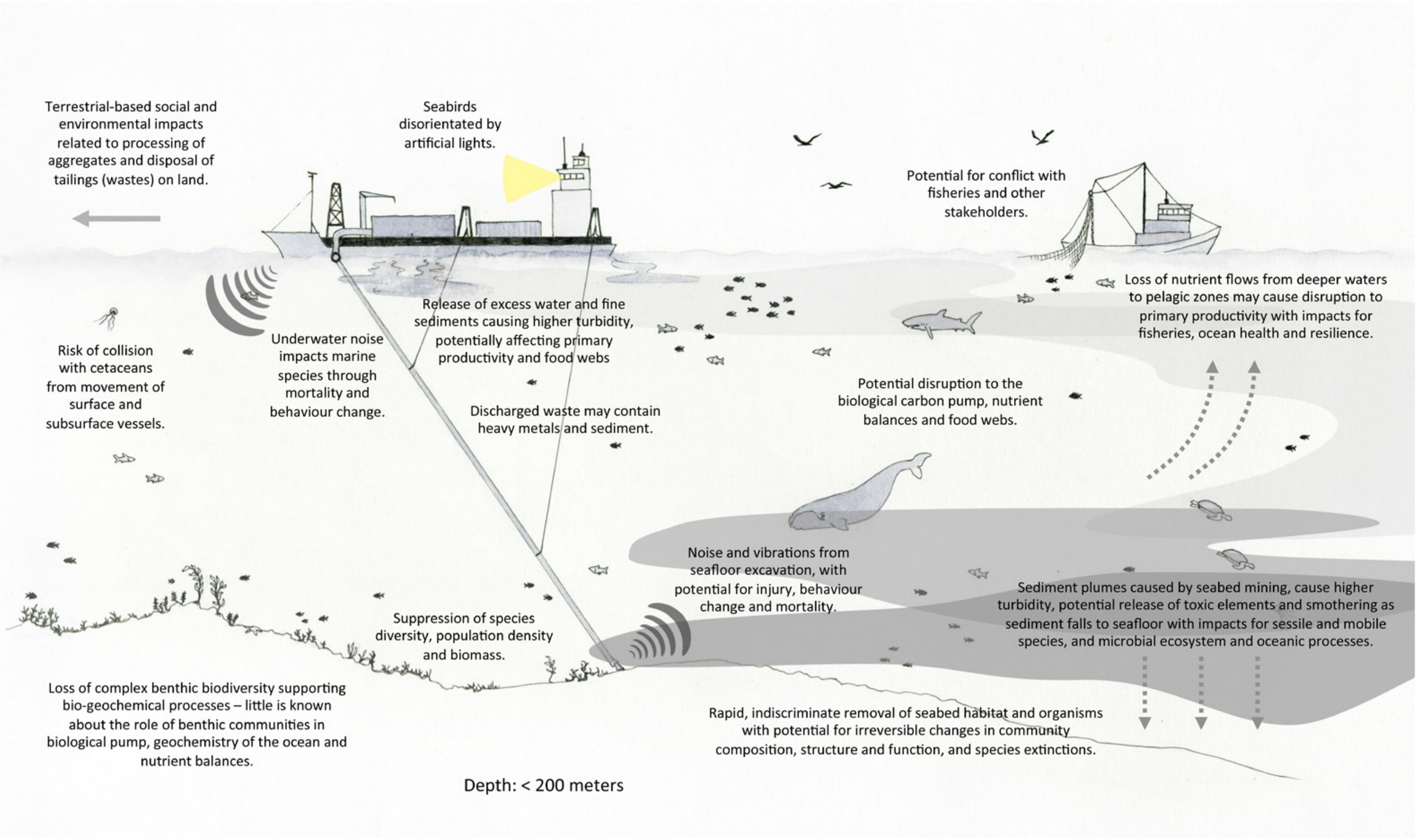
The nature and scale of potential impacts from marine aggregate dredging have been widely recognised (Figure 30).

Essentially, they comprise direct or ‘primary’ impacts under the footprint of the draghead and indirect or ‘secondary’ impacts that may occur outside the boundary of the dredge site. Impacts include:

- Loss of habitat and species
- The primary impacts of dredging on the marine fauna are significant, but affect only a small area of seabed under the path of the draghead in active dredge zones (Newell and Woodcock, 2013).
- Acoustic pulses of geophysical equipment, which can cause physical damage to fish and marine mammals, and avoidance of areas by affected species;
- Removal of large areas of sediment habitat on the seafloor, causing destruction of habitat for species occurring there, e.g. burrowing macrofauna, with implications for ecosystem structure and function;
- Removal of large contiguous blocks of sediment, so minimising the opportunity for recolonisation of biodiversity, e.g. benthic infauna;
- Release of sediments back to the ocean post-processing, causing high turbidity which potentially alters predator-prey relationships and reduces sunlight, potentially and may lead to the releasing of harmful compounds to the water column, and causing cause smothering of the seabed where sediments settle out; and
- Release of sediments that may also disrupt the biological (carbon and nutrient) pump and cycling of nutrients by affecting primary production and altering the chemistry of the water column.
- Secondary impacts generated from the dispersing plume and deposition of sediment and material mobilised by the dredging process and transported along the seabed by prevailing currents resulting in smothering of benthic organisms
- Potential impacts of noise and disturbance to organisms that are higher in the food web such as fish, mammals and birds.
- In almost all instances, aggregate dredging is reported to result in a major suppression of species diversity, population density and biomass of invertebrates that live in seabed deposits that have been dredged. A similar suppression of diversity, abundance and biomass of more mobile epifaunal assemblages has also been reported.

Mining of alluvial aggregates will generate a range of impacts generic to all seabed mining operations, including light and noise pollution, unplanned waste releases, collision risk from shipping and gaseous emissions.

Figure 30: Potential risks and impacts of mining alluvial aggregates in shallow waters. Illustration not to scale.



Credit: Nicky Jenner/FFI

10.1.3 Applying the mitigation hierarchy

10.1.3.1 Avoidance

- Avoidance of biodiversity and ecosystem services impacts can be achieved at a project scale through careful screening of key fishery areas and high biodiversity areas, including protected areas, to ensure operations do not overlap.
- Uncontrolled releases of liquid and solid waste are avoided through strict recycling and waste handling procedures both onboard vessels and at ports.
- Use stripwise mining to create alternate strips of mined and unmined seabed to improve rates of recolonisation of benthic fauna

10.1.3.2 Minimisation

- Stopping mining when large numbers of target organisms are detected at the screens
- Minimisation of shipping impacts through keeping vessels on station at mine sites and only returning to port for maintenance when necessary (e.g. every 2 years)
- Minimisation of fuel use through ship design and manufacture
- Using the latest mining technology to ensure full resource extraction to minimise the need for re-mining an area
- Returning sediments to the seabed mining location
- Screening sediments for harmful compounds prior to return to the seabed

10.1.3.3 Restoration

Physical recovery at aggregate sites where dredging had ceased is generally dependent on substrate type and the strength of tidal currents, with fastest restoration in fine muds and sandy deposits. Most studies on the recovery of marine communities regard ‘recovery’ as the establishment of a community that is similar in species composition, population density and biomass to that present prior to dredging or in a non-impacted reference site (Newell and Woodcock, 2013). However, many ecologists would argue that a more appropriate definition might be the return of the community to one that is within the normal spatial and temporal variation recorded prior to dredging or in non-dredged reference sites. Restoration of open coastal habitats is only possible by removal of aggregate dredging, prevention of other impacts such as heavy bottom gear by fishing vessels, and then allowing the system to recover over time through natural processes.

10.1.3.4 Offsetting

There are no offsetting activities being undertaken in relation to the mining of alluvial aggregates currently.

As with all mining, the implications of alluvial aggregate mining upon biodiversity and ecosystem services will depend to a large degree on the extent and sensitivity of the habitat type in question. Certain unique habitats are extremely restricted in their spatial extent and may already be threatened by other ocean uses. Mining in or near such a habitat could constitute a real threat to its persistence. Other benthic habitats may be more ubiquitous and widespread and hence mining in such habitats might threaten a small fraction of the total area covered by similar assemblages of species. It is imperative to that operations carefully consider the location of mining relative to threatened ecosystems and priority conservation targets during the ESIA process, and plan avoidance accordingly. As mining of the seabed can result in a permanently altered community, conservation of unique habitat types and their assemblage of biodiversity is not likely to be compatible with aggregate mining of the same area.

10.1.4 Gaps relating to marine aggregate mining

The impacts of dredging on higher levels in the marine food web are poorly understood. We have very little information, for example, on the significance of the small areas of seabed that are under licence for aggregate extraction as feeding areas for seabirds.

There is limited information on the effects of aggregate dredging on fisheries, mainly because of the difficulties in linking the abundance and variety of mobile organisms such as fish and shellfish such as crab and lobster to point sources of disturbance including aggregate dredging.

There have been numerous studies of the impacts of dredging on communities that live on the seabed. Benthic fauna that occurs at a particular site is generally well-adapted to survive and thrive in the dynamic conditions that occur on the seabed (Newell and Woodcock, 2013).

Lack of information available for light and noise emissions from aggregate dredging, and the scarcity of data on the impacts of noise on fish and invertebrates, as well as on many of the mammals and birds that form part of the food web. There have until recently been very few detailed studies on the noise levels generated by aggregate dredgers, so it has not been possible to place these into context in comparison with natural background noise levels at aggregate dredge sites, and in relation to other sources of noise from activities such as windfarms, seismic surveys and vessels passing through the licence area.

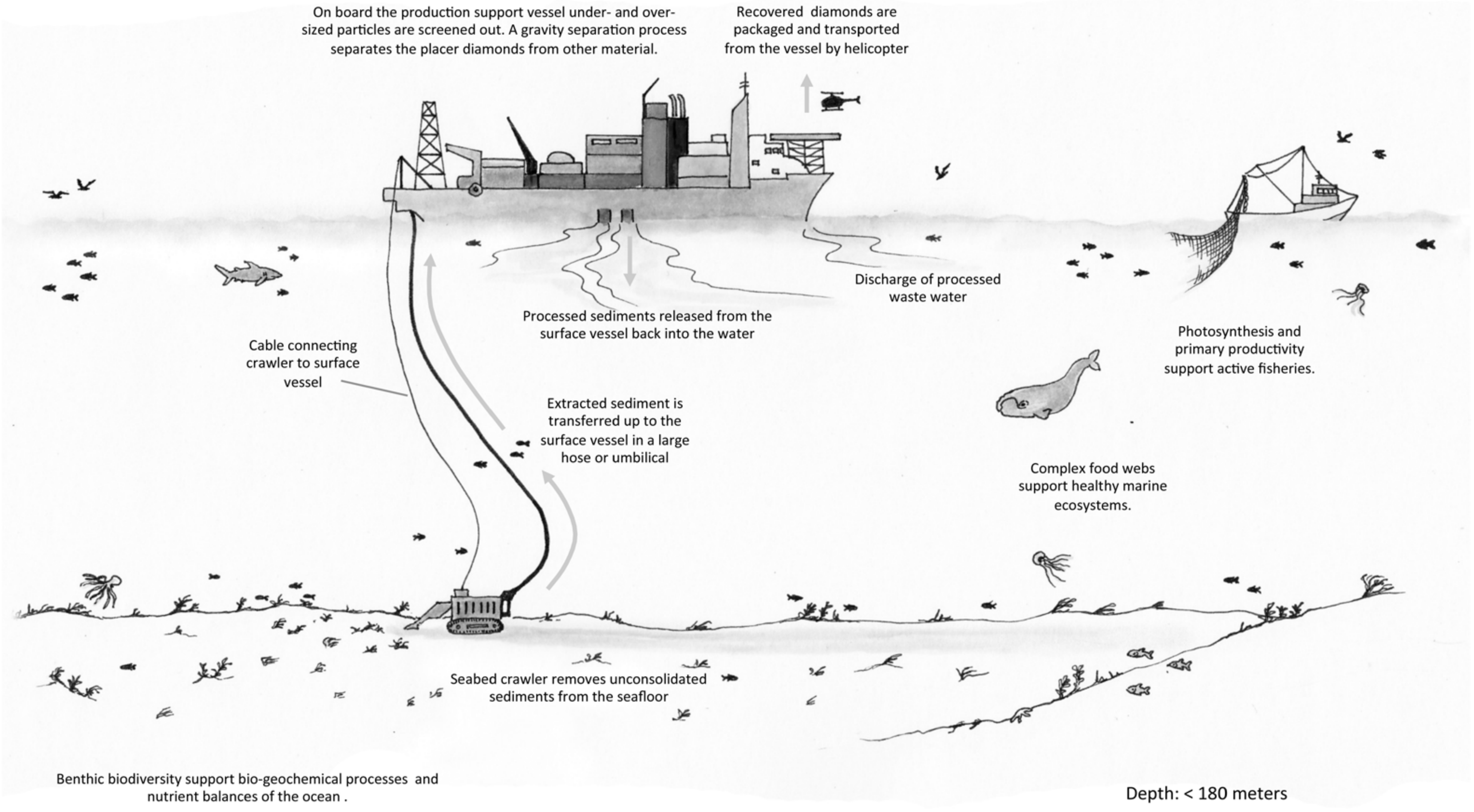
10.2 Marine placer diamond deposit mining

Marine diamonds were eroded from their primary (e.g. Kimberlite) source and deposited offshore through natural erosive and transport processes over millions of years. Marine diamond placer deposits are principally found on the Atlantic coast of South Africa and Namibia, where several large rivers disgorge diamond-bearing sediments to the sea. The diamond bearing gravel deposits have a patchy distribution and lie below a layer of sand or mud. Marine-based diamonds may be better quality than their terrestrially mined counterparts, as their transport along rivers can polish the stones and in the sea result in only the best quality stone surviving the journey.

10.2.1 Recovery of marine placer diamonds

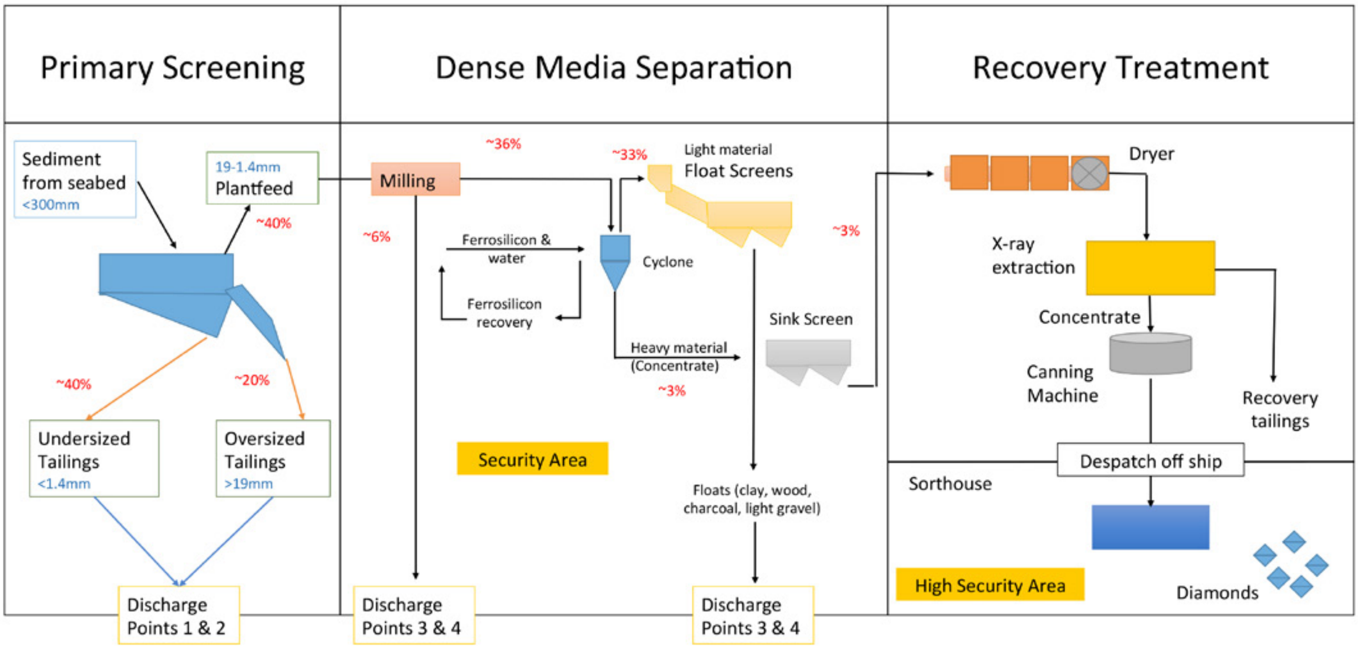
Marine mining of diamond placer deposits has been undertaken since the 1980s, with extraction of seabed diamonds from localised sediments containing concentrated diamond deposits. This type of mining is undertaken using surface mining vessels and either a seabed crawler or vertical mining tool (Figure 31), with sediments being transported in enclosed casing to the surface vessel for processing. On-board processing involves screening out under-and over-sized particles, which are immediately returned to the sea, then using a gravity separation process to separate diamonds from other material. The resulting material is then dried and x-rayed to recover the diamonds, which are packaged into small containers/tins and transported to shore for final sorting of this concentrated material (Figure 32).

Figure 31: Mining of marine-based diamonds in shallow waters using a seabed crawler. Illustration not to scale. Adapted from De Beers Marine Pty (ltd).



Credit: Nicky Jenner/FFI

Figure 32: Shallow water marine diamond mining – on-vessel processing of diamond-containing gravels to extract diamonds prior to return discharge to water column. Adapted from De Beers Marine Pty (Ltd).



* Percentages in red are approximate percentages of the total volume of sediment treated

10.2.2 Risks and impacts of marine placer diamond mining

Potential impacts of seabed diamond mining upon biodiversity and ecosystem services are illustrated in Figure 33 and include the following:

- Removal of the unconsolidated sediments within the mining area of impact. The sediments are mechanically removed by seabed tools, transported in enclosed casing to the vessel, processes and concentrated on board the vessel; and then all material (except for the final concentrate) is returned to the water before finally settling back to the seabed. It is assumed in addition to the removal of the sediment habitat, all organisms within the processed sediment are eliminated. This impact affects fauna associated with unconsolidated sediment habitats.

- The creation of sediment plumes at the mining head and in the water column when processed sediments are released from the mining ship back into the water. The sediment plume causes physical changes to the water column by blocking light and changing the water temperature, and levels of nutrient and dissolved oxygen, so potentially impacting primary production and energy flows as well as the behaviour of pelagic fauna.

- Re-suspension of sediments in water column, including potentially harmful compounds, could potentially impact primary production and energy flows.

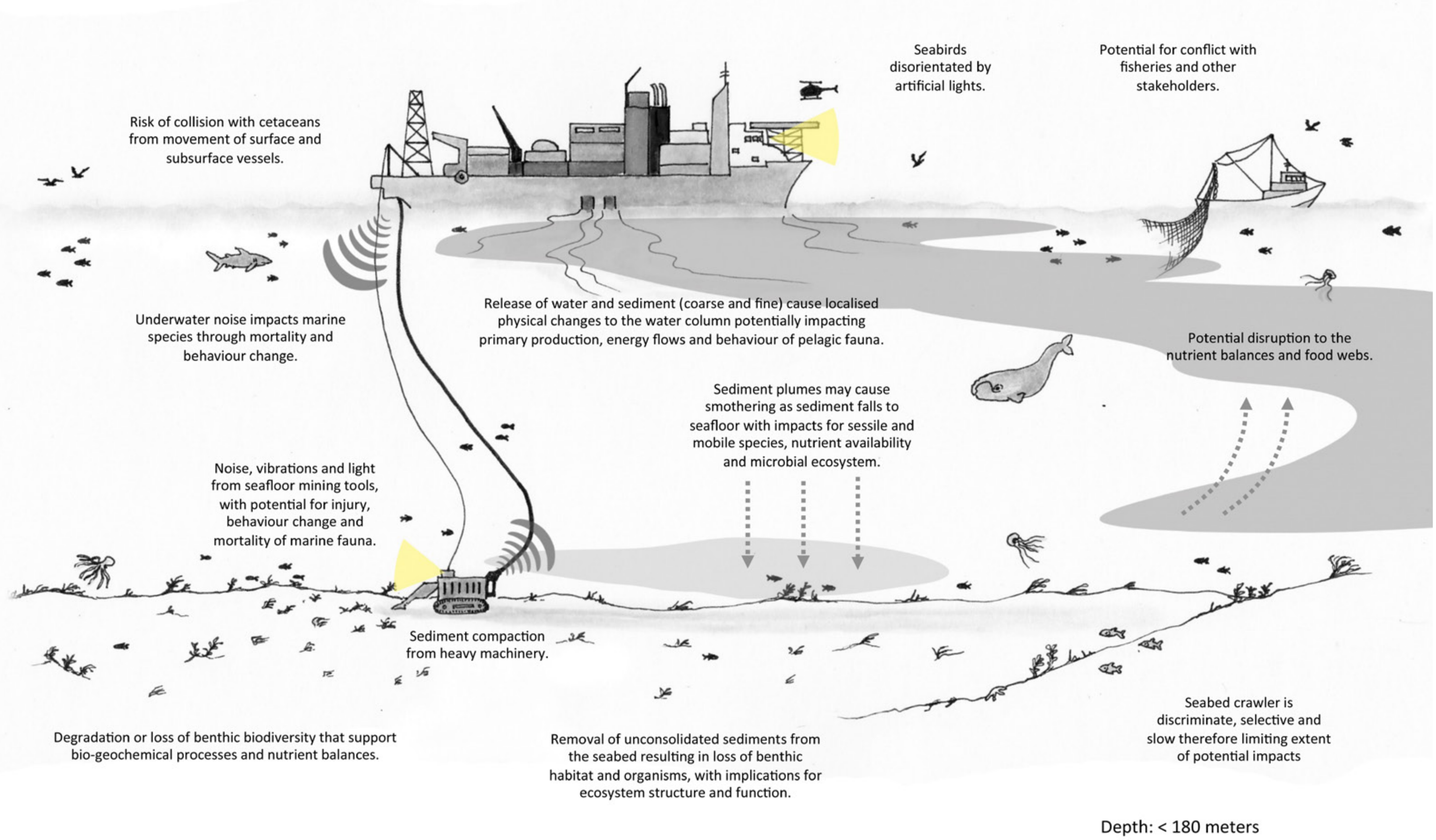
- Geosurvey activities, including low energy acoustic surveys could impact marine mammals and fish.

- Shipping may present a collision risk for marine mammals, and disturbance through noise and light.

- Generation of liquid and solid organic and inorganic wastes, including hazardous materials, could affect a wide range of marine biodiversity if not effectively contained.

Risks and impacts are assessed in more detail in Table 9.

Figure 33: Potential risks and impacts of marine placer diamond in shallow waters. Illustration not to scale.



Credit: Nicky Jenner/FFI

10.2.3 Applying the mitigation hierarchy

Mitigations relating to the mining of seabed diamonds are summarised below and a fuller assessment of preventative mitigations is presented in Table 9 whilst further generic opportunities for remediation are discussed in more detail in Section 13.

10.2.3.1 Avoidance

- Avoidance of some biodiversity and ecosystem services impacts can be achieved at a project scale through careful screening of key fishery areas and high biodiversity areas, including protected areas and other areas important for ecological processes and for species (including areas important for breeding, feeding, spawning etc.), to ensure operations do not overlap.
- High tech equipment and technology is used to map the seabed to identify potential diamond deposits. These are then tested by sampling these deposits and they are only targeted when their likely yield is clearly understood. Diamond recovery relies on high accuracy equipment targeting only those deposits identified. In this way mining activities avoid disturbing areas of seabed that do not contain viable deposits.
- Vessels are operated according to international legal requirements and in many cases best practice. The vessels go into dry dock every 2.5 to 3 years and undergo a full maintenance shutdown to ensure that they operate in optimal condition. These measures assist in the prevention of environmental incidents. The operation of the vessels is audited for compliance to the ISM Code, ISO14001:2015 and OHSAS18001.
- Uncontrolled releases of liquid and solid waste are avoided through strict recycling and waste handling procedures both onboard vessels and at ports.
- Pre-survey marine mammal scans with surveys only commencing when no marine mammals are observed

10.2.3.2 Minimisation

- Operations are designed such that the coarse tailings, and to some extent the finer sediments, discharged from the vessels land back into disturbed areas as far as possible. This avoids reprocessing the same sediments, minimises the disturbance footprint and provides material for re-establishment of habitat.
- Marine Mammal Observations (MMO) is undertaken at all times during geophysical survey operations and Passive Acoustic Monitoring (PAM) is undertaken in addition during the months of June and November and avoided during the months of July to October (whale breeding seasons).
- Soft starts are used for geophysical equipment.
- Strict adherence to approved Environmental Management Programmes and Authorisations.
- Stopping mining when large numbers of target specific organisms are detected at the screens
- Minimisation of shipping impacts through keeping vessels on station at mine sites and only returning to port for maintenance when necessary (e.g. every 2.5-3years)
- Minimisation of fuel use through ship design, equipment maintenance and manufacture
- Using the latest mining technology to ensure full resource extraction to minimise the need for re-mining an area
- Soft starts for geophysical survey equipment and marine mammal monitoring during operations.

10.2.3.3 Restoration

- There are no restoration activities documented for the mining of placer diamonds currently. Where alluvial mining is takes place in shallow water and/or close to large river mouths, sediment movement and sedimentation rates are naturally high and mined out areas are typically refilled fairly quickly which facilitates rapid structural and biological recovery (see Box 23). Although the majority of the sediments that are extracted are returned to the water after processing on the vessel and before finally settling back onto the seabed; it may be possible to further assist with the recovery of the sediment layers, by directly discharging the sediment down to the mined area, so assisting with structural recovery of the seabed. Such an approach will require further research and sea trials in shallow water at multiple locations, and is likely to be most effective in dynamic systems with high natural sedimentation rates.
- Evidence suggests that passive (natural) restoration occurs to achieve recovery of biodiversity composition, structure and function in seabed communities associated with diamond extraction.

10.2.3.4 Offsetting

- There are no offsetting activities being undertaken in relation to the mining of placer diamonds currently. Given the typically high natural variability of the environment in which placer mining occurs in on the south west coast of Africa, like-for-like offsets may not present the best value for marine biodiversity and ecosystem services. Rather, opportunities may exist for operations to invest in marine conservation priorities, as identified in the national Marine Protected Area strategies for Namibia and South Africa, and also in collecting scientific data that can contribute to the enhanced understanding and management of the environment.

BOX 23

Protecting biodiversity in DeBeers marine Namibia’s Atlantic 1 concession

Debmarine Namibia has been operating in its 6,000 square kilometres Atlantic 1 mining concession off the southern Namibia coast since 1991. During this time, it has been committed to minimising impacts to biodiversity. This included careful screening for protected areas, habitats of high biodiversity value and fisheries in order to avoid overlap with operations.

Impacts to biodiversity and ecosystem services have been minimised through designing and managing a fleet of mining vessels which exceed international standards (e.g. Marpol, Green Passport) and are designed to remain on site within Atlantic 1 for long periods, so minimising transit to port. Vessels are upgraded regularly to ensure the most efficient equipment is being used.

Debmarine Namibia has formed partnerships with various universities and marine scientists to research and better understand the impacts of diamond mining upon the marine environment, focusing upon sediment structure and benthic invertebrates. Their research has shown that the ecosystem has a high abundance of organisms, but a low diversity of species. Atlantic 1 is a high energy habitat with very high level of natural variability, including high sediment outflow from the Orange River during floods and storms. The seabed organisms are well adapted to tolerate the high natural variability, and therefore recover relatively quickly after disturbance.

During mining, the seabed sediment habitat is almost completely removed. However, mined areas infill with natural sediment quite rapidly, and the ecological function of the seabed (including benthic communities) has been found to re-establish within 10 years.

Debmarine Namibia operations rely on the “natural passive ecological restoration” processes described above for basic structural restoration of the seabed. Restoration is likely to be assisted by the patchwork nature of the mining, which rarely targets adjacent blocks, and to date has only affected 2% of the seabed within the Atlantic 1 mining concession. This means mined areas are generally surrounded by unmined areas which support the biological recolonisation process.

The operation is now working to a new target of net positive impact for biodiversity and ecosystem services, in alignment with the corporate standards of Anglo American. It is planning to expand its research into ecosystem services beyond fisheries to include regulating and cultural services. Further, it is assessing the feasibility of options for restoring and offsetting residual impacts to biodiversity and ecosystem services within Atlantic 1.

Table 9: Impacts to biodiversity and ecosystem services for marine placer diamonds and suitable mitigations, with further opportunities for research / experimentation identified

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity	Opportunities
									BES Impact mitigation		
Exploration	Shipping	See shipping table in Annex 2 for details of impacts and mitigations									
	Low energy acoustic surveys	Noise	Temporal avoidance by marine mammals (low energy acoustic survey)	Low	T				Avoid	Pre-start surveys are designed to ensure acoustic surveys won't be initiated in the presence of whales, dolphins and other species of concern	
									Minimise	On-board observers for marine mammals Soft starts	Data on whale movements from on-board observers to be communicated o the authorities and/or NGOs
	Removal of seabed sediments (wide spaced sampling using a seabed sampling tool)		Mortality of benthic organisms in excavated sediments	Low	T	Impacts on important fishery species, e.g. rock lobsters and fish	Low	T	Avoid	Avoid areas of high sensitivity, e.g. high biodiversity sensitivity or important fishery areas	Opportunity for ground truthing and enhancing habitat map info used to develop baseline sampling plan for physical and biological variables Environmental ground truthing (e.g. video, fish surveys, etc)
									Minimise	Return of 99% of sediments to sea immediately	
Mining Operations	Excavation of sediments and hard substrata	Loss / modification of habitat	Mortality of benthic organisms in excavated sediments and hard substrata	Low	PD	Impacts on important fishery species, e.g. rock lobsters and fish	High	PD	Avoid	Targeted mining to impact only mineral-bearing sediments Avoid important biodiversity and fishery areas	Identification of soft substratum organisms that are potentially rare; investigate presence outside license area Map hard substrata and collect visual data; Compile a collection of hard substratum organisms (e.g. gorgonians) from Atlantic 1 to assess rarity Assess mortality/survival of organisms on sorting screens
									Minimise	Mining stops when large numbers of specific organisms are detected at screens Using technology to ensure full resource extraction to prevent re-mining Return of overburden sediments to sea immediately Mining carried out in a patchwork of small blocks over a large area, leaving undisturbed seafloor to allow repopulation from adjoining areas	

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**	**Opportunities**
									BES Impact mitigation		
Mining Operations (cont.)	Deposition of sediments through tailings discharge	Smothering of seabed fauna by discharge sediments	Injury and mortality to benthic organisms Loss of ecosystem function through smothering of benthos, niche alteration	Medium	P	Loss of ecosystem function through smothering of benthos	Low	T	Minimise	Return 99% of seabed sediments to mined-out areas	
			Biological dispersal is dependent on the stratification of the water column and the depth of the surface mixing layer. Sharp pycnoclines reduce vertical mixing and promote the horizontal dispersion of suspended particulate matter (Ellis, 2001).	Low	PD	Reduced disperal of larvae and suspended particulate matter	Low	PD	Minimise	Surface water discharge can be sprayed over a large area to ensure dilution Operations are designed such that the coarse tailings, and to some extent the finer sediments, discharged from the vessels land back into disturbed areas as far as possible Mitigation strategies should aim at reducing the concentration, size and toxicity of particles in sediment plumes associated with various mining activities.	
	Mobilisation of sediments through seafloor operations and tailings discharge	Creation of sediment plumes	Injury and mortality to benthic organisms Loss of ecosystem function through occlusion, niche alteration	Medium	PD	Loss of ecosystem function through occlusion	Low	T	Avoid	Avoid dumping of processed sediments on sensitive habitats, e.g. reefs, nurseries for sharks Avoid important biodiversity and fishery areas	Process existing geophysical survey data Implement geophysical surveys on a wider scale.
			Clogging of suspension feeders and dilution of the food resource for deposit feeders	Low	PD	Disruption of the biological (carbon and nutrient) pump of the oceans. Reduction in ability of oceans to absorb and cycle carbon	Low	T	Minimise	Minimise turbidity and sediment loss from the mining tool through design	Investigate possible changes to the design of the seafloor mining tool(s) to reduce losses of suspended material during mining and of the discharge chutes to minimise entrainment of air and to maximise rate of descent of processed sediments back to the seafloor
			Generation of turbidity in the water column in general area of the mining vessel affecting pelagic organisms. Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification Suspended solids and increased sedimentation as a result of tailings discharge may cause significant reduction in light availability (Kirk, 1977), leading to reduced primary production	Low	PD	Impacts on important fishery species, e.g. rock lobsters and fish	Low	T	Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge Sediment discharge should be minimised at the surface to allow sufficient sunlight to penetrate for photosynthetic activity	Modelling and ground truthing of engineering solutions for minimising plume footprint in water column

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity	Opportunities
									BES Impact mitigation		
Mining Operations (cont.)	Mobilisation of sediments through seafloor operations and tailings discharge (cont.)	Creation of sediment plumes (cont.)	Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species, if present in the area (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	Medium	P	Impacts on important fishery species, e.g. rock lobsters and fish	Low	PD	Minimise	Return processed sediments directly to mined-out areas	
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	High	PD	Change in community structure of benthic fauna	Low	PD	Minimise	Where conditions are suitable, the concentration of discharge material should be such that it will have a positive effect e.g. artificial upwelling (which stimulates primary production)	
			Release of sulphides during sediment disturbance	Low	PD	Mortality of fauna due to sulphide toxicity	Low	PD	Avoid	This risk is associated with a sediment layer which is not currently targeted by mining activities	
			Suspended particulate matter from the sediment plume can potentially harm the eggs and larvae (Auld and Schubel, 1978; Partridge and Michael, 2010)	Low	PD	Mortality of eggs and larvae	Low	PD	Minimise	Minimise sediment return to water column Return overburden sediments directly to mined-out areas	
			Increased nutrient concentrations in the water column due to sediment resuspension (Klump and Martens, 1981; Lohrer and Wetz, 2003) may result in phytoplankton blooms	Low	PD	Increased nutrient concentrations promote algal blooms	Low	PD	Minimise	Design the suction/retrieval mouth of the seafloor mining tool for minimal escape of suspended material during exploitation.	Investigate possible changes to the design of the seafloor mining tool(s) to reduce losses of suspended material during mining and of the discharge chutes to minimise entrainment of air and to maximise rate of descent of processed sediments back to the seafloor
			The potential for trace-metal bioaccumulation	Medium	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea	
	Underwater noise from marine mining tool, sediment transport and processing upon fish and mammals	Noise	Impacts of noise on biodiversity and fishery resources	Low	T	Disruption to fishery through reduction of fish populations (mortality)	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018) Identify and avoid important fishery areas	

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity	Opportunities
									BES Impact mitigation		
Mining Operations (cont.)	Other Impacts	Incidental loss of mining equipment to the seabed, e.g. anchor, drill string	Creation of seabed hazards and disruption of sediment during retrieval efforts	Low	PD		Low	P	Avoid	“Engineering design to minimise incidental loss of equipment to the seabed No buoying off of lost equipment for later recovery (to prevent marine mammal entanglement)”	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
		Crew-change flights over sensitive areas (Orange River Mouth, Offshore Islands)	Disturbance of estuarine birds at the Orange River Mouth RAMSAR site by noise	Low	T		Medium	PD	Avoid	Flight paths aligned to avoid sensitive areas (Orange River Mouth, Offshore Islands)	
		Generation of wastes relating to mining e.g. steel balls (from ball mill), hydraulic fluids (drilling, crawler), dredging hoses, rubber lining, mountings, plastic screens, scrap metal	Impacts associated with the handling and disposal of waste	Low	PD				Avoid	Planned, regular maintenance undertaken, engineering design to minimise risk of wastes, modular design	
									Minimise	Recycling of waste metal, oil	
	Light	Lighting on sub-sea machinery and on surface vessels	Impacts of light on biodiversity	Low	PD	Disruption to ecosystem function through loss of primary producers and function of food web	Low	T	Avoid	Avoid areas of high biodiversity and important fishery areas	
			Disturbance affecting breeding and/or behaviour of animals	Low	PD	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties	
			The potential for trace-metal bioaccumulation	Low	PD				Minimise	Use directional lighting; only use lighting where and when necessary	
			Disturbance from support ship to bird species resulting in species range restrictions	Low	PD				Minimise	Use directional lighting; only use lighting where and when necessary	

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity	Opportunities
									BES Impact mitigation		
Mining Operations (cont.)	Chemical Spills		Reduction in primary productivity due to mortality of phytoplankton	Medium	PD	Disruption to ecosystem function through loss of primary producers and function of food web	Low	PD	Minimise	in the event of an incident, ensure application of best practice mitigation practices to ensure containment and remediation are expedited. Apply MARPOL and IMO regulations - avoid disposal of wastes to sea	
Mine Closure and Decommissioning	Abandonment of irretrievable equipment incidentally lost to the seabed		Creation of seabed hazards and disruption of sediment during retrieval efforts	Low	T				Avoid	Design equipment to minimise risk of incidental loss and designs that assist with retrieval in the case of loss	
									Minimise	Ensure materials used do not leach toxic substances over time	

10.2.4 Gaps relating to the mining of marine placer diamonds

The above assessment of mining marine placer diamonds through the lens of good practice impact assessment reveals the following gaps:

- Continued long-term monitoring required to understand long-term impacts to benthos from mining and recovery through sedimentation and recolonisation
- Ongoing studies to provide a clearer understanding of the impact of increased sediment upon biodiversity and ecosystem services within the water column
- No assessment currently of cumulative impacts from other industrial activities such as fishing and oil & gas exploitation within the wider Benguela Current ecosystem
- Further identification of priorities for biodiversity conservation underway, e.g. existing and planned protected areas, National Biodiversity Strategies and Action Plans, plans for marine protected areas, sustainable development strategies, poverty alleviation targets and climate adaptation plans.

11. Deep-seabed mining: impacts and mitigations

As with terrestrial mining, there are likely to be considerable impacts of seabed mining upon biodiversity and ecosystem services. However, these impacts are not yet fully articulated nor fully understood. This section provides an assessment of impacts for the main types of deep-seabed mining that are currently in operation or proposed in waters >800 metres depth.

Phosphate mining has been proposed between 150 metres and 400 metres and therefore falls between shallow and deep-seabed mining. All proposed projects are within national jurisdiction. This section starts by considering the risks and impacts, and potential mitigation options, for marine phosphates mining (Section 11.1) and then covers proposed deep-seabed mining of polymetallic mineral formations (Section 11.2 - 11.6).

Each section provides a general introduction of the mineral deposits (phosphates and polymetallic mineral formations in the deep sea) and an overview of the primary risks and impacts of deep-seabed mining. For deep-seabed polymetallic formations in international waters, we draw on the findings of the MIDAS project (MIDAS, 2013; Billet *et al*, 2015; MIDAS and Shirshov, 2016) and other key scientific initiatives, including outputs of the Deep Ocean Science Initiative (DOSI), (Section 11.2). We then present information on mining methods, impacts, and mitigations for the main types of polymetallic mineral formations:

- Polymetallic nodules from abyssal plains (Section 11.3)
- Active hydrothermal vents (Section 11.4)
- Seafloor massive sulphide (Section 11.5)
- Cobalt-rich ferromanganese crusts (Section 11.6)

For each resource we first describe in some detail the proposed mining methods, recognising this is a fast-moving sector with rapid technological development. This is followed by an assessment of risks and impacts for biodiversity, ecosystem services and biophysical processes. Options for applying the mitigation hierarchy are identified and assessed for applicability and appropriateness, with a focus on preventative mitigation (avoidance and minimisation). Restoration and offsetting in the context of deep-seabed mining are further discussed in Section 13. Impacts and mitigations are presented as detailed tables, with key points summarised in the text. Finally, the ability for the industry to conduct an appropriately detailed ESIA is judged against good practice ESIA criteria, leading to a gap analysis that highlights current areas for concern.

For ease of reference, information is provided for each type of resource in turn according to the structure outlined above. Presenting information in this way for each mining type and resource leads to repetition, as mining methods, impacts and mitigations can be similar for the different polymetallic mineral formations. However, it is necessary to present the fullest picture possible for every type of mining, to ensure each sub-section is stand-alone.

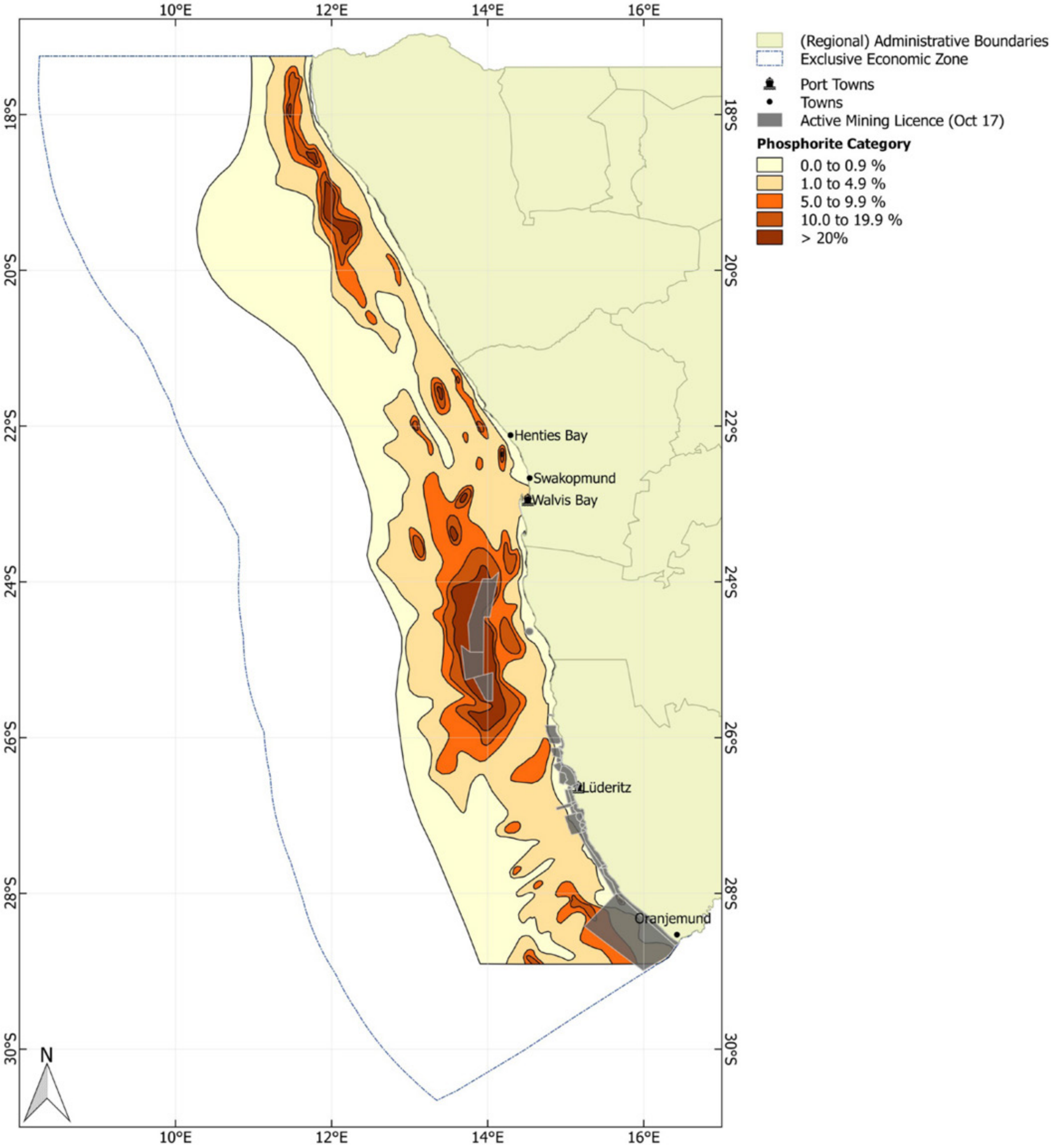
11.1 Deep-water mining for marine phosphates

Phosphate and other bulk sediments have not yet been mined on a commercial scale from the seafloor anywhere in the world. As a result, potential ecosystem impacts can at best be inferred from other types of mining operations that have taken place in similar biogeographic regions, at comparable depths and using similar tools, together with our understanding of the mining strategy and the local oceanography and ecology.

New methods and technologies have led to exponential increases in the achievable mining rate of the seafloor (*Workshop on Minerals Other than Polymetallic Nodules Of the (International Seabed Authority, 2004)*, culminating in technologies such as the Trailing Suction Hopper-Dredge, which allows large volumes of sediments to be dredged, stored in hopper compartments on board, and transferred to another vessel or onshore for further processing. Trailing Suction Hopper-Dredge vessels have the ability to dredge seafloor sediments at a rate of > 100,000 square metres per day (MMC, 2007) or 4,500 cubic metres per hour (Namibian Marine Phosphate (NMP), 2014) from depths exceeding 130 metres. Such new technologies are overcoming the economic restraints that have hindered the exploitation of deep-sea bulk minerals.

The south western coast of Africa is an area with rich phosphate deposits. The exceptional biological productivity of the Benguela Coastal Large Marine Ecosystem offshore Namibia has led to the formation of biogenic sediments enriched in phosphorous content up to 23% (Figure 34).

Figure 34: Overlay of active mining licences with the location of known phosphate deposits (EEZ) (Ministry of Fisheries and Marine Resources (MFMR), 2018).



11.1.1 Exploitation of marine phosphates

Global marine phosphorus deposits are highest in crusts from the Marshall Islands and the northwest Pacific but do not appear to occur in upwelling areas where nutrient enrichment and bio-productivity are greatest (east Pacific, east equatorial Pacific) as one might expect (Hein *et al*,. 1992). Phosphorus is relatively high in north Atlantic crusts, where bio-productivity is also high.

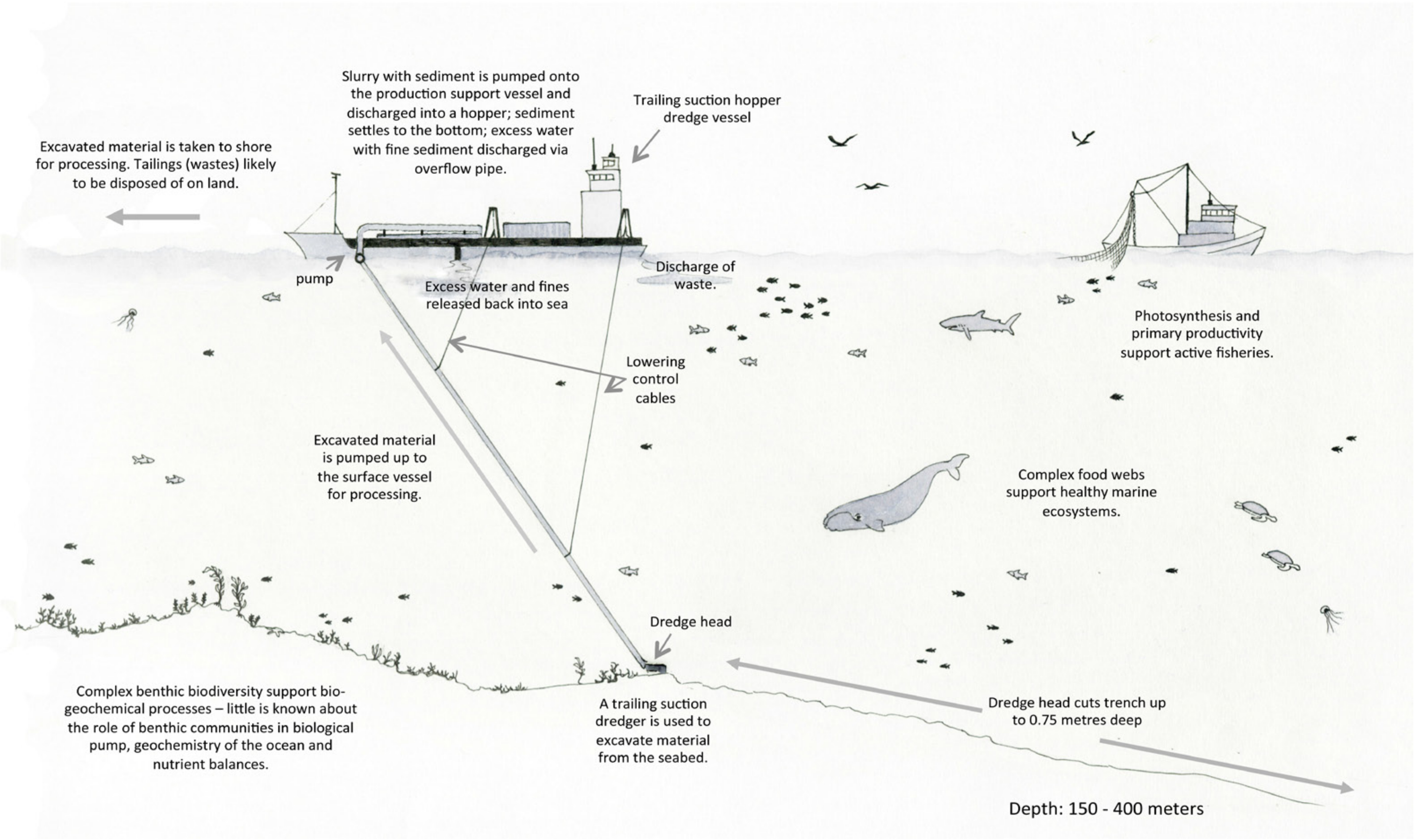
Exploration and mining claims for phosphorites have been made in South Africa, Namibia, New Zealand and Mexico, although the environmental ministries of the latter two States have recently rejected these based on environmental concerns.

The Namibian government has granted two mining licences (to two companies: Lev Leviev and Namibian Marine Phosphate), but a moratorium was instituted while further environmental impact assessment was conducted. As of August 2019, the official decision regarding marine phosphate mining in Namibian waters had not been announced, with the matter of strategically assessing the cumulative environmental impacts under review by the Government of Namibia. As of December 2019, a decision on phosphate mining in Namibian waters is still pending.

The approach to mining marine phosphate deposits is to dredge and process phosphate rich sediments (Figure 35). To give an example, the 223 metre long Trailing Suction Hopper-Dredge vessel, Cristobal Colon, which Namibian Marine Phosphate (Pty) Ltd proposes to use for their planned phosphate mining off the Namibian coast, has a dredging speed of 1-2 knots and drags an 11 metres wide dredge head over the seafloor, cutting a trench that is up to 0.75 m deep (Namibian Marine Phosphate (NMP), 2014). The dredge heads typically have cutting ‘teeth’ and powerful water jets to break up hard or consolidated sediments before they enter the suction tube (MMC, 2007). Excess water and fines are released back into the water column at 10-15 metres depth, from a hopper overflow funnel. Trailing Suction Hopper-Dredge vessels have the ability to dredge seafloor sediments at a rate of 4,500 cubic metres per hour (Namibian Marine Phosphate (NMP), 2014) from depths exceeding 130 metres. The 46,000 cubic meters hopper capacity of the Cristobal Colon will allow transfer of 64,175 tonnes of sediment to shore per 36-hour dredging cycle in the Namibian project (Namibian Marine Phosphate (NMP), 2014). The company plans to eventually mine 5.5 million tonnes of sediment during 47 weeks at sea annually, removing sediments up to 3 metres in depth and over areas of ~2.4 square kilometres in extent.

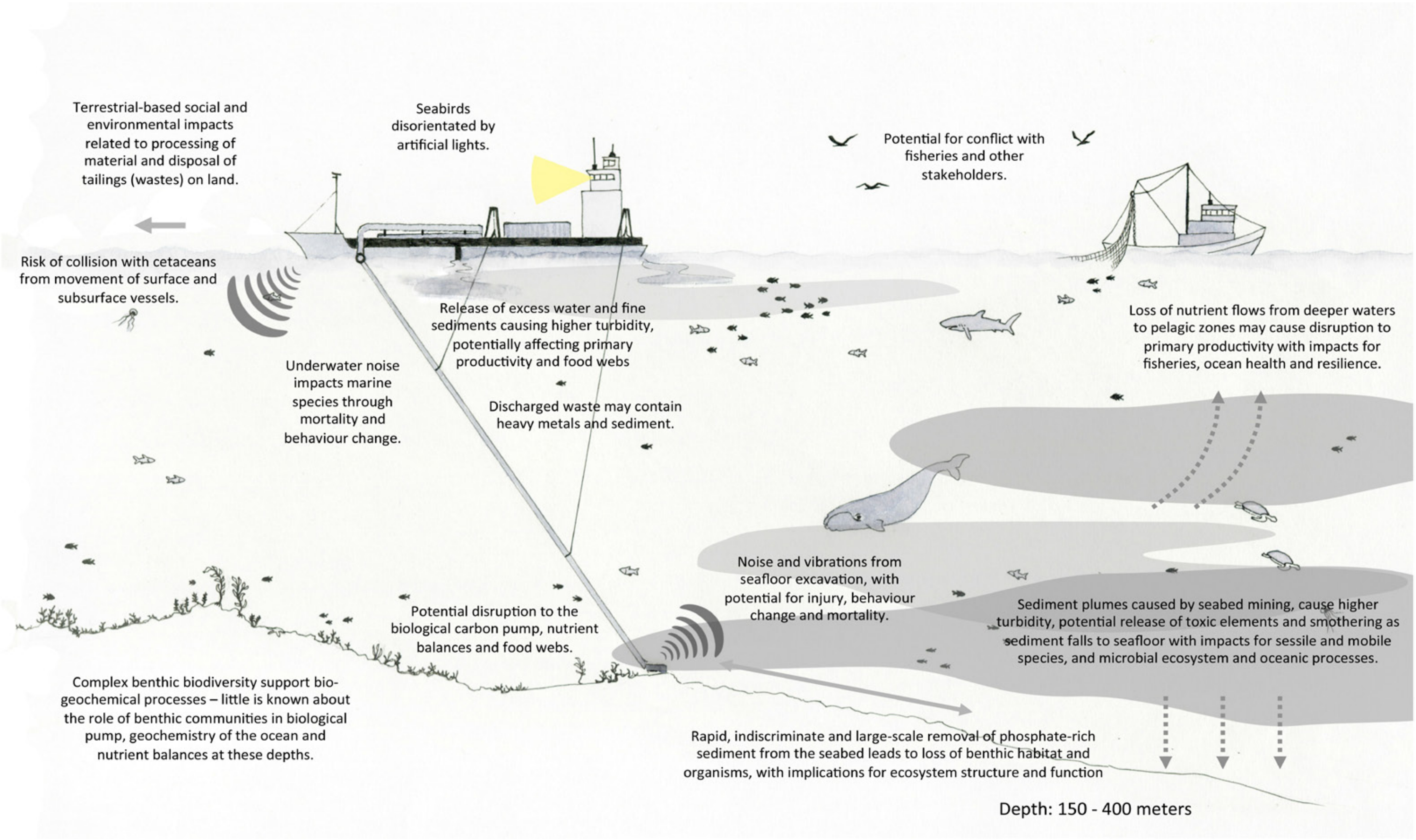
As large-scale dredging of the seafloor has not taken place before, there is an urgent requirement to understand the impacts of such proposed activities on the surrounding ecosystems, which encompass unique biodiversity and sustain valuable natural resources. The following sections outline the potential threats to these ecosystems, drawing upon the EIA for the proposed Namibian Sandpiper Project (Midgley, 2012) and literature covering the effects of seabed mining and other dredging operations.

Figure 35: Mining of marine phosphates using a trailing suction dredger. Illustration not to scale.



Credit: Nicky Jenner/FFI

Figure 36: Potential risks and impacts of mining marine phosphates. Illustration not to scale.



Credit: Nicky Jenner/FFI

11.1.2 Impacts of marine phosphate mining

The potential effects of marine phosphate (or any similar bulk sediment) mining operations on marine ecosystems is likely to be considerable, not least because of the speed and method by which dredgers operate.

Sources of impact from operations mining marine phosphates on the seabed will include the following:

- Acoustic pulses of geophysical equipment, which can cause physical damage to fish and marine mammals, and avoidance of areas by affected species;
- Removal of large areas of sediment habitat on the seafloor, causing destruction of habitat for species occurring there, e.g. burrowing macrofauna, with implications for ecosystem structure and function;
- Removal of large contiguous blocks of sediment, so minimising the opportunity for recolonization of biodiversity, e.g. benthic infauna;
- Release of sediments back to the ocean post-processing, causing high turbidity which potentially alters predator-prey relationships and reduces sunlight, and may lead to the release of harmful compounds to the water column, and cause smothering of the seabed where sediments settle out;
- Release of sediments that may disrupt the biological carbon pump and cycling of nutrients by affecting primary production and altering the chemistry of the water column.

Further, phosphate mining will generate a range of impacts generic to all seabed mining operations, including light and noise pollution, unplanned waste releases, collision risk from shipping and gaseous emissions. Full details are provided in Table 10 (below).

11.1.3 Applying the mitigation hierarchy

Mitigations relating to the mining of marine phosphates are summarised below and a fuller assessment of preventative mitigations is presented in Table 10, whilst generic remediation options and constraints are discussed in more detail in Section 13. Mitigation measures should be informed by monitoring marine macrofauna, monitoring of benthic fauna, and applying best practises of pollution control.

11.1.3.1 Avoidance

- Avoidance of biodiversity and ecosystem services impacts can be achieved at a project scale through careful screening of key fishery areas and high biodiversity areas, including protected areas, to ensure operations do not overlap.
- Uncontrolled releases of liquid and solid waste are avoided through strict recycling and waste handling procedures both onboard vessels and at ports.
- Use stripwise mining to create alternate strips of mined and unmined seabed to improve rates of recolonisation of benthic fauna

11.1.3.2 Minimisation

- Stopping mining when large numbers of target organisms are detected at the screens
- Minimisation of shipping impacts through keeping vessels on station at mine sites and only returning to port for maintenance when necessary (e.g. every 2 years)
- Minimisation of fuel use through ship design and manufacture
- Using the latest mining technology to ensure full resource extraction to minimise the need for re-mining an area
- Returning sediments to the seabed mining location
- Screening sediments for harmful compounds prior to return to the seabed

11.1.3.3 Restoration

Due to the total removal of substrate and no return of sediments to the water column, restoration of benthic habitats is unlikely

11.1.3.4 Offsetting

As with all mining, the implications of phosphate mining upon biodiversity conservation will depend to a large degree on the extent of the habitat type in question. Certain unique habitats are extremely restricted in their spatial extent and may already be threatened by other ocean uses. A bulk sediment mining operation in or near such a habitat could provide a real threat to its survival. Other benthic habitats may be more ubiquitous and widespread and hence mining in such habitats might threaten only a small fraction of the total area covered by similar assemblages of species. It is imperative to that operations carefully consider the location of mining relative to threatened ecosystems and priority conservation targets during the ESIA process, and plan avoidance accordingly. As the mining can result in a permanently altered community, conservation of unique habitat types and their assemblage of biodiversity is not likely to be compatible with bulk sediment mining of the same area.

Table 10: Impacts to biodiversity and ecosystem services from marine phosphate mining and suitable mitigations, with further opportunities for research / experimentation identified

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	Low	T				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected aeas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities of eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	In the supply of raw materials for technologies – to move toward a circular economy
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T				Minimise	Establish effective recycling programs and find alternative technologies that reduce, or eliminate, the use of supply constrained metals

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	Low	P				Minimise	Minimise sampling area
			Permanent alteration of the benthic geomorphology	Low	P					No mitigations have been identified currently
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Loss of ecosystem function through occulsion and smothering of benthos	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Low	T	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P				Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Disruption of the Biological (carbon and nutrient) pump of the oceans	Low	P				Minimise	Minimise lifting of sediments near the seafloor
	Removal of phosphate samples	Removal of substrates	Removal of phosphate from the ocean system which is a fundamental element for the growth of photosynthetic organisms and which is likely to impact on primary production	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Low	P	Avoid	Avoid areas of high biodiversity
			Removal of species associated with phosphorous deposits	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	P	Minimise	Use machinery and technology designed to Best Practice Standards to reduce the impacts of phosphorous removal
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown				Minimise	Sample with minimum viable sample size
									Minimise	Ensure Scientific study to establish the formation of and relevance of the micro-organisms of polymetallic nodules
Resource Development	Use of Large Extractive Machinery designed to be mobile on seabed	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed	Noise	Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
									Avoid	Exploitation contracts should not be issued until MPA networks are implemented
									Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected aeas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortality to eggs, microorganisms and disrupt beviour etc.)
									Minimise	Use best practice design and techology to minimise noise output
		Light	Impacts of light on biodiversity	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Understand the total area that will be affected including the total water volume (3D)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Integrated Approach - take into account stressors such as ocean acidification, climate change and pollution. Such an approach could help to avoid fragmented, inconsistent approaches to regulating activities in different regions, though some level of systematic and permanent damage to ecosystems would be unavoidable.
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	Avoid areas of high biodiversity
			Disturbance to benthic species resulting in species range restrictions	High	PD				Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance from support ship to bird species resulting in species range restrictions	High	PD				Minimise	Use directional lighting; only use lighting where and when necessary
									Minimise	For seabed equipment, minimise use of light through design of equipment
		Loss or modification to benthic habitat	Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Avoid areas of high biodiversity

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Loss or modification to benthic habitat (cont.)	Loss of habitat of benthic fauna	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Habitat loss and the modification of seabed morphology, physiological disturbance to organisms, and changes in the intra- and interspecific competition patterns affecting food web structures	High	P	Disruption of the ocean biological pump	High	P	Minimise	Minimise lifting of sediments near the seafloor
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999).	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	Unknown	Unknown				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge. Surface water discharge can be sprayed over a large area to ensure dilution
			The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008).	Unknown	Unknown				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be uniform distribution of the discharge in the entire water column
			Changes in faunal distribution	Unknown	Unknown				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Changes in benthic species composition and an increase in opportunistic species resulting from mineral extraction can also benefit certain demersal fish as food becomes more abundant (de Jong *et al.*, 2014).	Unknown	Unknown				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			Decrease in abundance of meiobenthos	Unknown	Unknown				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Loss or modification to benthic habitat (cont.)	Increased plume dispersion during high flow periods may influence larval dispersal, while low-flow regimes with lower spreading rates and greater blanketing may adversely affect abundance and diversity.	High	Unknown				Restore	The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008). Communities in naturally high-energy areas with exposure to currents or waves are more adept at readjusting to the impacts of mineral extraction than more stable communities In the absence of primary production, the resource limited deep-sea communities have a lower abundance and are reliant on the phytodetrital nutrient supply from the surface (Smith *et al.*, 2008). Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks. Natural restoration through sediment settlement results in recolonisation over impacted areas Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through ‘set aside’ areas, used exclusively as “impact reference zones” and “preservation references zones” as stipulated by the ISA (International Seabed Authority, 2010) Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	Unknown	Unknown					
			Extraction of material from the seabed changes the composition of the sediments	Unknown	Unknown					
			The release of sulfides during sediment disturbance	Medium	Unknown					
			Mineral extraction activities that cause topographical changes on the seabed may modify its biogeochemical processes.	Unknown	Unknown					
			Large pits and borrow holes created when using a suction dredger in shallow areas may trap organic matter, enriching the sediment and increasing the oxygen consumption as the organic matter decomposes	Unknown	Unknown					
			The potential for trace-metal bioaccumulation	Unknown	Unknown					
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		
				Low	T		Low	T		

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	Suspended loads will travel laterally over vast distances causing clogging of fliter feeding appartus of benthic organisms in the area.	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Recommended approach to prediction and environmental assessment of plume development during mineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/ global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Direct impacts along the track of the collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/ global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Loss of ecosystem function through occulsion and smothering of benthos	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P	Avoid	Apply the Precautionary Principle - avoid impacts as with limited information on the physiology of deep-sea organisms, it is currently not possible to estimate the toxic impacts from metal release from the mined material on deep-sea species (Hauton *et al.*, 2017).
			Addition of bottom sediments to the surface resulting in change in the marine ecosystem	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Minimise sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	High	P				Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Smothering or entombment of the benthic fauna away from the site of phosphate removal where sediment plume settles (if and when). Even low levels of sediment redeposition may be destructive to certain benthic organisms as increased solids in the water may smother or clog their feeding organs or gills (Ellis *et al.*, 2002), especially harming filter-feeding organisms such as mussels and other bivalves (Mestre *et al.*, 2017).	High	P				Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Mobilisation of sediments (creation of sediment plumes) (cont.)	Generation of turbidity in the water column over large areas affecting pelagic organisms. Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	High	PD				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			Suspended solids and increased sedimentation as a result of harvesting the sediment may cause significant reduction in light availability (Kirk, 1977), leading to the reduced vitality or death of aquatic macrophytes (Riul *et al.*, 2008).	High	P				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be uniform distribution of the discharge in the entire water column
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	High	P				Minimise	Surface water discharge can be sprayed over a large area to ensure dilution
			Decrease in abundance of meiobenthos due to reduced sunlight in water column from sediment	High	P				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	High	P				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			The release of sulfides during sediment disturbance	High	P				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			Suspended particulate matter and toxic substances from the sediment plume can potentially harm eggs and larvae (Auld and Schubel, 1978; Partridge and Michael, 2010)	High	P				Minimise	Minimise sediment return to water column
			Dispersal is dependent on the stratification of the water column and the depth of the surface mixing layer. Sharp pycnoclines reduce vertical mixing and promote the horizontal dispersion of suspended particulate matter (Ellis, 2001).	High	P				Minimise	Mitigation strategies should aim at reducing the concentration, size and toxicity of particles in sediment plumes associated with various mining activities
			Sediment in the water column causes occlusion and potential habitat fragmentation through visual screening	High	P				Minimise	Reducing the concentration, size and toxicity of particles in sediment plumes can be achieved through modifications to mining equipment or procedures.

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Mobilisation of sediments (creation of sediment plumes) (cont.)	Increased nutrient concentrations in the water column due to sediment resuspension (Klump and Martens, 1981; Lohrer and Wetz, 2003) may result in phytoplankton blooms	High	P				Minimise	Design the suction/retrieval mouth of the seafloor mining tool for minimal escape of suspended material during exploitation
			In oligotrophic waters, the intrusion of nutrient rich bottom water and sediment may drastically increase primary production (Hyun *et al.*, 1998)	Low	Low					
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High	P					
		Reduction of biomass around disturbance area	Loss of biodiversity and changes to the marine ecosystem and foodwebs with potential consequences to fisheries, ocean health and function and the biological (carbon and nutrient) pump	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Avoid areas of high biodiversity
									Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through 'set aside' areas, used exclusively as "impact reference zones" and "preservation references zones" as stipulated by the ISA (International Seabed Authority, 2010)
									Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
									Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community
		Mobilisation and removal from oceans of key geochemical nutrients	The potential for trace-metal bioaccumulation	High	P					No mitigations have been identified currently
			Suspended loads will remain over very long periods	High	P					No mitigations have been identified currently
			Disruption of the Biological (carbon and nutrient) pump of the oceans	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
		Changes in the physic-chemical conditions around disturbance area	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Changes in the physic-chemical conditions around disturbance area (cont.)	Mining activities will change the ocean chemistry and have consequential impact on ecological processes. A major disruption of the chemical conditions that permit microbial chemosynthesis could have devastating consequences for all animals in that ecosystem	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently
			The release of sulfides during sediment disturbance	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P		No mitigations have been identified currently
			The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	High	P					No mitigations have been identified currently
		Removal of seabed substrates	Changes in environmental conditions may alter metal partitioning and bioavailability (Calmano *et al.*, 1993; Cantwell *et al.*, 2002).	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
		Estimate disturbance of 300-600km2 per year through mining for 1.5-3 million metric tonnes of nodules per year	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Unknown	Unknown	loss of ecosystem function	High	P		No mitigations have been identified currently
			Removal of species associated with polymetallic formation (high species diversity)	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
			Mining process will release metal ions into the water column, either in the benthic plume created by mining vehicles or, following dewatering on the surface vessel, in a mid-water plume	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Nodules may be collected whole, the transfer of nodules up the riser pipe will likely result in them also turning to slurry requiring processing at surface	Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process.	Unknown	Unknown					No mitigations have been identified currently
			Sediment dispersion changes both the chemical properties of the water and the seafloor sediment composition (Newell *et al.*, 1999; Desprez *et al.*, 2009)	Unknown	Unknown					No mitigations have been identified currently
		Deposition of sediments near surface following processing	Introduction of debris and sediment in the water column	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never deposit sediment at surface
			Considerable quantities of organic contaminants and heavy metals may be released from the seabed sediments when they are disturbed (Latimer *et al.*, 1999).	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Increased turbidity causes occlusion and reduced availability of sunlight photsynthesis causing long term effects on biological productivity	Medium	T	Disruption to fishery through reduction of fish populations	Medium	Unknown		No mitigations have been identified currently
			The potential for trace-metal bioaccumulation	Medium	P					No mitigations have been identified currently
			Reduction in primary productivity due to shading of phytoplanton	Medium	T					No mitigations have been identified currently
			Impacts on marine mammal behaviour	Medium	T					No mitigations have been identified currently
		Introduction of bottom water at the surface	Introduction of bottom water with its higher nutrient values could result in artificial upwelline increasing the surface productivity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never introduce or deposit bottom water at surface
			Ecological disturbances and imbalances through dissolution of heavy metals (Cu and Pb) within the oxygen minimum zone	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
		Discharge of tailings and effluent below the oxygen-minium zone	May cause some environmental harm to pelagic fauna	Unknown	Unknown	Disruption to fishery through reduction of fish populations	Unknown	Unknown	Avoid	Never discharge of tailings and effluent below the oxygen-minium zone
			Mortality and change in species composition of zooplankton	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown		No mitigations have been identified currently
			Effects on meso- and bathypelagic fishes and other nekton	Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Unknown	Unknown		No mitigations have been identified currently

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile on seabed (cont.)	Discharge of tailings and effluent below the oxygen-minium zone (cont.)	Impacts on deep diving marine mammals	Unknown	Unknown	Disruption of the ocean biological pump	Unknown	Unknown		No mitigations have been identified currently
			Impacts to bacterioplankton	Unknown	Unknown					No mitigations have been identified currently
			Depletion of oxygen by bacterial growth on suspended particles	Unknown	Unknown					No mitigations have been identified currently
			Effects on fish behaviour and mortality caused by sediments or trace metals	Unknown	Unknown					No mitigations have been identified currently
At sea processing, ore transfer and transport	Mining operations	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	High Low	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to bird species resulting in species range restrictions	High	PD					
		Light	Impacts of light on biodiversity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Medium	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Medium	T				Minimise	Use directional lighting; only use lighting where and when necessary
			Disturbance from support ship to bird species resulting in species range restrictions	Medium	T				Minimise	Use directional lighting; only use lighting where and when necessary
		Chemical Spills	The potential for trace-metal bioaccumulation	Medium	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T	Minimise	In the event of an incident, ensure application of best pro-active mitigation practices to ensure containment and remediation are expedited
			Impacts on marine mammals	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		
			Impacts and mortality of pelagic fish	Medium	T					

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport (cont.)	Mining operations (cont.)	Waste Disposal	May cause some environmental harm to pelagic fauna	Medium	T	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Mortality and change in species composition of zooplankton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T		
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		
			Effects on meso- and bathypelagic fishes and other nekton	Medium	T					
			Impacts on marine mammals	Medium	T					
			Depletion of oxygen by bacterial growth on suspended particles	Medium	T					
			Effects on fish behaviour and mortality caused by sediments or trace metals	Medium	T					

11.1.4 Gaps relating to marine phosphate mining

The above assessment of phosphate mining through the lens of good-practice impact assessment reveals the following gaps:

- Limited information on baseline conditions for biodiversity, ecosystem services and biophysical processes from which to determine their current state (see Section B).
- Limited understanding of the effects of large quantities of sediment upon the water column, including changes to the light regime and water chemistry.
- Limited understanding of effects of dredging large contiguous areas of the seabed with little or no unimpacted areas.
- Limited understanding of the effects of large quantities of sediment and coarser material settling on the seabed.
- Given the proposed phosphate mining operations occur within the mesopelagic zone, which is crucial for pelagic fisheries, more information is required of the effect of removal and mobilisation of phosphates

Lack of information available for light and noise emissions from aggregate dredging, and the scarcity of data on the impacts of noise on fish and invertebrates, as well as on many of the mammals and birds that form part of the food web.

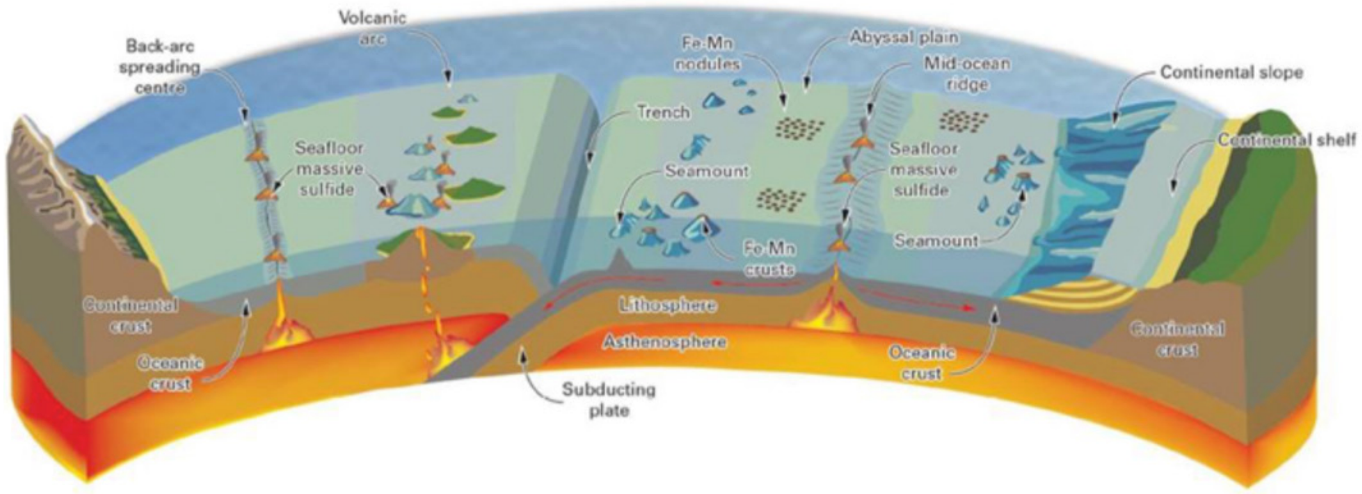
11.2 Mining polymetallic mineral formations in the deep sea: summary of impacts

11.2.1 Introduction

11.2.1.1 Metallic formations in the deep sea

Deep-sea metallic formations include polymetallic nodules on the abyssal plain, polymetallic crusts on seamounts and seafloor massive sulphide deposits at mid-ocean ridges (Figure 37). Typically, these mineral deposits occur in waters of over 800 metres depth and have been observed at depths of more than 6,000 metres.

Figure 37: A cross-section through the earth's crust showing the different types of plate boundary, the topography of the ocean floor and the distribution of major metal-rich deep-ocean mineral deposits in the deep sea. Image by Ian Longhurst. Credit: British Geological Survey UKRI 2018



11.2.1.2 Mining deposits in the deep sea

The first attempt to exploit deep-sea manganese deposits ended in failure as a result of the collapse of world metal prices, the provisions imposed by the UNCLOS, and the over-optimistic assumptions about the viability of nodule mining. Attention then focused on cobalt-rich manganese crusts from seamounts. Since the mid-1980s, a number of new players have committed themselves to long-term programmes to establish the viability of mining deep-sea manganese nodules. These programmes require heavy subsidy by host governments.

In general terms, resource extraction from the deep seabed requires the movement of heavy equipment around the sedimented seafloor, or across hard substrata. If the target mineral is within sediment, such as polymetallic nodules, the sediment is likely to be removed with the nodules using suction, taken to the surface for extraction of the nodules, returning the sediment to the water column. For hard substrata (e.g. crusts) the mineral and crust is likely to be mechanically broken up with some form of cutter. This impacts the substratum through removal of habitat and creates a sediment plume. Collected resources are then transported up to the processing vessel on the surface where a secondary post-processing plume is returned to the water column (Cuvelier *et al.*, 2019).

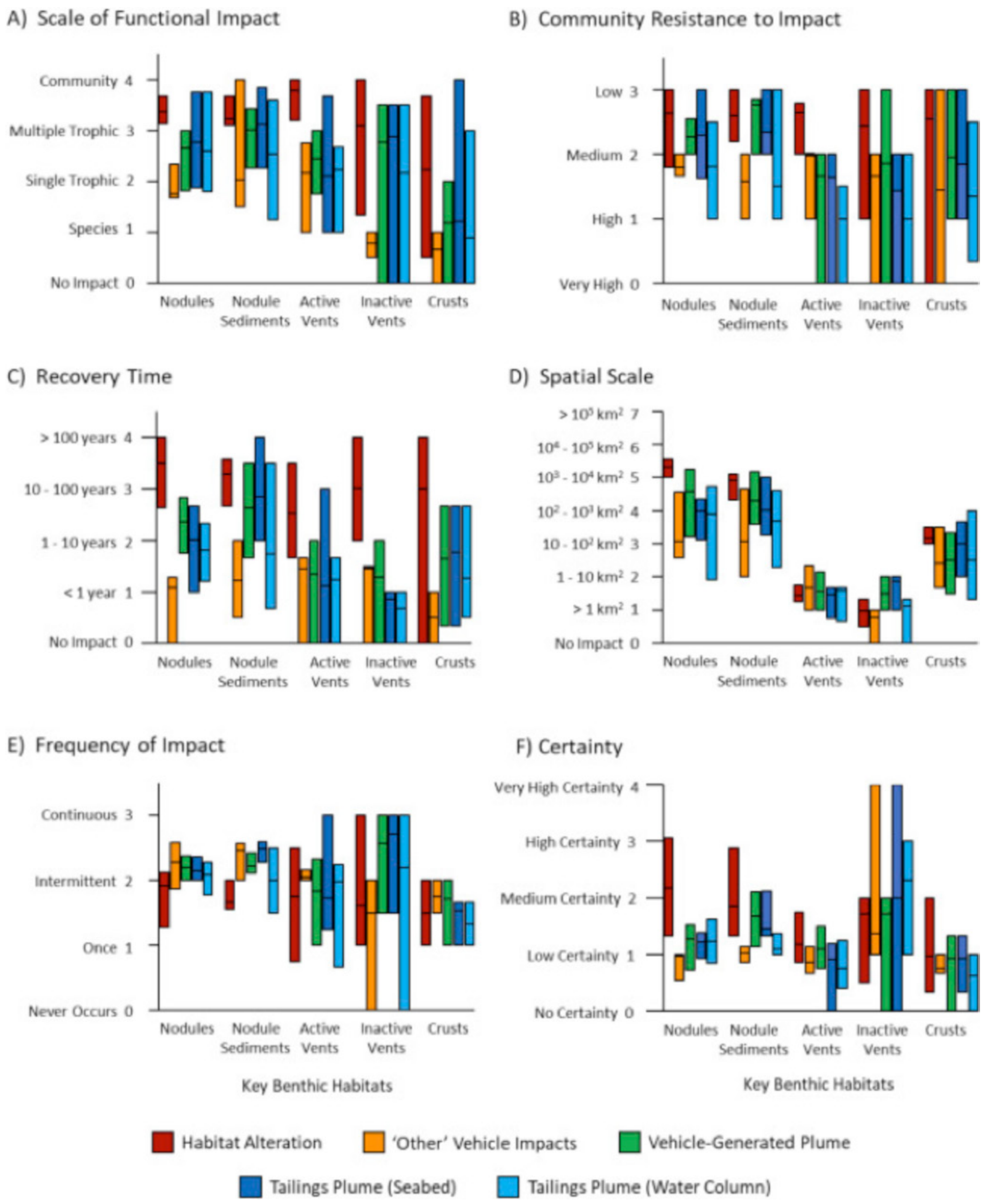
11.2.1.3 Shedding light on impacts from deep-seabed mining

Despite growing concern over the impacts of deep-seabed mining (Boschen *et al.*, 2013; Miller *et al.*, 2018), knowledge of the pressures from deep-seabed exploitation on ecosystems has not been synthesised, and studies addressing the adverse effects rarely offer empirical evidence of the overall impacts. Previous reviews on the impacts of seabed mining have focused on the loss of biodiversity and recovery of benthic ecosystems (Ellis, 2001; Jones *et al.*, 2017) or specific ecosystems, such as hydrothermal vents (Boschen *et al.*, 2013; Van Dover, 2014) or polymetallic nodule fields (Vanreusel *et al.*, 2016). While different scenarios of the potential impacts have been envisaged (Ramirez-Llodra *et al.*, 2010; Van Dover, 2011), links between the findings of empirical studies and specific pressures from mining have not been established. The current challenges regarding mineral extraction from the seafloor are how to estimate the impacts on ecosystems before commercial activities start and how to deal with uncertainty stemming from the scarcity of data.

Recognising this gap, between 2013 and 2016 a consortium of 32 European universities, research institutes and mining companies known as the MIDAS (Managing Impacts of Deep Sea Resource Exploitation, MIDAS, 2013) project conducted an extensive scientific investigation into the potential consequences of deep-seabed mining. The MIDAS programme has made an excellent contribution to defining and scoping environmental impacts from deep-seabed mining and much of this section draws from this seminal work, augmented by the findings of other key scientific initiatives, including outputs of the Deep Ocean Science Initiative (DOSI).

Scientific work in MIDAS was divided into the examination of the scale of the potential impacts (e.g. the size of the areas to be mined, the spread and influence of plumes away from these areas and the potential toxic nature of the material mined or thrown up into suspension) and how these impacts would affect the ecosystems (e.g. impeding the connectivity between populations, interrupting species' lifecycles, loss of habitat, and the impact of reduction or loss of species on ecosystem function and services). MIDAS also addressed the ability of ecosystems to recover once mining ceased in an area further confirmed and elaborated in recent work by Washburn *et al* (2019), (Figure 38).

Figure 38: Ability of deep-sea ecosystems to recover after mining activity. Source: Washburn (2019)



Habitat alteration was perceived to have a functional impact at multiple trophic levels or the entire community in nodule and vent habitats, but only a single trophic level in crust habitat (A), with active vents ranked as most vulnerable in aggregate for risk sources within this risk category. Community resistance to habitat alteration was perceived to be low for nodule and vent habitats, with a large range of perceptions for inactive vent and crust habitats, from low to high or very high resistance (B). Recovery following mining was perceived to take decades or longer for nodule and vent habitats that were altered or removed by mining activities; a large range of recovery times (from no impact, i.e., zero recovery time, to greater than a century) for crusts was elicited from experts (C). Expert perception was that spatial scales of impact were on the order of 1000's of square kilometres in nodule habitats compared to spatial scales of 10 square kilometres for crusts and <10 square kilometres for vents (D). The frequency of impacts from habitat alteration was perceived to be intermittent for all habitats (E).

Impacts are likely to be compounded in the oceans by the connectivity of ocean systems, the movement of highly mobile species, and the ocean's central role in large-scale atmospheric processes. Deep-sea species are inherently vulnerable to environmental change. Characteristics of deep-sea organisms include increased longevity, slow growth rates, reproduction late in life and low fecundity (Carreiro-Silva *et al.*, 2013; Mengerink *et al.*, 2016; Danovaro *et al.*, 2017; Montero-Serra *et al.*, 2018). These particular life history strategies mean that many deep-sea species have an increased sensitivity to human activities such as mining, fisheries and climate change. Knowledge gaps have led researchers to urge caution and adopt the precautionary approach to seabed mining (Lallier and Maes, 2016; Boetius and Haeckel, 2018).

A growing consensus among marine scientists is that at any scale **seabed mining will systematically deplete resources, disturb, damage or remove structural elements of ecosystems, cause biodiversity loss and impact ecosystem services** (Le Gouvello *et al.*, 2017; Van Dover *et al.*, 2017; Boetius and Haeckel, 2018). The scale of potential damage is hard to predict because our understanding of deep-sea marine biota remains limited. Also unknown is the extent to which an ecosystem will recover when mining ceases and over what timescales (Jones, Amon and Chapman, 2018).

MIDAS included much more than basic science. Industry partners provided links to the commercial sector so that opinion could be gathered on likely mining scenarios, and to enable determination of best practice in other sectors of offshore exploitation. Three MIDAS partner organisations were exploration licence holders for areas in the Clarion Clipperton Zone and the Mid-Atlantic Ridge, enabling the project to take a view from the perspective of the mining community. The combination of new scientific data with projected mining scenarios and accepted best practice enabled MIDAS to put forward an environmental management framework that could facilitate responsible mining whilst taking account of environmental concerns.

Among the greatest concerns raised by MIDAS in relation to deep-seabed mining were:

1. The loss of habitat and life-supporting substrates;
2. The impact of plumes of sediment dredged up from mining on species and habitat;
3. The exposure of seabed life to toxic metals released during mining operations; and
4. Whether mining will harm or sever genetic links between different populations of deep-sea animals.

Deep-seabed mining activities are also considered likely to cause to the following impacts on biodiversity and ecosystem services:

- Mortality of fauna and flora
- Habitat loss through removal or destruction, and modification through sediment, light and noise
- Habitat fragmentation
- Impacts to primary production in the water column and food webs
- Impacts to ecosystem function through disruption of key processes
- Alteration of large-scale cycles including carbon, nutrients and trace metals
- Toxicity

These effects can be intertwined: for example, habitat loss can lead to localised mortality of certain species or could even result in the extinction of entire populations, depending on the scale (Cuvelier *et al.*, 2019).

Sections 11.2.2 - 11.2.8 (below) summarise the general impacts that MIDAS found to be associated with deep-seabed mining.

11.2.2 Sound and noise impacts

The impacts of noise on deep-sea ecosystems is a bit of an unknown. There is undoubtedly constant, intermittent, background noise in the oceans. NOAA has deployed hydrophones to the deepest part of the ocean where constant noise was detected. The ambient sound field is dominated by the sound of earthquakes, both near and far, as well as ship propellers, whale calls and extreme weather events (e.g. typhoons). Further research is needed to better understand the impacts from additive noise generated by mining machinery. Establishing a baseline for ambient noise is needed to allow scientists to determine if noise levels in the ocean are growing and how this might affect marine animals, such as whales, dolphins, and fish that use sound to communicate, navigate, and feed. Impacts to noise on microbial species, microorganisms and the behaviour of megafauna is poorly understood.

11.2.3 Loss of habitat

11.2.3.1 Geological impacts

Some types and methods of deep-seabed mining may be comparable to land-based mining (e.g. mining of seafloor massive sulphides) yet the extraction of manganese nodules, cobalt crusts, rare earth elements and gas hydrates is likely to be significantly different to current mining practice. New environmental issues need to be considered, such as the large surface areas affected by nodule mining, the potential risk of submarine landslides through sediment destabilisation in gas hydrate extraction, or the release of toxic elements through oxidation of minerals during seafloor massive sulphide mining.

11.2.3.2 Physical alteration - removal of niche habitats in an ecosystem

Alteration of the topography, substrates and physical features of the seabed will change the flows and physical energy dynamics of the ocean at both a local and gross scale. This in turn will alter the suitability of niche habitats established over millennia enabling communities and ecosystems to evolve in seabed habitats. Removal of these habitats will disrupt or remove established communities changing the physical and chemical properties suitable to these organisms. Change in seabed characteristics could disrupt these ecosystems over evolutionary timescales.

We do not yet understand the scale and interdependence of the ocean’s physical flows on life forms but know they dictate the levels of biodiversity, where and what types of biodiverse communities are present and their life histories.

11.2.3.3 Loss of habitat of larger fauna across local and basin scale

Removal of benthic substrates during all deep-seabed mining will result in the loss of habitat of charismatic fauna, such as octopi, fish, larger crinoids and corals (Vanreusel *et al.*, 2016) that are found, for example, within manganese nodule areas in both the north and south Pacific (e.g. certain fish, crinoids, crustaceans), (Simon-Lledó *et al.*, 2019). Microbial organisms associated with these habitats will also be impacted. The implications of loss of habitat and associated biodiversity on the health, resilience and stability of ecosystem function are predicted to be significant (MIDAS and Shirshov, 2016).

11.2.3.4 Loss of Microbial life

Mining activities can upset the chemical energy supplies that fuel microbial life in these ecosystems, and how this can result in a disruption of the ecosystem services that microscopic life provides.

11.2.4 Loss of polymetallic nodules causes loss of biodiversity of abyssal epifauna

Nodule bearing areas have higher diversity and densities of epifaunal taxa compared to areas where nodules are absent (MIDAS and Shirshov, 2016). These findings have ramifications for the designation of potential preservation reference zones in the Clarion Clipperton Zone and should be incorporated into conservation management plans. The Joint Programme Initiative Oceans cruises and related MIDAS research highlighted the importance of nodules in maintaining epifaunal biodiversity in the Clarion Clipperton Zone (Gollner *et al.*, 2017).

11.2.5 The exposure of seabed life to toxic metals released during mining operations

11.2.5.1 Release of heavy metals

The mining of seafloor massive sulphides will expose ‘fresh’ sulphide mineral surfaces to seawater, resulting in the oxidation of these sulphides and the release of heavy metals into seawater. Laboratory experiments designed to quantify the rates of these processes under seafloor conditions demonstrated how rapidly metals such as iron, copper and zinc (the principle components of the sulphides studied) can be released into seawater. Reactions between different sulphide minerals result in the protection of pyrite and preferential dissolution of sphalerite and chalcopyrite (copper iron sulphides); the latter appears to continuously react and release copper into seawater, which has implications for ecosystem health through bio-accumulation and disruption to cell and organism health and function.

For polymetallic nodules and crusts, the effects are likely to be more subtle than for seafloor massive sulphide deposits, and it is not yet known whether there will be toxic effects from mining in these areas (Hauton *et al.*, 2017).

11.2.5.2 Metal toxicants

Metals released during deep-seabed mining will occur in different physical states. Metals may enter solution/aqueous phase and be taken up across the gills, body wall and digestive tracts of exposed animals. Alternatively, metals may adsorb onto sediment particles or flocculates and be ingested; this may be particularly the case for metals released during dewatering of the ore slurry.

11.2.5.3 Sub-lethal impacts of chronic exposure

Deep-seabed mining within a licence block will continue for years to decades, and organisms will be subject to chronic metal exposures that might be orders of magnitude lower than the lethal dose and at a considerable distance from the mined site. MIDAS (Gjerde *et al*, 2016) demonstrated that even shrimp that have evolved to live in the metal-rich environment of a hydrothermal vent field (*R. exoculata*) are sensitive to copper exposure in solution and induce detoxification pathways in response to metal exposure.

11.2.5.4 Potential toxic impacts of deep-seabed mining

Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process. The mining of seafloor massive sulphides or cobalt crusts will involve fragmented ore being pumped from the seafloor to the surface as a slurry. Whilst nodules may be collected whole, the transfer of nodules up the riser pipe will likely result in them also turning to slurry. Consequently, for all three ore types, there is a risk that the mining process will release metal ions into the water column, either in the benthic plume created by mining vehicles or, following dewatering on the surface vessel, in a mid-water plume. Such plumes can potentially travel over distances of hundreds to thousands of square kilometres (Grupe, Becker and Oebius, 2001), carrying potential toxicants with them. The mid-water plume may impact photosynthetic microalgae or animals within the water column.

MIDAS research has highlighted the impossibility of identifying robust toxicity limits for bathyal and abyssal marine organisms exposed to metals through deep-seabed mining. The complexity caused by the differential moderation of toxicity by temperature and pressure, the fact that mineral ores represent complex mixtures of metal ions in different oxidation states that will be differentially weathered, and the complexity of the biological communities concerned and their physiological states at the time of mining, means that any proposed ‘toxicity limits’ will be will be highly challenging for the above reasons.

11.2.5.5 Resource toxicity

It is impossible to apply current toxicological limits and thresholds from terrestrial or shallow water contexts to deep ocean environments, as pressure and temperature play a fundamental role in ocean chemistry and we are currently unable to determine the impacts thresholds for toxicity other than to say it will be increased.

A further issue with using existing toxicity data to regulate mining activity in the deep-sea is that many assessments of metal toxicity are based on a single metal presented at a single oxidation state. Mineral ores comprise complex mixtures of metals that are site-specific and will change with chemical weathering (Van Dover, 2014). It is therefore extremely difficult, or even impossible, to predict the exact toxic potential of a mineral deposit from laboratory studies on single metals, or even metal mixtures. Further work in this area is only likely to develop incremental insights of 'real world' toxicity of mineral resources. MIDAS argues that it will be necessary to assess the toxicity of individual mineral deposits independently to identify the potential toxic risk during mining. However, from a toxicological perspective, it may not be necessary to characterise the individual toxicity of each metal ion within each mineral deposit. It may only be necessary to determine – under controlled, ecologically relevant conditions – the bulk lethal toxicity of that ore deposit for a number of different biological proxy organisms in relevant physical phases (e.g. in solution/aqueous, as particulates, or adsorbed onto the surface of particulates). A similar approach could be adopted to determine the bulk lethal toxicity of any return waters from surface dewatering before any discharge into the ocean takes place (Hauton *et al.*, 2017).

11.2.6 The impact of plumes of sediment from mining on species and habitats

11.2.6.1 Smothering from sediment plumes in a dynamic environment

Plumes present perhaps the most significant potential source of environmental impact from deep-seabed mining. Impacts may arise from smothering by settling material from high particle concentrations within the water column, or from toxicity of plume material, but the thresholds at which these factors lead to significant impact are poorly known. Plumes essentially transport impacts from directly mined sites to adjoining areas in a manner that is shaped by the prevailing currents and turbulence of the overlying water column. Deep-sea flow environments are inherently complex and variable, so an understanding of the nature and variability of the flow environments that might be encountered by mining activities is essential to be able to predict plume behaviour within deep-sea environments.

The difficulty of adequately measuring plumes in such a challenging environment means that modelling approaches are needed. The plumes resulting from deep-seabed mining will not be apparent at the ocean surface, being capped by density stratification, and they will be difficult to meaningfully map in three dimensions in the deep-sea environment. So, accurate models that have been constructed with an understanding of the environment that they represent, and an appreciation of the limitations of their inherent assumptions, are vital tools for predicting and understanding plume impact. Hence the need to understand ocean currents and flows, and connectivity.

11.2.6.2 Impacts from sediments disbursed widely by currents and turbulence in the deep sea

Impacts from sediments can be transported huge distances from the source. In broad terms, the deep sea is a low energy environment with current speeds that are considerably slower than those nearer the ocean surface. Yet the deep sea may also be highly turbulent, because density stratification - which suppresses turbulence near the surface - is weak. Scales of variability are also short in the deep sea, and the complexity of seafloor topography drives complexity in the pattern of currents and turbulence. While topography provides a local influence on the flow environment of a site, remote influences are also important. However, there is generally low energy on the seabed and it is highly unlikely that sediments are resuspended, implying that the abyssal ecosystem is not adapted to smothering and therefore that impacts to the ecosystem would be incurred if sediments are mobilised by mining machinery.

Flows (current, eddies etc.) in the relatively flat abyssal nodule fields of the Clarion Clipperton Zone can show significant changes in near-bed current speeds and may be driven remotely by the passage of eddies generated thousands of kilometres away by winds blowing through gaps in the mountains of Central America (Aleynik *et al.*, 2017). One particular eddy has been traced over a period of 10 months from its formation to its detection by a mooring within the Clarion Clipperton Zone. A local model of the response to large-scale currents reveals that the scattered abyssal hills of the Clarion Clipperton Zone develop lee waves and turbulence downstream according to the current direction and strength, so the location and nature of these features moves around, with the level of turbulence increasing and declining according to eddy-induced variability. The environment encountered by mining operations can therefore be highly variable, reflecting both remote and local factors across a broad range of scales.

Flow in the mid-ocean ridge environments in which seafloor massive sulphide deposits are found are less well monitored or modelled.

11.2.6.3 Inaccuracies and vulnerabilities in modelling deep-sea plumes

Impacts from sediment can vary due to deposition rates and particle size, causing suffocation and smothering in some cases. Plume modelling within MIDAS showed the huge range of sediment particle settling speeds with larger particles settling very close to the site where they enter the water column whereas fine particles may disperse vast distances.

Measurements of actual particle plumes in the deep sea are few and sparse, so accurate models are important guides as to potential impacts. Modelling approaches must represent scales from metres to the extent of ocean basins.

The monitoring of plumes within the water column will reveal great patchiness and difficulty in clearly resolving the shape and extent of the plume.

11.2.7 Impacts on species connectivity

MIDAS identified three fundamental impacts relating to species integrity:

1. Fragmentation of the distribution of individual species (biogeography)
2. Genetic isolation of populations of a species (connectivity)
3. Impacts to the life history of species, particularly their reproduction and larval traits

Understanding the distribution of species at regional scales and the extent of gene flow among populations is key for the development of strategies for biodiversity conservation and sustainable management for seabed mineral (either seafloor massive sulphide or nodules) and gas hydrate extraction.

11.2.7.1 Fragmentation of species and populations

Deep-seabed mining can cause fragmentation of species and populations. However, our current level of knowledge of connectivity and biogeography is not sufficient to make accurate predictions of the consequences of deep-seabed mining, which may continue for many decades. One reason for this lack of knowledge is that very few deep-sea species are the subject of detailed connectivity work, which is usually done with population genetic approaches, though there are some good examples from vents and a Clarion Clipperton Zone sponge (Taboada *et al.*, 2018). These species are always common taxa, as lots of individuals are needed for population genetic work. These common taxa are the ones that you would expect to be widely distributed.

This lack of knowledge is compounded by the observation that the majority of species are only rarely sampled and it has been difficult to establish whether such species are genuinely rare and in danger of extinction or merely very widely distributed in low numbers and, therefore, at less risk.

Some species are widely distributed at scales of 100 kilometres to 1,000 kilometres. However, many species have not been collected in sufficient numbers or from across different areas, so we cannot say whether they will be impacted by mining activity.

11.2.7.2 Loss of connectivity

Deep-seabed mining may cause loss of connectivity between species, affecting the re-colonisation and recovery potential of areas that will be impacted by deep-seabed mining. Connectivity between populations describes the significance of the exchange of migrants between distinct populations. While the distribution of genetic variation among populations may indicate the long-term average dispersal rate over evolutionary time scales, it does not directly translate into demographic connectivity, which typically takes place over inter-annual or inter-generational time scales. Mining may impact the evolutionary history of each population and demographic connectivity through disturbance of the extent to which immigration and emigration contributes to the population dynamics.

Deep-seabed mining may impact connectivity due to evidence that there are very low numbers of migrants in some ecosystems and communities to homogenise genetic variability among populations which can result in decreased rates of recovery or recolonisation of impacted areas. Therefore, a precautionary approach to genetic estimates of connectivity must be considered. However, with such limited knowledge, general predictions on post-mining recolonisation and recovery are difficult.

11.2.7.3 Impacts to larval dispersion

The reproductive and larval biology of deep-sea species are likely to be impacted by deep-seabed mining due to loss of habitat, fragmentation from sediment plumes, changing ocean chemistry and environmental conditions.

11.2.7.4 Disturbance of reproduction and larval traits

Deep-seabed mining is likely to change ecological processes and environmental parameters with impacts on a range of reproductive and life history parameters such as: spawning time, spawning sites, feeding and prey environments, sex ratio, fecundity, reproductive success and resilience. Similarly, the impacts of changes to the physical and chemical environments as a result of deep-seabed mining may cause changes in the distribution and dispersion on larvae. Further investigation and robust modelling are needed to support environmental impact assessments.

Resilience of deep-sea animal communities facing impact from mining activities may largely depend on the capacity of new recruits to re-establish at impacted sites. Some vent species show periodic and seasonal reproduction, and produced planktotrophic larvae, whereas others (e.g. corals) exhibit continuous reproductive patterns. Such reproductive traits suggest high vulnerability of the studied species to potential disturbance. Some species have unbalanced sex ratios and therefore any small-scale damage to the population numbers may have large-scale impacts on the reproductive success of the community.

11.2.8 Impacts on ecosystem functioning

The potential impacts that deep-sea resource extraction may have on ecosystem functioning include:

1. Sediment burial on soft and hard substrate ecosystems.
2. Ecosystem stress through disturbance of food and energy flows through deep-sea ecosystems.
3. Ecosystem stress through changing the ocean chemistry through depletion of nutrients, and changes in nutrient flux rates, fundamental to physiological processes.
4. Loss of ecosystem function through physical alteration and removal of ecosystem niche habitats and connectivity.

11.2.8.1 Impacts of sediment burial on deep-sea ecosystem functions

Overall, MIDAS results show that deep-sea ecosystems continue to be impacted for decades after impacts occur and recover extremely slowly, even from small-scale disturbance events. Commercial-scale deep-seabed mining is therefore likely to significantly impact seafloor ecosystems over very long timescales.

Investigations of biogenic sediment compounds and meiofauna (animals between 32 and 300 microns in size) communities indicated a redistribution of labile organic matter and a decline in nematode abundance approximately one week after the disturbance, suggesting that even mild sediment disturbance can significantly alters deep-sea benthic ecosystem diversity and ecosystem function and recovery.

11.2.8.2 Disturbance of food and energy flows

The extraction of polymetallic nodules from the ocean floor can have important consequences for the structure and biodiversity of benthic food webs and key ecological processes (e.g. biomass production, organic matter cycling, nutrient regeneration). MIDAS scientists noted that 26 years after a small area of the seabed was disturbed during an experiment to simulate a mining operation, they could still measure adverse impacts to the habitat and adjacent areas, such as a decrease in abundance of some taxonomic groups. MIDAS experiments carried out in four exploration Contract areas in the Clarion Clipperton Zone (the German, InterOcean Metal, Belgian and French Contract areas) further showed that sediment disturbance reduced the food availability for benthic deep-sea heterotrophic consumers. Disturbance also led to a significant decrease of the benthic prokaryotic standing stock and the degradation and turnover rates of nitrogen-rich organic compounds (i.e. proteins, with potential cascade effects on biomass production and nitrogen cycling). Impacts caused by relatively small-scale disturbance on the abyssal seafloor (relative to the scale of commercial mining activities) were still detectable almost 40 years later (MIDAS 2017). It is therefore possible to conclude that the impact of deep-seabed mining will alter trophic conditions and the efficiency of microbial assemblages in exploiting organic matter for decades or more, and this will have important consequences on the functioning of the benthic food webs and biogeochemical processes over long-term timescales.

MIDAS also undertook an assessment of the long-term effects of mining-related sediment disturbance by investigating benthic biogeochemical processes in disturbance tracks created 26 years ago by the DISCOL (DIS-turbance and re-COL-onisation) experiment in the abyssal Peru basin. The data clearly indicate that benthic fluxes of oxygen (an integrated measure for seafloor metabolism) in the most severely disturbed parts of the study site are still reduced compared to undisturbed areas, 26 years after a relatively small-scale disturbance event. This matches sample-based observations of lower abundances and metabolic activities of microorganisms at these sites. These pioneering studies underline the potential of autonomous flux observations for ecosystem function monitoring in the context of deep-seabed mining.

11.2.8.3 Depletion of nutrients fundamental to physiological processes

The role of minerals in ecosystem function has been demonstrated above, including the fundamentals of basic cellular function for all life forms. Removal of minerals from the ocean will alter the ocean chemistry and this in turn may meaningfully alter the availability of these minerals to processes such as cell respiration, photosynthesis, nutrient transport and transfer systems in organisms, and maintaining a habitable stasis in the ocean that enables diversity of life. The maintenance of a healthy, functioning ocean is dependent on the ocean chemistry and the organisms (most of which are micro-organisms) that enable primary production or maintain ocean chemical balances that in turn enable complex life forms and ecosystems to thrive. Ocean ecosystem chemistry and function are also fundamental to the biological pump and the role of the ocean in regulating climate is correspondingly essential to maintaining planetary health (see also Section 6.2).

We do not yet understand the scale and interdependence of the ocean’s chemistry, and the precautionary principle needs to be applied.

Fundamentally, the scientific evidence suggests that the impacts of some types of deep-seabed mining may be extensive and irreversible, permanent and immitigable. After conducting experiments in areas of the Clarion Clipperton Zone to be mined for polymetallic nodules, MIDAS researchers concluded mining would affect seabed food webs and biochemical processes “over long-term timescales.”

11.3 Mining of polymetallic nodules: impacts and mitigation

11.3.1 Polymetallic nodules on abyssal plains

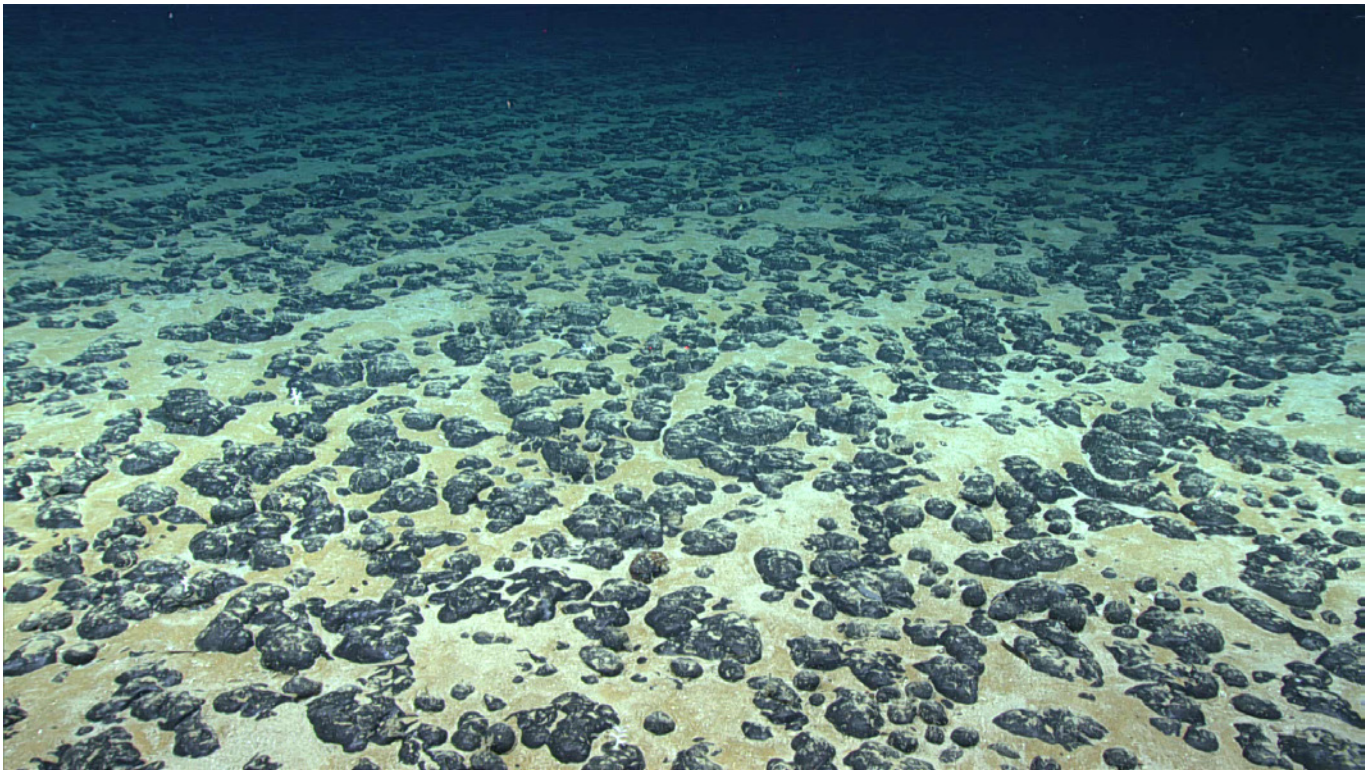
Polymetallic nodules are found predominantly on abyssal plains (Figure 39 and Figure 40). They are metallic concretions on the sea bottom which are formed of concentric layers of manganese and iron hydroxides around a core. Nodules nucleate on small bits of rock, bone, or old nodule fragments on the surface of sediments. Abyssal plains (see Section 5.6.2) and the polymetallic nodules they contain exert significant influence upon ocean carbon cycling, dissolution of calcium carbonate, and atmospheric carbon dioxide concentrations over time scales of hundreds to thousands of years (see Section 6.2).

Microbes on polymetallic nodules fix trace metals onto the nodules through processes that are newly described but still poorly understood, contrary or in addition to theories that diagenetic and hydrogenetic processes (how oil and coal are made) are responsible. This extraction of trace metals from the ocean environment is likely to stabilise ocean chemistry and maintain healthy oceanic conditions through balance of metal-based elements and reducing potentially toxic metal compounds.

Figure 39: Polymetallic nodule – cross section showing concentric rings of metallic compounds. Credit: NOAA 2018

Nodule growth is extremely slow (millimetre to centimetre accumulations per million years (Ku and Broecker, 1965; Bender, Ku and Broecker, 1966; Boltenkov, 2012), and surrounding pelagic sediments accumulate manganese at approximately similar rates as nodules (<5 cubic centimetres of manganese per 1,000 years (Bender, 1971). Nodules can acquire manganese from sediment pore waters or from the overlying water column. The growth mechanism is mediated by the redox state of overlying waters and, in some environments, growth can be supported by hydrothermal influence and may change throughout the growth history of the manganese nodule (Mewes *et al.*, 2014; Wegorzewski and Kuhn, 2014). Whether nodule growth proceeds purely abiotically, or is influenced by microbial activity or seeding is not currently known, although microbial communities have been detected in nodules (Tully and Heidelberg, 2013; Lindh *et al.*, 2017). Recent studies have also documented novel animal communities that are supported by nodule fields (Bluhm, Schriever and Thiel, 1995; Purser *et al.*, 2016; Vanreusel *et al.*, 2016; Peukert *et al.*, 2018).

Figure 40: Polymetallic nodules on the seabed, Clarion-Clipperton Fracture Zone. Credit NOAA, 2018



Taxa that live in sediments of the abyssal plain and manganese nodule beds are arguably at the low extremity of the disturbance-resilience context in the deep sea. At these depths, natural disturbances tend to be biogenic and subtle compared to those experienced at hydrothermal vents or when buffeted by complex hydrography of seamounts. Such disturbances include periodic pulses of phytodetritus deposition (Gooday, 2002), bioturbation (Smith *et al.*, 1998), boom-bust cycles of echinoderms (Billett *et al.*, 2010), and climatic (Salzman and Ruhl, 2007). In these low-disturbance, low-resilience regimes there is generally relatively low abundance, biomass, growth rates, and reproductive output of benthic invertebrates (McClain *et al.*, 2012).

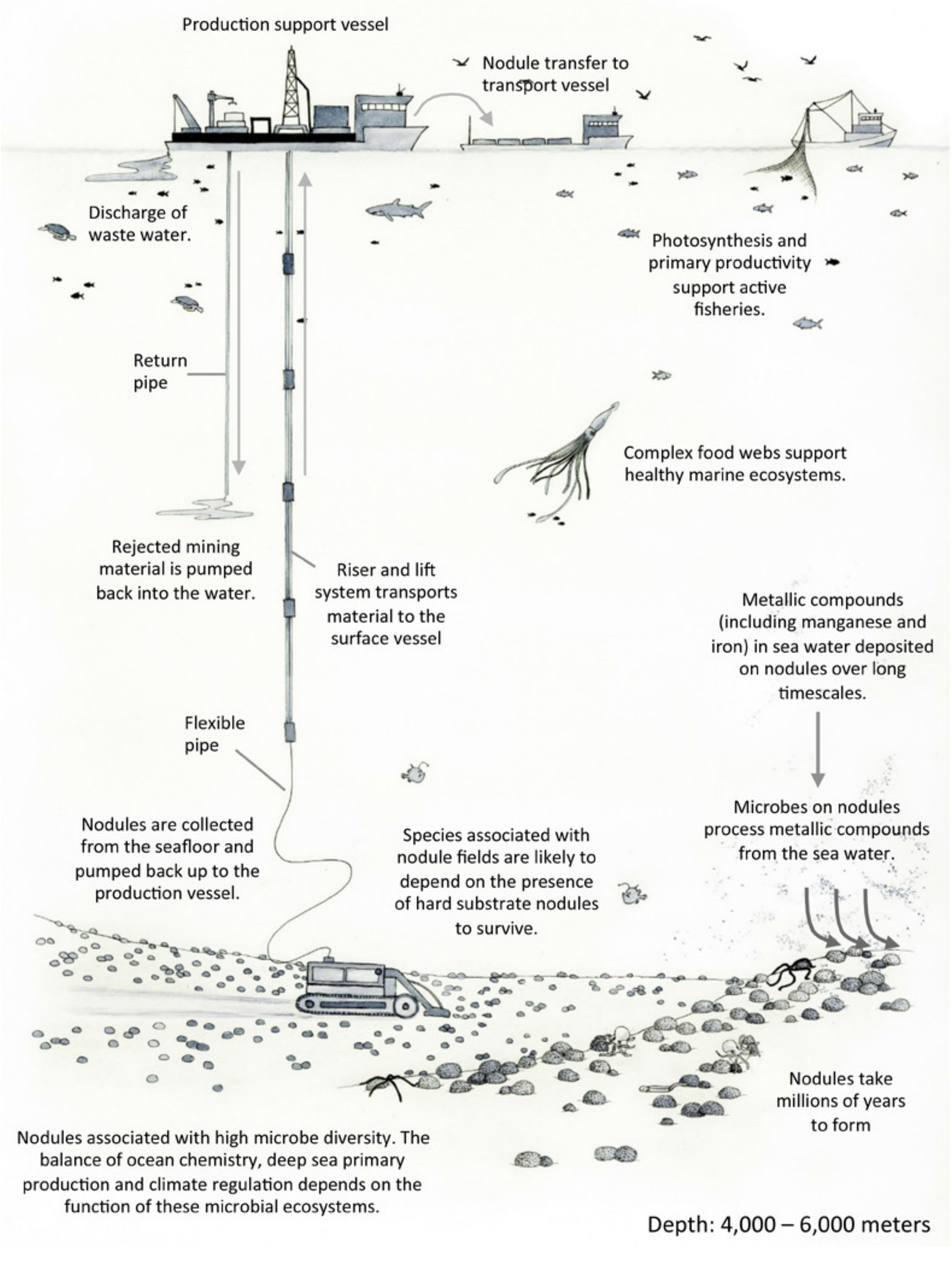
The elements most strongly enriched over abyssal polymetallic (ferromanganese) nodules include iron, cobalt, platinum, lead, arsenic, bismuth, bromine, vanadium, phosphorus, calcium, titanium, strontium, tellurium, and rare earth elements (REEs), whereas nodules are more enriched in copper, nickel, zinc, lithium, aluminium, potassium (only Pacific crusts), and cadmium.

11.3.2 Exploitation of polymetallic nodules

A planned mining system for polymetallic nodules is likely to consist of a mining support vessel on the sea surface, a remotely operated nodule collector, a riser and lifting system, and a waste-water re-circulation system connected to the mining platform for the discharge of sediment, discharge water, and erode nodule (Thiel, 2001; Peukert *et al.*, 2018). A description of some of the most recent plans for nodule mining activities in the deep sea and more technical details are given, for example, in Volkmann and Lehnen (2017).

Several options have been proposed for nodule extraction with a combination of these different configurations. In the most basic case, nodules and the layer of the sediment collected from the seafloor are entrained with water into a semi-liquid and lifted on board a mining support vessel by a hydraulic transport pump system. The ore-containing slurry is de-watered and the residual sediment is pumped back to the sea. To minimise the dispersion of sediment plumes, the slurry could be discharged close to the ocean floor (Volkmann and Lehnen, 2017). To further avoid sediment dispersal, another technique under consideration has been designed to minimise sediment is by separating sediment and nodules on the seafloor without pumping the sediment to the surface. In this case, nodules would be extracted by a collector that sieves the upper layers of the sediment, separating nodules from the sediment and redepositing it on the seafloor. Nodules may then be pumped up to a mining support vessel to be dewatered, the remaining water then being returned to the sea (Weaver and Billett, 2018). In certain designs, the system would not include a riser for pumping nodules to the mining support vessel. While other collector types may cause different types of specific disturbance to the seafloor, similar configurations and pressures on the environment may be expected. The extraction techniques for deep and shallow seabed are schematically illustrated in Figure 41.

Figure 41: Mining of polymetallic (ferromanganese) nodules on abyssal plains. Illustration not to scale.
Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

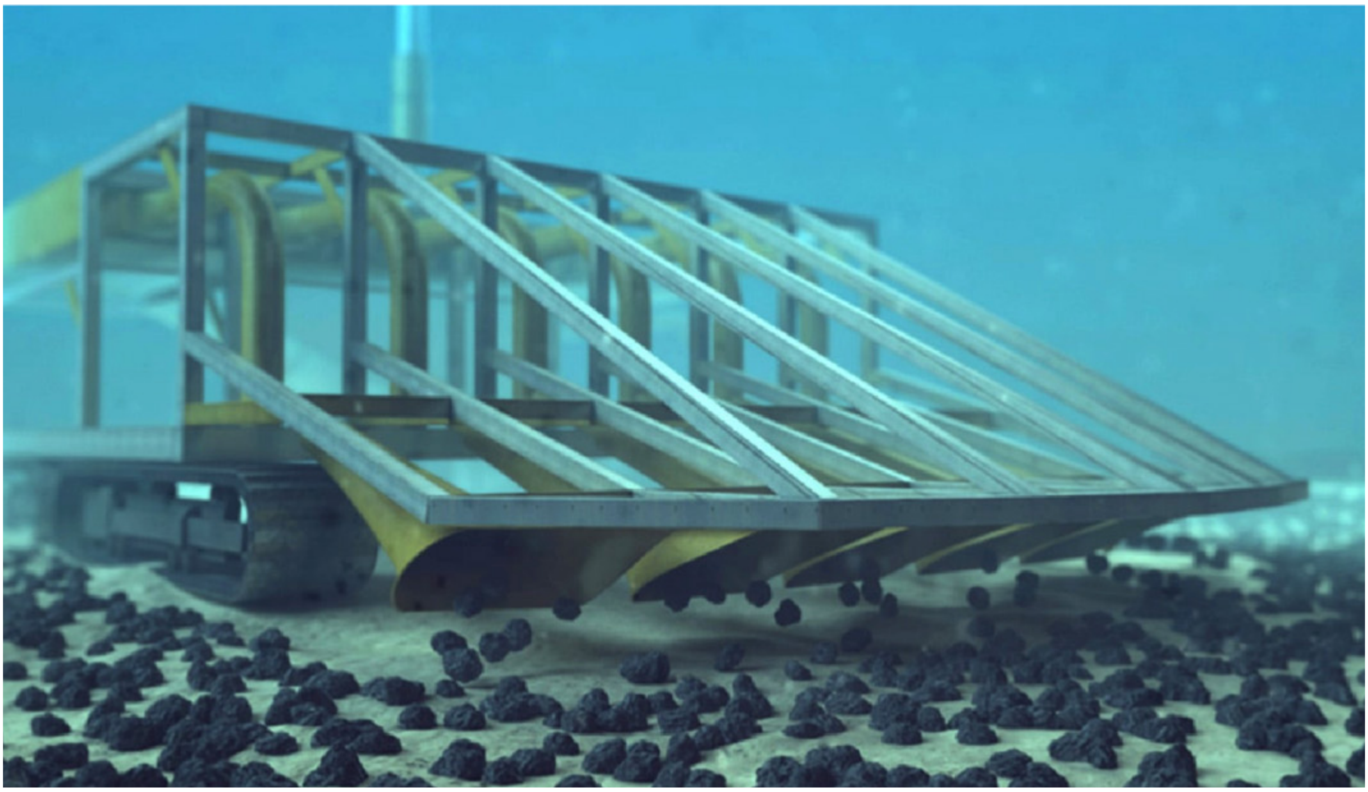
11.3.2.1 A proposed engineering system for nodule mining

As recently as 2012, an engineering system for the recovery of seabed nodules has been proposed and assessed for its feasibility based on conditions in the Clarion Clipperton Zone (Santo *et al.*, 2013). The integrated system they proposed is comprised of individual subsystems determined to be the most efficient and best performing. The system starts with a production support vessel, which is the source of the power supply for the entire mining operation, and serves as the platform by which the mining operations are controlled. The production support vessel is connected to one or more mining collection systems, which collects nodules from the seabed. Nodules are transported up the riser to the production support vessel where they undergo several pre-processing steps. Water from the pre-processing steps is transported back down the riser to be discharged near the seafloor. The pre-processed nodules are transferred to a shuttle barge which takes them to a processing facility.

The primary task of the collector is to lift and collect the nodules and aid in their movement upward from the seafloor. Each collector unit has several components that determine its overall efficiency in collecting nodules from the seafloor. For the purposes of the proposed system, the study recommends the use of a hybrid collector with a crawler propulsion system. The hybrid collector combines both mechanical and hydraulic components and has several advantages:

- A more effective technique for separating nodules from sediment.
- A hydraulic lift that involves zero contact with the seafloor while extracting nodules, thus minimising the amount of suspended sediment.
- A crawler subsystem that has a lower penetration depth into the soft sediment.

Figure 42: A rendering of the machinery that might be used to harvest polymetallic nodules. Credit: DeepGreen Metals.



Vertical transport of nodules: directly above the collector units is a "black-box" buffer system that pre-processes the nodules prior to transport up a vertical riser. The black box cleans sediments from the nodules using the wastewater from the pre-processing on-board the production support vessel. This reduces the mass concentration of sediments to less than 2% from the initial intake of 20% (Fletcher *et al.*, 2012). It also allows sediments and nutrient rich water to be discharged at depth, minimising the potential for adverse environmental impacts. After cleaning, the nodules are transported to the production support vessel via a riser system. Nodules are dewatered and the wastewater from the production support vessel is transported back down the riser to the black box. The design of the riser system is based on technology currently employed in the oil and gas industry known as a fully enclosed riser and lifting system.

Surface operations: before transferring the nodules to the shuttle barge, they are dewatered and dried. This process allows for nodule sampling to test for metal concentrations, returns excess water, and reduces the total weight of the nodules. Once this process is complete, the dry nodules would be transferred to the shuttle barge and transported to the closest coastal port with a processing facility.

Onshore processing: many nations with interest in mining polymetallic nodules lack the ability to process them. For example, the Cook Islands currently lack the infrastructure (power, water, roads, etc.) necessary to support an onshore processing facility. However, several stakeholders in the Cook Islands expressed interested in understanding the potential costs and benefits if a deep-seabed mining company were to invest in a processing facility on the Island. No commercial scale processing has yet been developed and is therefore not dealt with in this report.

BOX 24
Deepgreen: Case study

Deepgreen focus on polymetallic nodules – rationale given: (1) nodules sit unattached on the ocean floor in the area of the South Pacific international waters known as the Clarion-Clipperton Zone, which means they can be collected without the need for destructive rock cutting required for mining seafloor massive sulphides and cobalt crusts; (2) nodules are high grade and do not contain toxic levels of heavy elements, and the metal contents of the nodules is uniquely aligned with the base metal needs of Electro-voltaic battery manufacturers; (3) the Clarion-Clipperton Zone nodule resource alone contains enough metals to electrify the global Electro-voltaic fleet several times over (Paulikas *et al.*, 2019).

Deepgreen states:
"The apparent lack of plant life on the seafloor in the Clarion-Clipperton Zone suggests that nodule-removal techniques could be developed to encourage mobile forms of life on the ocean floor to relocate, such as through the use of strategic strobe lighting (for one hypothetical example). This might be a useful area of research to consider for minimising biodiversity loss to even further improve the indicated scenario of several magnitudes of species lower than land, with no plant life likely to be damaged."

Deepgreen acknowledges that it is difficult to say with certainty that biodiversity and species impacts from deep-sea nodule collection would be less significant than those observed and measured on land. This uncertainty is exacerbated by two assumptions. First, while it is likely that the number of species is more limited in the deep-sea plateau where nodule collection would occur, much remains unknown with regard to the number and type of species that live in or depend on this ecosystem, and where a majority of sea-based animals more generally remain unidentified. https://deep.green/.

Deepgreen acknowledges there will be impacts through the removal of nodules and creation of sediments, however there is no consideration of the implication on biogeochemical systems and ocean function.

11.3.3 Risks and impacts of mining polymetallic nodules on abyssal plains

Nodule exploitation and removal results in physical actions such as scouring, smothering, burial and compaction. Unfortunately, we know little about the specific effects of these drivers in deep-sea ecosystems, especially in low energy systems areas with potentially low sedimentation rates, such as the abyssal plains. That said, several large-scale experiments undertaken to mimic the potential impacts of mining and monitor recovery in abyssal nodule fields (Box 25) provide important insight into the possible effects of mining polymetallic nodules in abyssal plains.

Some of the likely impacts of nodule mining are illustrated in Figure 43 and include:

- Disruption to deep-sea sediment environments that have evolved over millennia and could take the same length of time for the physical structure of the habitat to recover to pre-disturbance conditions. It is not known over what time scales biotic recovery would occur.
- Re-suspension of sediments (Thiel *et al.*, 1993), potentially altering the ecosystem service of carbon sequestration (low impact however, as volumes are low and slow).
- Long-lasting impacts on the geochemistry of the underlying sediment (Paul *et al.*, 2018).
- The capacity for metal sequestration via scavenging onto nodules will be substantially limited during the recovery period.
- Nodule regrowth may also be limited by both the geochemical and microbiological changes following mining-related disturbances. For example, thermodynamic and kinetic constraints limit the oxidation of reduced manganese to oxidized manganese by oxygen (Luther, 2010). The interplay between sediment geochemistry and nodule microbial community structure remains poorly understood. Removal of nodules and sediment will decrease the ecosystem services associated with this habitat through the destruction of paleo-scientific records, a valuable educational aspect of this environment.
    - Marine sediment cores are an immensely valuable resource for reconstructing climate conditions over the Earth's history. Plant and animal fossils found in sediments are frequently used to reconstruct and understand the past chemistry and temperature of the ocean.
    - Marine sediment and nodules serve as a valuable resource for reconstructing past climate conditions as well as understanding and predicting future climate change.
- Impacts to biogeochemical cycling and ecological functioning are not understood and require further investigation
- Loss of habitat and associated microorganisms: microbial communities associated with nodules can likely use metals as an energy source and carry adaptations to tolerate the high heavy metal concentrations, potentially playing a role in metal cycling in oceans. The implications of their loss for trace metal cycles are not understood.
- Adverse impacts for crustal microorganisms that have demonstrated the ability to immobilize cobalt from seawater, release trace metals like nickel, and may also be capable of scavenging other metals (Krishnan *et al.*, 2007; Antony *et al.*, 2011). These traits are of interest for biotechnological applications, or applications that involve metal/microbe interactions such as bioremediation of polluted sites, bioleaching, and metal recovery.

Potential cumulative impacts:

- Regional losses of brood stock, genetic diversity, species, trophic interactions and complexity
- Loss of resilience
- Changes in community structure
- Genetic isolation
- Species extinctions
- Species invasions

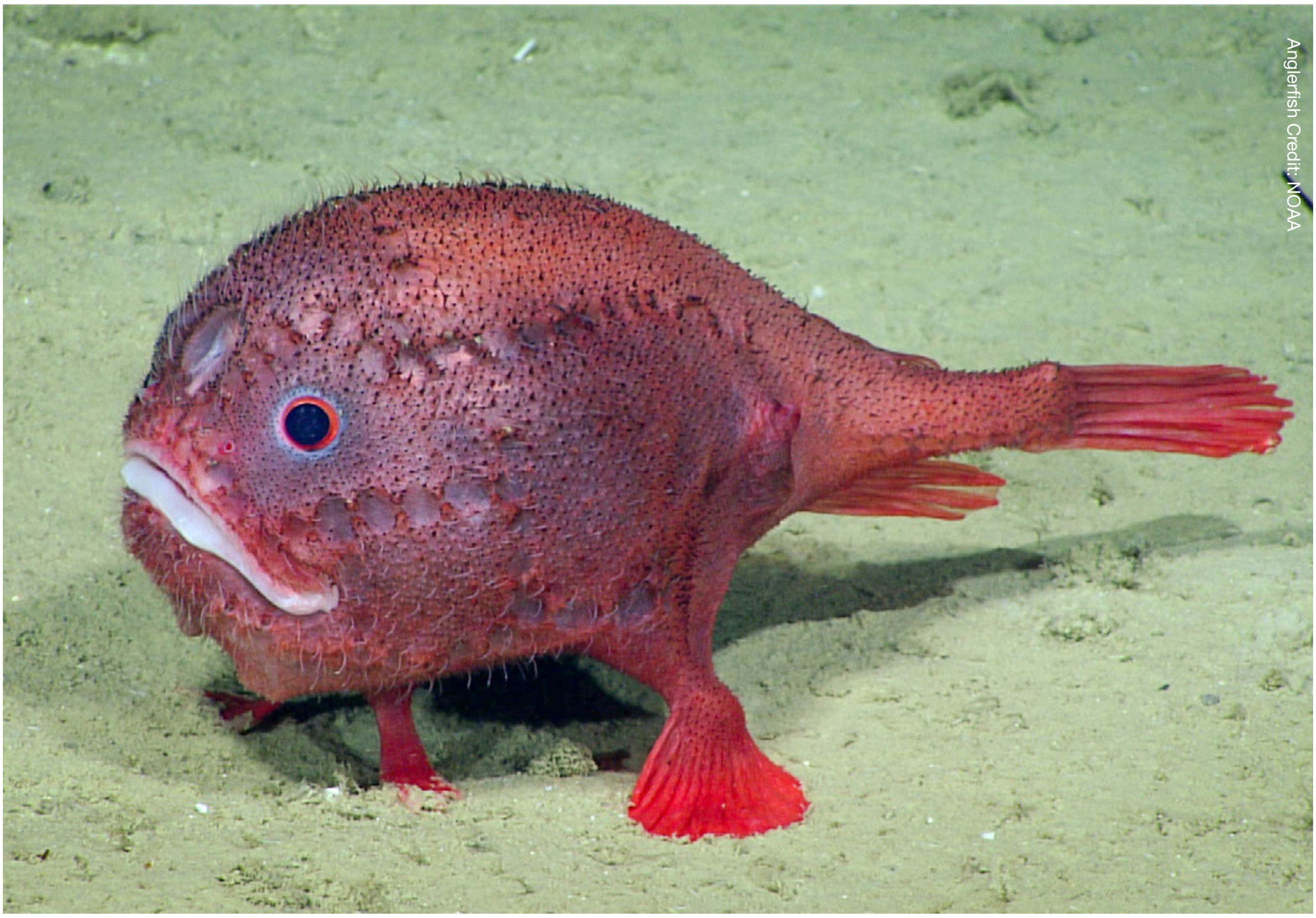
Cumulative impacts need to be assessed, mitigated and managed. Of particular concern is the impact of cumulative mining events in a region, with potential for species extinctions and unanticipated changes in ecosystem structure and function if the extractive activities are not appropriately.

A more detailed assessment of potential risks and impacts of mining polymetallic nodules is provided in Table 11.

BOX 25

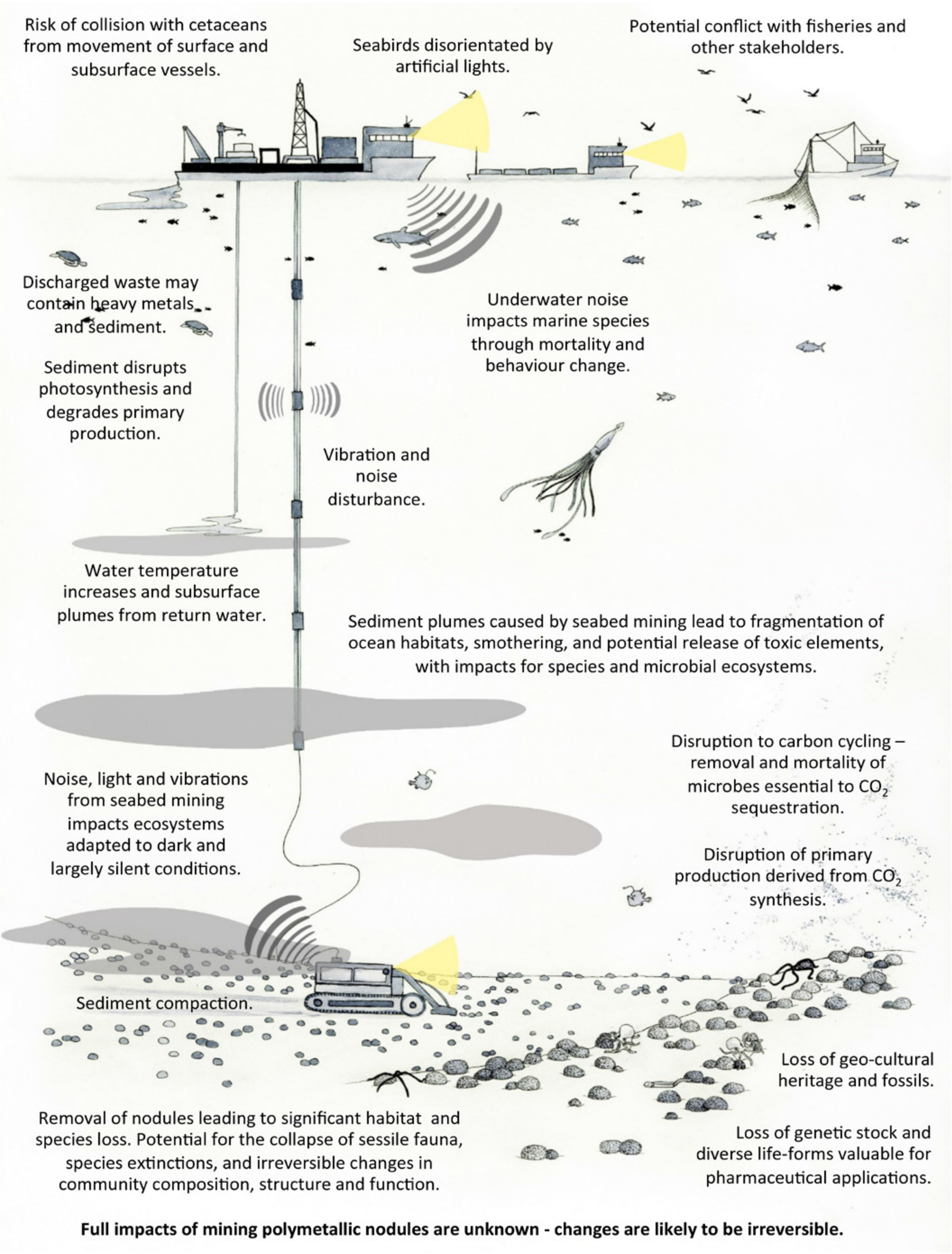
Effects of polymetallic nodule mining upon the biodiversity of the abyssal plain

Several large-scale experiments have been undertaken to mimic the potential impacts of mining, and to monitor recovery in abyssal nodule fields, the first of these being in 1970. These experiments typically show that it takes decades before there are signs of recovery of deep-sea ecosystems, and if faunal abundance does eventually recover, the species that colonise can be different to those that were originally there (Mullineaux *et al.*, 2012). Jones *et al* (2017) evaluated the changes in faunal densities from multiple experiments and found the effects are usually severe immediately after mining, with major negative changes in density and diversity of most faunal groups. At seven sites in the Pacific, multiple surveys over 26 years revealed recovery in faunal diversity for meiofauna (animals between 32 and 300 microns in size) and mobile megafauna even within one year. However, very few faunal groups had returned to baseline or control conditions after two decades. This indicates the impacts of mining of polymetallic nodules upon fauna are likely to be long-term.



Anglerfish Credit: NOAA

Figure 43 : Risks and impacts of mining of polymetallic (ferromanganese) nodules. Illustration not to scale.
Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

11.3.4 Applying the mitigation hierarchy

Mitigations relating to the mining of polymetallic nodules in the deep sea are summarised below and a full assessment of preventative mitigations is presented in Table 11.

11.3.4.1 Avoidance

- Avoidance is the first and most important step in the mitigation hierarchy.
- Avoidance of biodiversity and ecosystem services impacts can be achieved at a project scale through careful screening of key fishery areas and high biodiversity areas, including protected areas, to ensure operations do not overlap.
- Use baseline studies to identify set-aside areas with representative biodiversity and ecosystem services and geomorphological features to mining areas.
- Uncontrolled releases of liquid and solid waste are avoided through strict recycling and waste handling procedures both onboard vessels and at ports.
- Use stripwise mining to create alternate strips of mined and unmined seabed to improve rates of recolonisation of benthic fauna.
- A proposal for the protection of Areas of Particular Environmental Interest (APEIs) for manganese nodule beds under the jurisdiction of the International Seabed Authority has been put forward in the past (Wedding *et al.*, 2013).

11.3.4.2 Minimisation

- Stopping mining when large numbers of target organisms are detected at the primary screening stage
- Using the latest mining technology to ensure full resource extraction to minimise the need for re-mining an area.
- Returning sediments to the seabed mining location.
- Screening sediments for harmful compounds prior to return to the seabed.
- Applying best practice thresholds for noise at surface and in the water column.
- Designing and developing seabed collector machines to minimise sediment disturbance while collecting polymetallic nodules.
- Separate nodules from sediments as close as possible to the seabed to minimise water column impacts from sediment plume.

11.3.4.3 Restoration and offsetting

- Ecological recovery and restoration following removal of polymetallic nodules is tenuous.
- No active restoration nor offsetting are considered to be possible. See Section 13.4.2 for further details.

Table 11: Impacts to biodiversity and ecosystem services for polymetallic nodules and suitable mitigations, with further opportunities for research / experimentation identified

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is approved should be a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	Low	T				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities of eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T				Minimise	Establish effective recycling programs and find alternative technologies that reduce, or eliminate, the use of supply constrained metals

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration (cont.)	Use of ROVs for sampling (cont.)	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	L	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	Low	P		Low	T	Minimise	Minimse sampling area
			Permanent alteration of the benthic geomorphology	Low	P				Minimise	Use directional lighting; only use lighting where and when necessary
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Loss of ecosystem function through occulsion and smothering of benthos	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Low	T	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P				Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Disruption of th Biological (carbon and nutrient) pump of the oceans	Low	P				Minimise	Minimise lifting of sediments near the seafloor
	Removal of polymetallic nodule samples	Removal of substrates	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Low	P	Avoid	Avoid areas of high biodiversity
			Removal of species associated with polymetallic formation (high species diversity)	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	P	Minimise	Use machinery and technology designed to Best Practice Standards to reduce the impacts of nodule removal
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown				Minimise	Sample with minimum viable sample size
									Minimise	Ensure Scientific study to establish the formation of and relevance of the micro-organisms of polymetallic nodules
Resource Development	Use of Large Extractive Machinery designed to be mobile of seabed	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is approved should be a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	Establishing MPAs before exploration and exploitation is approved should be a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Noise (cont.)	Disturbance to benthic species resulting in species range restrictions	High	PD				Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to bird species resulting in species range restrictions	High	PD				Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
									Avoid	Exploitation contracts should not be issued until MPA networks are implemented
									Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected aeas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities of eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Understand the total area that will be affected including the total water volume (3D)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Integrated Approach - take into account stressors such as ocean acidification, climate change and pollution. Such an approach could help to avoid fragmented, inconsistent approaches to regulating activities in different regions, though some level of systematic and permanent damage to ecosystems would be unavoidable.
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	Avoid areas of high biodiversity
			Disturbance to benthic species resulting in species range restrictions	High	PD				Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance from support ship to bird species resulting in species range restrictions	High	PD				Minimise	Only use lighting where necessary
		Loss or modification to benthic habitat	Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Avoid areas of high biodiversity

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Loss of habitat of benthic fauna	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Habitat loss and the modification of seabed morphology, physiological disturbance to organisms, and changes in the intra- and interspecific competition patterns affecting food web structures	High	P	Disruption of the ocean biological pump	High	P	Minimise	Minimise lifting of sediments near the seafloor
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999).	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	High	P				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge. Surface water discharge can be sprayed over a large area to ensure dilution
			The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008).	Unknown	Unknown				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column Surface water discharge can be sprayed over a large area to ensure dilution
			Changes in faunal distribution	Unknown	Unknown				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Changes in benthic species composition and an increase in opportunistic species resulting from mineral extraction can also benefit certain demersal fish as food becomes more abundant (de Jong *et al.*, 2014).	Unknown	Unknown				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			Decrease in abundance of meiobenthos	Unknown	Unknown				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Increased plume dispersion during high flow periods may influence larval dispersal, while low-flow regimes with lower spreading rates and greater blanketing may adversely affect abundance and diversity.	Unknown	Unknown				Restore	The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008). *
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	Unknown	Unknown				Restore	Communities in naturally high-energy areas with exposure to currents or waves are more adept at readjusting to the impacts of mineral extraction than more stable communities
			Extraction of material from the seabed changes the composition of the sediments	Unknown	Unknown				Restore	In the absence of primary production, the resource limited deep-sea communities have a lower abundance and are reliant on the phytodetrital nutrient supply from the surface (Smith *et al.*, 2008).
			The release of sulfides during sediment disturbance	Unknown	Unknown				Restore	Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks.
			Mineral extraction activities that cause topographical changes on the seabed may modify its biogeochemical processes.	Unknown	Unknown				Restore	Natural restoration through sediment settlement results in recolonisation over impacted areas
			Large pits and borrow holes created when using a suction dredger in shallow areas may trap organic matter, enriching the sediment and increasing the oxygen consumption as the organic matter decomposes	Unknown	Unknown				Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through 'set aside' areas, used exclusively as "impact reference zones" and "preservation references zones" as stipulated by the ISA (International Seabed Authority, 2010)
			the potential for trace-metal bioaccumulation	Unknown	Unknown				Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
			Disruption of th Biological (carbon and nutrient) pump of the oceans	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community **

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	Suspended loads will travel laterally over vast distances causing clogging of fliter feeding appartus of benthic organisms in the area.	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Loss of ecosystem function through occulsion and smothering of benthos	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P	Avoid	Apply the Precautionary Principle - avoid impacts as with limited information on the physiology of deep-sea organisms, it is currently not possible to estimate the toxic impacts from metal release from the mined material on deep-sea species (Hauton *et al.*, 2017).
			Addition of bottom sediments to the surface resulting in change in the marine ecosystem	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	High	P				Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Smothering or entombment of the benthic fauna away from the site of nodule removal where sediment plume settles (if and when). Even low levels of sediment redeposition may be destructive to certain benthic organisms as increased solids in the water may smother or clog their feeding organs or gills (Ellis *et al.*, 2002), especially harming filter-feeding organisms such as mussels and other bivalves (Mestre *et al.*, 2017).	High	P				Minimise	Minimise lifting of sediments near the seafloor

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	Clogging of suspenstion feeders and dilution of deposit-feeders foor resources	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Generation of turbidity in the water column over large areas affecting pelagic organisms. Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	Low	PD				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			Suspended solids and increased sedimentation as a result of harvesting the sediment may cause significant reduction in light availability (Kirk, 1977), leading to the reduced vitality or death of aquatic macrophytes (Riul *et al.*, 2008).	High	P				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	High	P				Minimise	Surface water discharge can be sprayed over a large area to ensure dilution
			Decrease in abundance of meiobentho	High	P				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	High	P				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			The release of sulfides during sediment disturbance	High	P				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			Suspended particulate matter and toxic substances from the sediment plume can potentially harm the eggs and larvae (Auld and Schubel, 1978; Partridge and Michael, 2010)	High	P				Minimise	Minimise sediment return to water column [†]
			Dispersal is dependent on the stratification of the water column and the depth of the surface mixing layer. Sharp pycnoclines reduce vertical mixing and promote the horizontal dispersion of suspended particulate matter (Ellis, 2001).	High	P				Minimise	Mitigation strategies should aim at reducing the concentration, size and toxicity of particles in sediment plumes associated with various mining activities
			The debris and sediment in the water column cause occlusion and potential habitat fragmentation (screens)	High	P				Minimise	Reducing the concentration, size and toxicity of particles in sediment plumes can be achieved through modifications to mining equipment or procedures.
			Increased nutrient concentrations in the water column due to sediment resuspension (Klump and Martens, 1981; Lohrer and Wetz, 2003) may result in phytoplankton blooms	High	P				Minimise	Design the suction/retrieval mouth of the seafloor mining tool for minimal escape of suspended material during exploitation

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									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	In oligotrophic waters, the intrusion of nutrient rich bottom water and sediment may drastically increase primary production (Hyun *et al.*, 1998).	High	P					No mitigation action identified currently
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High	P					No mitigation action identified currently
		Reduction of biomass around disturbance area	Loss of biodiversity and changes to the marine ecosystem and foodwebs with potential consequences to fisheries, ocean health and function and the biological (carbon and nutrient) pump	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Avoid areas of high biodiversity
									Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through ‘set aside’ areas, used exclusively as “impact reference zones” and “preservation references zones” as stipulated by the ISA (International Seabed Authority, 2010)
									Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
									Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community ††
		Mobilisation and removal from oceans of key geochemical nutrients	The potential for trace-metal bioaccumulation	High	P					No mitigation action identified currently
			Suspended loads will remain over very long periods	High	P					No mitigation action identified currently
			Disruption of the Biological (carbon and nutrient) pump of the oceans	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigation action identified currently
		Changes in the physic-chemical conditions around disturbance area	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigation action identified currently
						Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigation action identified currently
			The release of sulfides during sediment disturbance	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P		No mitigation action identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Changes in the physic-chemical conditions around disturbance area	The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigation action identified currently
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	Unknown	Unknown					No mitigation action identified currently
		Removal of polymetallic nodules as substrates	Changes in environmental conditions may alter metal partitioning and bioavailability (Calmano *et al.*, 1993; Cantwell *et al.*, 2002).	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigation action identified currently
			For every tonne of Mn nodule mined 2.5-5.5 tonnes of sediment with be resuspended ~ 40,000 metric tonnes per day sedminet disturbed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigation action identified currently
		Estimate disturbance of 300-600km2 per year through mining for 1.5-3 million metric tonnes of nodules per year	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Unknown	Unknown	Loss of ecosystem function	High	P		No mitigation action identified currently
			Removal of species associated with polymetallic formation (high species diversity)	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigation action identified currently
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigation action identified currently
			Mining process will release metal ions into the water column, either in the benthic plume created by mining vehicles or, following dewatering on the surface vessel, in a mid-water plume	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigation action identified currently
		Nodules may be collected whole, the transfer of nodules up the riser pipe will likely result in them also turning to slurry requiring processing at surface	Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process.	Unknown	Unknown					No mitigation action identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Nodules may be collected whole, the transfer of nodules up the riser pipe will likely result in them also turning to slurry requiring processing at surface (cont.)	Sediment dispersion changes both the chemical properties of the water and the seafloor sediment composition (Newell *et al.*, 1999; Desprez *et al.*, 2009)	Unknown	Unknown					No mitigation action identified currently
		Deposition of sediments near surface following processing	Introduction of debris and sediment in the water column	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never deposit sediment at surface
			Considerable quantities of organic contaminants and heavy metals may be released from the seabed sediments when they are disturbed (Latimer *et al.*, 1999).	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigation action identified currently
			Increased turbidity causes occlusion and reduced availability of sunlight photsynthesis causing long term effects on biological productivity	Medium	T	Disruption to fishery through reduction of fish populations	Medium	Unknown		No mitigation action identified currently
			The potential for trace-metal bioaccumulation	Medium	P					No mitigation action identified currently
			Reduction in primary productivity due to shading of phytoplanton	Medium	T					No mitigation action identified currently
			Impacts on marine mammal behaviour	Medium	T					No mitigation action identified currently
		Introduction of bottom water at the surface	Introduction of bottom water with its higher nutrient values could result in artificial upwelling increasing the surface productivity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never introduce or deposit bottom water at surface
			Ecological disturbances and imbalances through dissolution of heavy metals (Cu and Pb) within the oxygen minimum zone	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigation action identified currently
		Discharge of tailings and effluent below the oxygen-minium zone	May cause some environmental harm to pelagic fauna	Unknown	Unknown	Disruption to fishery through reduction of fish populations	Unknown	Unknown	Avoid	Never discharge of tailings and effluent below the oxygen-minium zone
			Mortality and change in species composition of zooplankton	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown		No mitigation action identified currently
			Effects on meso- and bathypelagic fishes and other nekton	Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Unknown	Unknown		No mitigation action identified currently
			Impacts on deep diving marine mammals	Unknown	Unknown	Disruption of the ocean biological pump	Unknown	Unknown		No mitigation action identified currently
			Impacts to bacterioplankton	Unknown	Unknown					No mitigation action identified currently
			Depletion of oxygen by bacterial growth on suspended particles	Unknown	Unknown					No mitigation action identified currently
			Effects on fish behaviour and mortality caused by sediments or trace metals	Unknown	Unknown					No mitigation action identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport		Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to bird species resulting in species range restrictions	High	PD					No mitigation action identified currently
		Light	Impacts of light on biodiversity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Medium	T	Disruption to fishery through reduction of fish populations	Low	Low	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Medium	T		Low	Low	Minimise	Use directional lighting
			Disturbance from support ship to bird species resulting in species range restrictions	Medium	T		Low	Low		
		Chemical Spills	The potential for trace-metal bioaccumulation	Medium	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T	Minimise	In the event of an incident, ensure application of best pracctive mitigation practices to ensure containment and remediation are expedited
			Impacts on marine mammals	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		
			Impacts and mortality of pelagic fish	Medium	T		Low	Low		
		Waste Disposal	May cause some environmental harm to pelagic fauna	Medium	T	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Mortality and change in species composition of zooplankton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T		
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		
			Effects on meso- and bathypelagic fishes and other nekton	Medium	T					

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport (cont.)		Waste Disposal (cont.)	Impacts on marine mammals	Medium	T				Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Depletion of oxygen by bacterial growth on suspended particles	Medium	T					
			Effects on fish behaviour and mortality caused by sediments or trace metals	Medium	T					
Mine Closure and Decommissioning	Abandonment of machinery on seabed	Machinery and infrastructure left on seabed	The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	Medium	P				Avoid	Ensure machinery does not degrade in deep seabed envrionments
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	Medium	P				Avoid	Ensure materials used do not leach toxic substances over time
			Alteration of habitats and substrate (niche for biodiversity)	Medium	P				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
	Removal of seabed mining infrastructure	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
			Disturbance to bird species resulting in species range restrictions	Low	T					No mitigation action identified currently
		Light	Impacts of light on biodiversity	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T					No mitigation action identified currently
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T					No mitigation action identified currently

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Mine Closure and Decommissioning	Removal of seabed mining infrastructure	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Loss of habitat of benthic fauna	Low	P	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Minimise lifting of sediments near the seafloor
			Permanent alteration of the benthic geomorphology	Low	P					
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Minimise	Minimise Sediment penetration
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P	Disruption to fishery through reduction of fish populations (mortality)	Low	T	Minimise	Minimise lifting of sediments near the seafloor

[*] The original community structure may not be able to recover due to habitat loss as a result of substrate alteration (Desprez, 2000).

[**] Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

[†] Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.

[††] Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

11.3.5 Key gaps relating to polymetallic nodule mining

There is a lack of systematic monitoring of experiments and baseline conditions at high resolution over relevant temporal and spatial scales, limiting the power of detecting changes resulting from simulated mining.

- In a low energy system it is not known how long the recovery of the physical structure of the habitat would take to recover to pre-disturbance conditions. Likewise, it is not known over what time scales biotic recovery would occur.
- The interplay between sediment geochemistry and nodule microbial community structure remains poorly understood.
- The impact to biogeochemical cycling and ecological functioning is not understood and requires further investigation.
- Pelagic biota are not well known, so impacts to pelagic biota are not well understood.
- The impact of light and noise upon deep water pelagic and benthic fauna is currently not known. Research is needed to understand the physiological and behavioural implications of operational lighting upon biodiversity and ecosystem services.

11.4 Mining of active hydrothermal vents: impacts and mitigation

11.4.1 Hydrothermal vent systems (active and inactive)

This section investigates the mining of active hydrothermal vents, i.e. those that are producing water at temperatures up to 400°C, heated by volcanic activity, and with its associated chemosynthetic communities (see also Section 5.6.5). We go on to assess mining of inactive hydrothermal vents, which are composed of deposited polymetallic sulphides and a very different biological community, in Section 11.5.

A hydrothermal vent is a fissure on the seafloor that releases geothermally heated water, like a hot spring on land. Hydrothermal vents are found at between 1,000 and 4,000 metres depth and are characterised by water temperatures up to 400°C and high acidity (pH 2–3). On contact with cold, oxygenated seawater, the minerals in those hot fluids precipitate to build spire-like deposits called vent chimneys, and sometimes produce a black smoke of suspended particles that rises and disperses above the vents. This characteristic gives them the nickname ‘black smoker’. Such vents are usually associated with volcanic activity such as mid-ocean ridges or hot spots in the crust.

Deep-sea vents usually occur in fields, each of which is a collection of vent chimneys clustered together in a relatively small area. Vent fields vary in size: some are just a couple of hundred metres across, while at others the vent chimneys can be spread over several kilometres (Copley, 2014b). Vent fields are usually discrete features which are separated from each other on the seafloor by relatively large distances (from tens to hundreds of kilometres) where there is no vent activity at all. Vents are usually associated with mid-ocean ridges but can also be associated with volcanoes, forming rings several kilometres long called ‘back arcs’.

Hydrothermal vents do not remain active forever. Depending on their geological setting, some vent fields may only be active for a few decades, before their fluid flow shuts down, for example if the area is smothered by lava flows from nearby undersea volcanoes, or if the plumbing beneath the vent field is disrupted by earthquake activity (Copley, 2014b). In other circumstances, a vent field can remain active for thousands of years and go through cycles of being active and inactive in this time span.

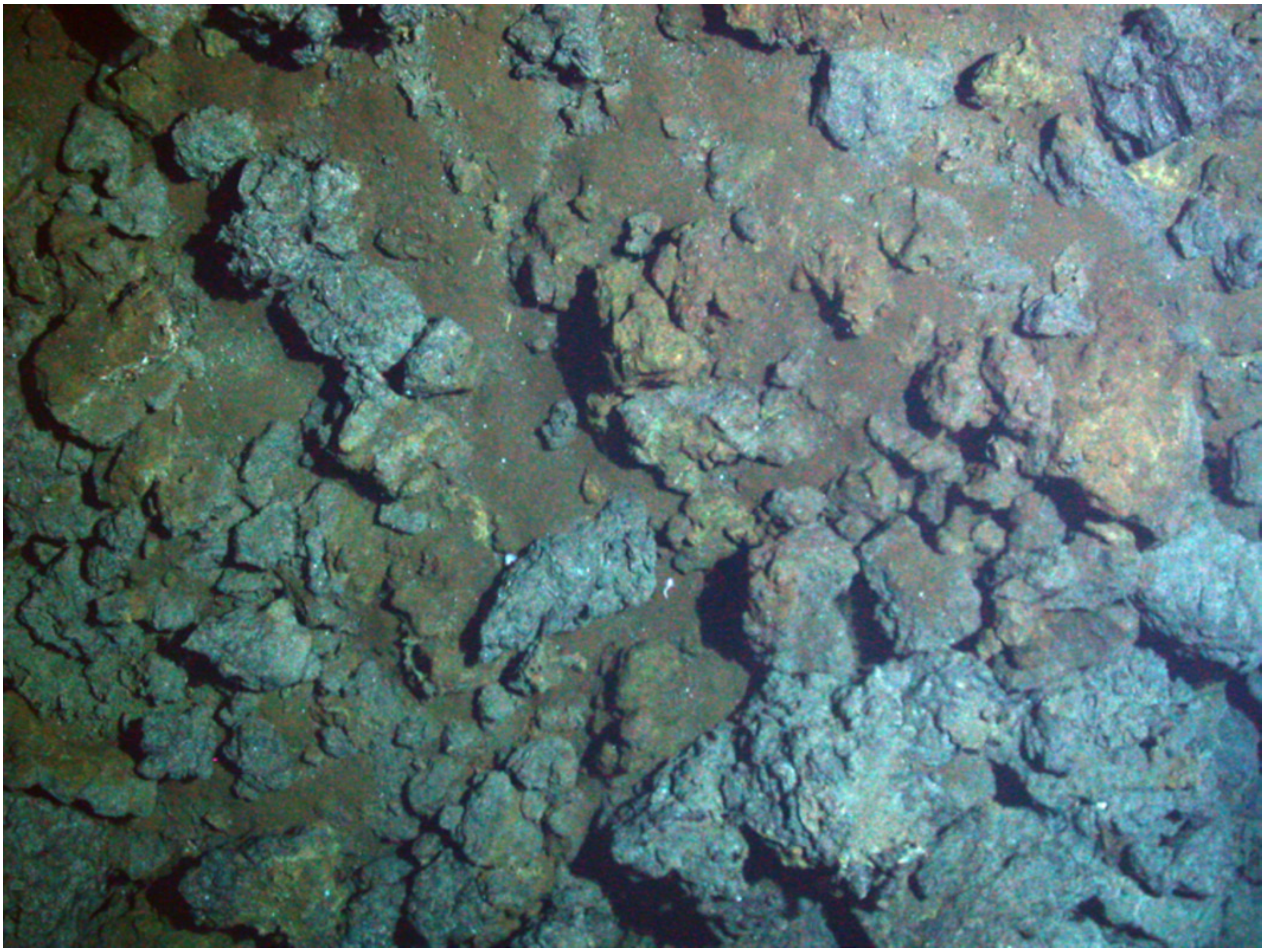
Despite their extremes of temperature and acidity, hydrothermal vents support vast communities of organisms (Ramirez-Llodra, Shank and German, 2007). Chemosynthetic bacteria form the basis of vent ecosystems, and in turn support a large biomass of invertebrates that include molluscs, annelid tube-dwelling worms, and crustaceans (Van Dover *et al.*, 2002).

The faunal communities are characterised by high biomass, low diversity and rapid growth rates (Van Dover, 2000). Faunal composition of vents includes familiar creatures such as fish, shrimp, mussels, and snails, as well as stalked barnacles (first described in 2018), yeti crabs (2015), with their characteristic blonde, furry hair, scaly footed snails (2015) which have only recently been discovered and which armour their soft interior with an iron shell. This species is the first deep-sea animal to be declared endangered because of the threat of mining (Nugent, 2019). The fauna of inactive sites is less well-studied but is likely to comprise suspension-feeding and grazing invertebrates (e.g. corals, sponges, echinoderms) that may also be found on seamounts and other rocky outcrops (Van Dover, 2011).

11.4.2 Exploitation of polymetallic sulphide deposits at hydrothermal vents

Hydrothermal vents are of interest to the seabed mining industry owing to the polymetallic sulphide deposits they create (Figure 44 and Figure 45), which are usually rich in copper and zinc as well as silver, gold, manganese and cobalt. Currently the extreme environments associated with mining active vents means that mining companies are currently focusing their attentions upon inactive vents.

Figure 44: Mineral precipitates on a hydrothermal vent. Credit: Nautilus Minerals



Mining of seafloor massive sulphide deposits will require massive large-scale excavation and removal of substrate, namely the chimneys and the associated rubble around them (Figure 46). Technologies currently proposed for extraction of mineral deposits at hydrothermal vents involve bulk removal of minerals akin to an underwater equivalent of terrestrial open-cast mining. One proposed method is mechanical cutting and slurry transportation of ore through a riser system to a support vessel and a return water pipe (see Box 27) which returns the seawater separated from the ore after removal of particles greater than 8 millimetres (Systems, 2008), to 25 - 50 metres above the deep-seafloor (Niner *et al.*, 2018).

Other concepts for commercial mining of vent systems under consideration include a ‘grab’ system (removal and transport of mineral deposits in a grab to a surface vessel), magnetic separation at the seabed, and solution mining or bio-leaching (Scott, 2007). The impacts of mineral extraction remain theoretical in the absence of a pilot mining operation or experiment although some aspects can be estimated based on other seafloor operations such as dredging, trenching and mining of marine-based diamonds. There continues to be uncertainty about whether mineral extraction will be undertaken at active hydrothermal vent ecosystems (Hein, no date) particularly given that high temperature and caustic characteristics of vent fluids associated with vigorously active black smokers may be incompatible with extraction technologies (Yamazaki, 2011).

Figure 45: Vent urashima chimneys. Credit: NOAA

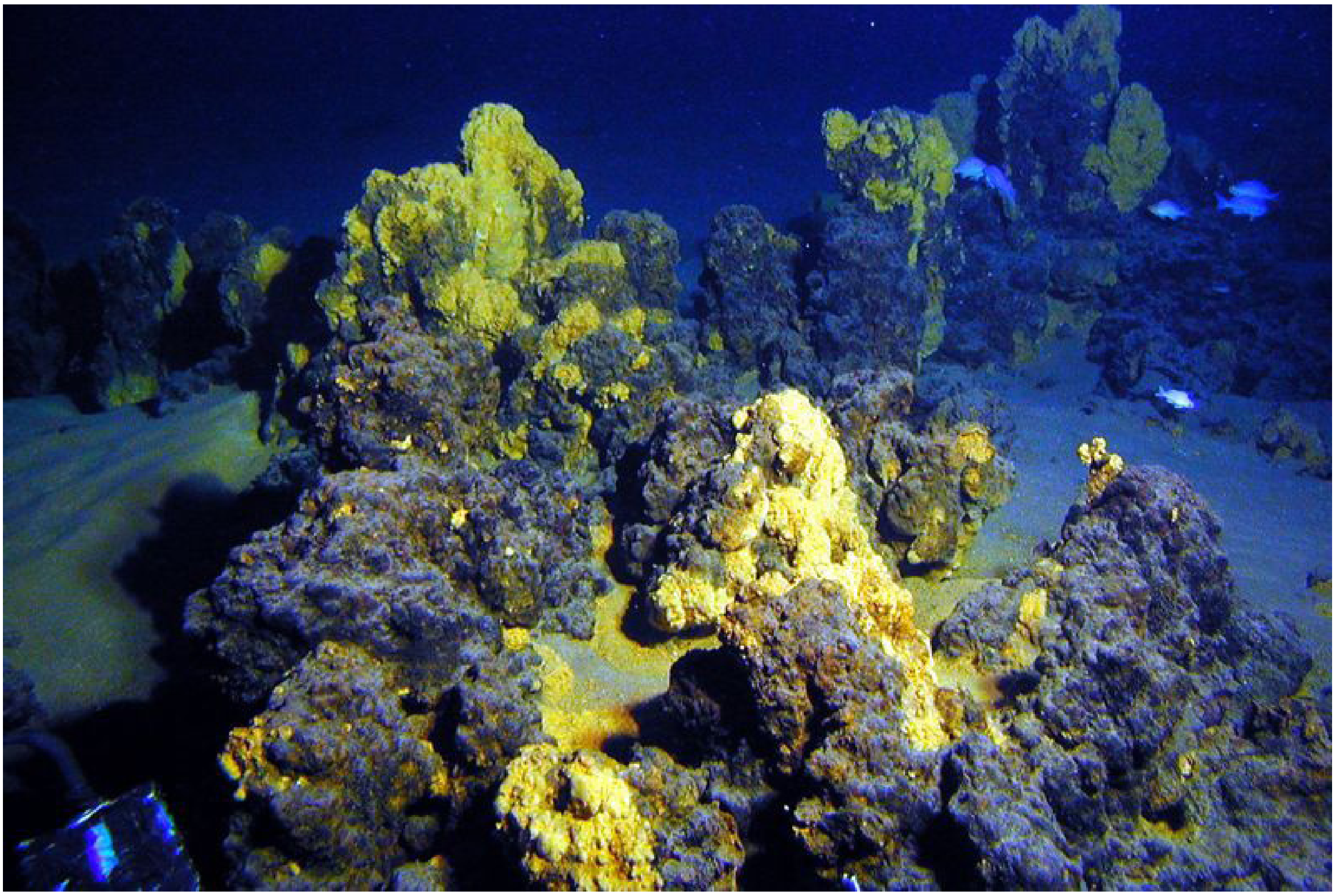
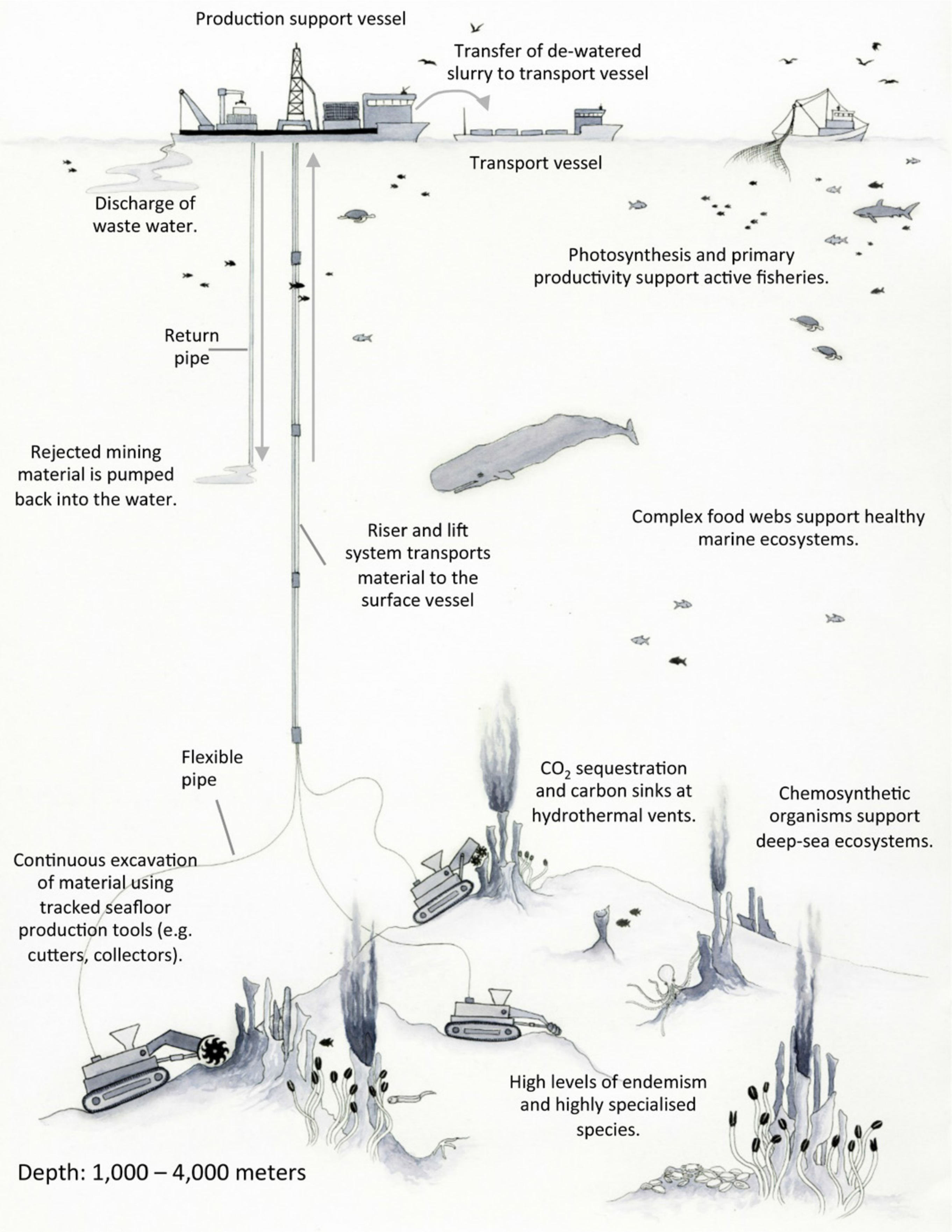


Figure 46: Mining of seafloor massive sulphides on active and inactive hydrothermal vents.
Illustration not to scale. Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

BOX 26

Nautilus minerals and seafloor massive sulphides mining approach (Nautilus Minerals Technology, no date)

Nautilus Minerals is making use of proven technologies from the offshore oil and gas industries, dredging and onshore mining industries to develop deep-seafloor resource production tools. Their system has three main components: 1) seafloor production tools, 2) riser and lifting system, and 3) the production support vessel.

There are three seafloor production tools: the auxiliary cutter, the bulk cutter and the collecting machine. Rock is disaggregated on the seafloor by the auxiliary cutter and the bulk cutter (see photographs below). They excavate material by a continuous cutting process, similar to continuous mining machines used in terrestrial coal mines. The auxiliary cutter is a preparatory machine that deals with rough terrain and creates benches for the other machines to work. It will operate on tracks and has a boom mounted cutting head for flexibility. The second machine, the bulk cutter, has higher cutting capacity but will be limited to working benches created by the auxiliary cutter. Both these machines will leave cut material on the seafloor to be collected by the collecting machine. The collecting machine will collect the cut material (sand, gravel, silt) by drawing it in as seawater slurry with internal pumps and pushing it through a flexible pipe to the Riser and Lifting System.

Auxiliary Cutter Bulk Cutter Collecting Machine

Photographs credit: Nautilus Minerals
http://www.nautilusminerals.com/irm/content/seafloor-production-tools.aspx?RID=333

The riser and lifting system is designed to lift the mineralised material to the production support vessel using a subsea slurry lift pump and a vertical riser system. The seawater/rock is delivered into the lift pump at the base of the riser, where it is pumped to the surface vessel via the riser which is suspended from the production support vessel.

The production support vessel provides a stable platform for operations using state-of-the-art dynamic positioning technologies to ensure it stays on location irrespective of wind and wave conditions. The vessel will be designed for use in offshore construction and seafloor mining and be equipped with a moonpool through which the subsea slurry and lift pump and riser system can be deployed. On deck, the slurry is dewatered. The dewatered solid material is stored temporarily in the production support vessel's hull, and then discharged to a transportation vessel every 5 to 7 days. Filtered seawater is pumped back to the seafloor through the riser pipes and provides hydraulic power to operate the lift pump. Discharge of the return water at the seafloor from where it came eliminates mixing of the water column and minimises the environmental impact of the operation.

The production support vessel is currently under construction. When completed, the vessel will measure 227 metres in length and 40 metres in width with accommodation for up to 180 people and generate approximately 31MW of power.

11.4.3 Risks and impacts of extraction operations at active hydrothermal vents

Hydrothermal vents are dynamic systems characterised by periods of activity and inactivity and occasional eruptions. It is possible these natural disturbances may mimic some impacts associated with mining (Gollner, Kaiser, Menzel, Jones, Brown, C. Mestre, *et al.*, 2017), and that species found there will be adapted to a certain level of disturbance. However, the only experiments on the impacts seabed mining upon fauna indicated significant long-term impacts to fauna density and diversity (Jones *et al.*, 2017).

Potential impacts of a mineral extraction activity on a hydrothermal-vent ecosystems are illustrated in Figure 47 and fall into two broad categories: causal physico-chemical (pH, temperature, chemical conditions) changes and biological response or consequence. These conditions relate to the environmental parameters defining life-forms and ecological processes at hydrothermal vents, and are summarised below and expanded upon in Table 12. Potential cumulative impacts are highlighted below also.

Causal physico-chemical changes:

- Loss or modification of benthic habitat through removal of ore and associated organisms, leading to faunal mortality, reduction in available habitat, modification and fragmentation of habitat
- Degradation of habitat quality (altered topography, substrata) through reshaping of the seabed
- Modification of fluid flux regimes (flow rates, distribution, chemistry)

The intensity of impacts relating to habitat loss and degradation and modification of fluid flux regimes is expected to be major at the site scale.

- Removal of energy source through clogging, leading to faunal mortality and potential local extinction of species
- Mobilisation of sediment plumes which are different to natural composition and extent: while vent ecosystems are naturally exposed to fallout of minerals from black-smoker plumes and possibly from plumes of nearby volcanoes, the intensity of sediment plumes generated during mining activities may be in considerably in excess of natural exposures at the local scale during certain phases of operations.
- Sediment deposition, causing disruption to and smothering of benthic fauna
- Likely minor to moderate impacts may result from pumping water from near the seabed at vents where larvae of vent invertebrates tend to be most concentrated.
- Light disturbance, affecting faunal behaviour (e.g. in vent fish and other mobile organisms that may avoid or be attracted to light) and potentially causing damage to optic sensors of some species.
- High levels of noise at the seabed, potentially leading to physical and behavioural impacts (e.g. vent fish and other mobile organisms that may avoid or be attracted to noise).

Some impacts associated with noise and/or light may be minor (likely short-term).

Biological impacts resulting from mining activities:

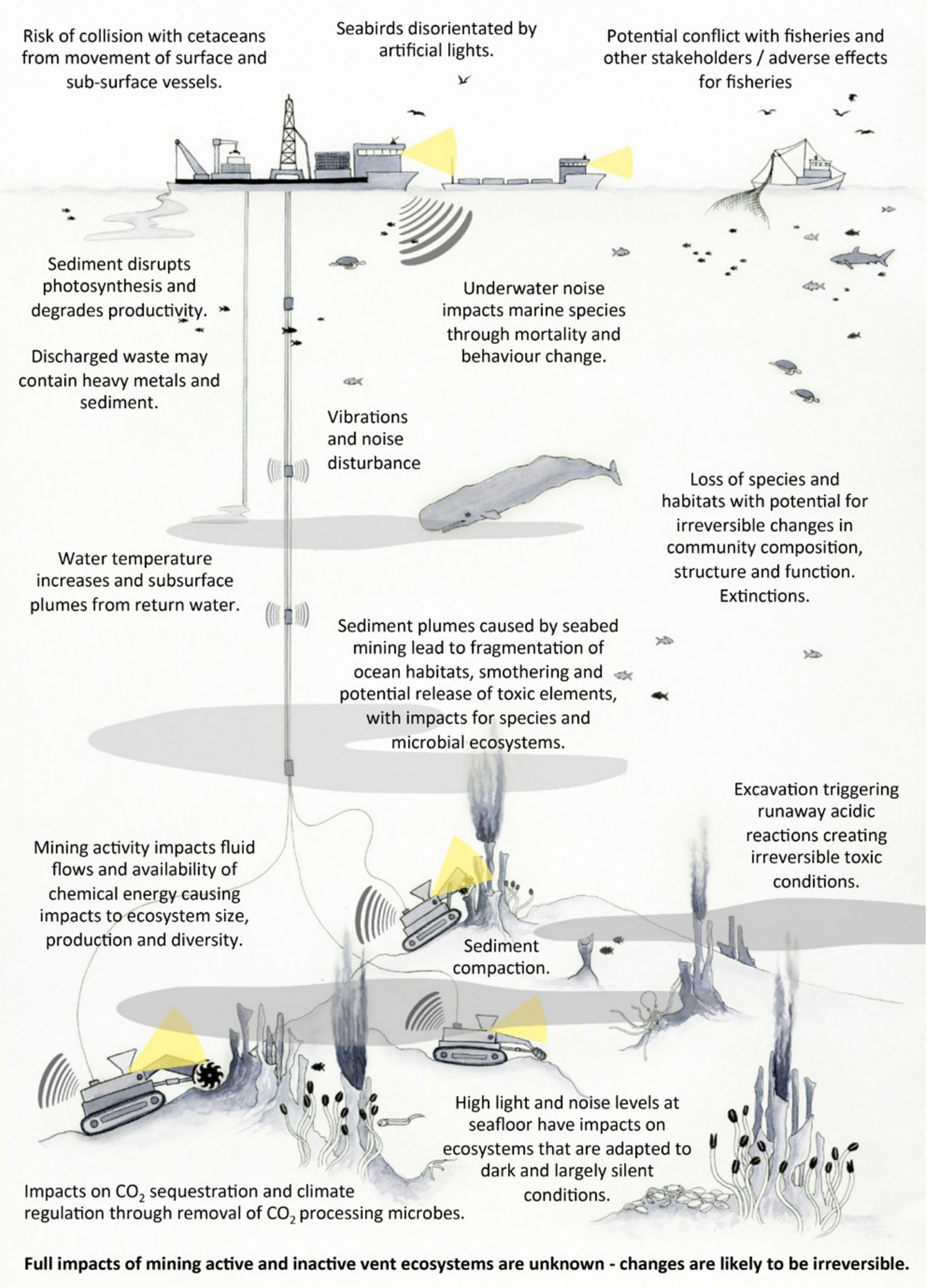
- Elimination or reduction of local populations, particularly where ore and organisms are removed together, and decreased reproductive output
- Loss of larvae/zooplankton in lift system
- Local, regional or global extinction of rare species
- Decreased seafloor primary production
- Modification of trophic interactions
- Decreased local diversity (genetic, species, habitat)
- Altered behaviours

Potential cumulative impacts:

- Regional losses of brood stock, genetic diversity, species, trophic interactions and complexity
- Loss of resilience
- Changes in community structure
- Genetic isolation
- Species extinctions
- Species invasions

Cumulative impacts need to be assessed, mitigated and managed. Of particular concern is the impact of cumulative mining events in a region, with potential for species extinctions and unanticipated changes in ecosystem structure and function if the extractive activities are not appropriately managed.

Figure 47: Impacts of mining seafloor massive sulphides on hydrothermal vents. Illustration not to scale.
Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



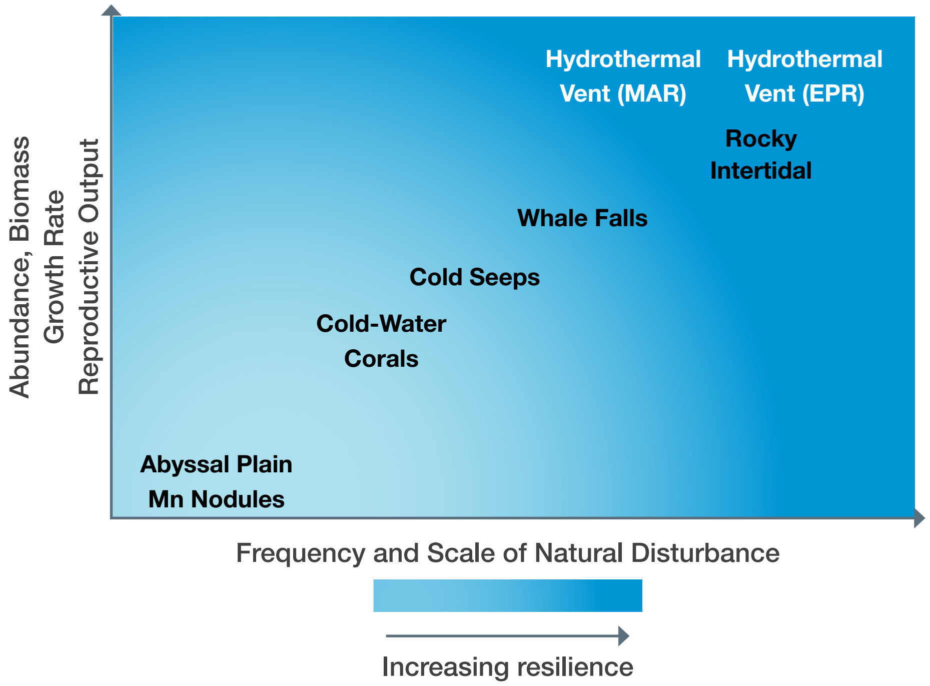
Credit: Nicky Jenner/FFI

Unlike other polymetallic formations in the deep sea, vents are exposed to frequent and sometimes locally catastrophic natural disturbances.

Changes in fluid flow resulting from seismic activity could have many biological consequences, including mortality of taxa intolerant of the altered thermochemical conditions and enhanced growth, reproduction, and recruitment of taxa adapted to the altered conditions. Tectonic events may also generate plumes of suspended sediments that might cause burial of organisms, clog filtering mechanisms of suspension-feeding invertebrates, or otherwise interfere with biological activity (Binns and Dekker, 1998), but such an event and its consequences are so far not documented.

The frequency of such disturbances varies: vents on slow-spreading centres such as the Mid-Atlantic Ridge experience less frequent volcanic eruptions than those on fast-spreading centres like the East Pacific Rise. This characteristic of vent ecosystems, means that vent taxa have ecological attributes consistent with higher levels of resilience: high abundance, biomass, growth rates, reproductive output (Figure 48). This further has implications for the likely impacts of mining activities on hydrothermal vent ecosystems and their potential for recovery.

Figure 48: Hydrothermal vent ecosystems in an ecological (e.G. Abundance, biomass, growth rate, reproductive output), disturbance (likelihood and spatiotemporal scale) and resilience framework. (Van Dover, 2014). Hydrothermal vents from two locations are represented: Mid-Atlantic Ridge (MAR) and East Pacific Rise (EPR).



Once an impact has occurred, recovery of a vent ecosystem is dependent on both immigration of mobile species and successful colonization by larvae (Adams, Arellano and Govenar, 2012). In a region where there is only a single geographically constrained mining event, vent communities may re-establish within years, as they do following volcanic eruptions (Van Dover, 2011), although structure and function may differ from what existed prior to mining and a range of factors will influence the potential and speed of recovery.

Natural recovery from a single mining event depends on immigration and larval recruitment and colonisation.

The relative impact of mining activity on a vent ecosystem from the perspective of larval supply depends on the size of the local adult population that remains in the vicinity and continues to produce propagules, the degree of isolation of the site relative to larval dispersal capabilities, the degree of change in the geochemical and geophysical setting (Metaxas, 2011), and on the consequences of stochastic and deterministic processes related to succession and development of the vent community (see also Box 27).If extraction takes place at non-active, ‘old‘ vent systems, there is likely to be a different set of, potentially more deleterious, impacts based on our current understanding of ecological responses to disturbance (Van Dover, 2011).

BOX 27
Impacts of mining hydrothermal vents upon pelagic larvae

Most attention has been paid to benthic components of vent ecosystems in the face of mining activities, but most vent invertebrate species undergo a pelagic larval phase. Our understanding of the impacts of mineral extraction technologies on larval demographics and on re-colonisation dynamics and process is embryonic, but ensuring that there are adequate brood stocks and sources of larvae to support unassisted recovery of a vent site is a key mitigation approach (Mullineaux *et al.,* 2010).

Where larval retention occurs near natal sites, larval supply will be at least temporarily diminished following an eruption or other disturbance that removes benthic adult populations (Mullineaux *et al.,* 2010); larval supply is likely correlated with benthic population density (Metaxas, 2011).

Implications include:

- **Changes in substratum, fluid chemistry, and other vent properties concomitant with seabed eruptions and other massive disturbances can select for subsets of species with tolerances to the changed and changing conditions, at least temporarily changing the nature of the vent community (Mullineaux *et al.,* 2010).**
- **Temporal variability and stochasticity (Mullineaux *et al.,* 2010) in larval supply will influence post-disturbance colonization options and outcomes.**
- **Colonisation success by previously rare or absent species may be facilitated by natural or anthropogenic resets of the hydrothermal cycle that alter competitive interactions in the earliest stages of succession relative to established systems (Mullineaux *et al.,* 2010).**

11.4.3.1 Impacts to hydrothermal vent ecosystem function

- The vast majority of microbial biomass in hydrothermal systems probably resides in the porous subseafloor underlying the chimneys therefore mining activities risk removing the bulk of microbial biomass in areas where the habitable crustal area is thin:

  – Geological and geochemical heterogeneity of vent fields leads to localised differences in fluid and deposit chemistry (Fouquet *et al.*, 2010; German *et al.*, 2016), which translates to animal endemism and biodiverse animal populations (Van Dover, 2000; Tunnicliffe *et al.*, 2018).

  – Changes to hydrothermal venting chemistry or intensity could have repercussions on the types of microbial life that can exist, and therefore on the animals that can be supported.

  – Microbes inhabit nearly every niche associated with active hydrothermal systems including the rocks and fluids in the subsea floor, sulphide chimney walls and surfaces, and in animal assemblages as internal and external symbionts (Fischer *et al.*, 2007; Dubilier, Bergin and Lott, 2008; Schrenk, Brazelton and Lang, 2013).

- Mining activities will change the ocean chemistry and have consequential impact on ecological processes. A major disruption of the chemical conditions that permit microbial chemosynthesis could have devastating consequences for all animals in that ecosystem:

  – Diffuse fluids contain active microbial cells that are in one to two orders of magnitude greater abundance than that of the surrounding seawater (Huber, Norris and MacLeod, 2002; Meyer and Huber, 2014) with diverse metabolic capacities that affect global chemical cycling of carbon, nitrogen, iron, and sulphur (Mehta and Baross, 2007; Wankel *et al.*, 2011; Fortunato *et al.*, 2018).

  - The annual global production of biomass of chemosynthetic communities is estimated to reach 1.4 giga tonnes carbon, significantly influencing deep-sea chemical cycling (McNichol *et al.*, 2018). Thus, despite the small size of active vent fields, the rates of microbial primary productivity by microorganisms fuelled by chemosynthesis in active vent systems can rival that of coastal and open ocean photosynthetic systems, making them productivity hotspots in an otherwise energy-starved deep sea (McNichol *et al.*, 2018).
  - Disruption of the dominant base of the food web at these sites which supports abundant and diverse animal life at distinct "oases" on the seafloor. These microbial ecosystems comprise abundant standing stock of life that is diverse and highly productive, fuelled by the abundant chemical energy supplies in these active vent systems.

- Mining activities will cause loss of biodiversity, and of microbes in particular, on vent substrates which will have consequences for ecological patterns and processes and the productivity and food webs dependent on microbes:
  - Many microbes in hydrothermal ecosystems play essential roles for animals by providing cues for larvae to settle (O'Brien *et al.*, 2015).
  - The concentration of energy and nutrients in complex, microbially-created habitats with strong spatial gradients fosters the evolution of highly diverse microbial communities, making hydrothermal vent systems hotspots of microbial diversity on the seafloor (Campbell *et al.*, 2006; Schrenk, Huber and Edwards, 2010; Olins *et al.*, 2013; Meier *et al.*, 2017).

- Mining activities near active vents could disrupt the nature of fluid flow, and therefore the availability of chemical energy to these ecosystems, potentially causing a cascade effect on the size, production, and diversity of these ecosystems (Tunnicliffe *et al.*, 2018).

Anthropogenic activities are likely to interfere with the natural physico-chemical conditions conducive or deterrent to colonisation and succession of life at hydrothermal vents. We understand little about how to predict the strength and duration of such interference effects, but expect that changes in characters such as fluid chemistry, substratum texture, microtopography, and microbial biofilm regeneration resulting from mineral extraction activities may not differ quantitatively from changes in these characteristics that take place following a volcanic eruption or other circumstances that cause new vents to form, followed by rapid colonisation.

In other words, natural disruption occurs at hydrothermal vents. Human interference may have similar impacts, however the scale and frequency of such impact events is difficult to predict and the recovery of these systems is unknown.

Table 12: impacts to biodiversity and ecosystem services from polymetallic sulphide deposit mining at active hydrothermal vents and suitable mitigations, with further opportunities for research / experimentation identified

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	Low	T				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities of eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T				Minimise	Establish effective recycling programs and find alternative technologies that reduce, or eliminate, the use of supply constrained metals
									Restore	Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	Low	P				Minimise	Minimse sampling area
			Permanent alteration of the benthic geomorphology	Low	P					No mitigations have been identified currently
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Loss of ecosystem function through occulsion and smothering of benthos	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of ecosystem function through occlusion and smothering of benthos	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Low	T	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P				Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Disruption of th Biological (carbon and nutrient) pump of the oceans	Low	P				Minimise	Minimise lifting of sediments near the seafloor
	Removal of samples	Removal of substrates	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Low	P	Avoid	Avoid areas of high biodiversity
			Removal of species associated with polymetallic formation (high species diversity)	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	P	Minimise	Use machinery and technology designed to Best Practice Standards to reduce the impacts of nodule removal
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown				Minimise	Sample with minimum viable sample size
			Mining activities will change the ocean chemistry and have consequential impact on ecological processes. A major disruption of the chemical conditions that permit microbial chemosynthesis could have significant consequences for all animals in that ecosystem						Minimise	Ensure Scientific study to establish the formation of and relevance of the micro-organisms of polymetallic nodules
Resource Development	Use of Large Extractive Machinery designed to be mobile of seabed	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Noise (cont.)	Disturbance to pelagic species resulting in species range restrictions	Unknown	Unknown				Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	Unknown	Unknown				Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions						Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Understand the total area that will be affected including the total water volume (3D)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Integrated Approach - take into account stressors such as ocean acidification, climate change and pollution. Such an approach could help to avoid fragmented, inconsistent approaches to regulating activities in different regions, though some level of systematic and permanent damage to ecosystems would be unavoidable.
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	Avoid areas of high biodiversity
			Disturbance to benthic species resulting in species range restrictions	High	PD				Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance from support ship to bird species resulting in species range restrictions	High	PD				Minimise	Only use lighting where necessary
		Loss or modification to benthic habitat	Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Habitat loss and the modification of seabed morphology, physiological disturbance to organisms, and changes in the intra- and interspecific competition patterns affecting food web structures	H	P	Disruption of the ocean biological pump	H	P	Minimise	Minimise lifting of sediments near the seafloor
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999).	H	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	Unknown	Unknown				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008).	Unknown	Unknown				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column. Surface water discharge can be sprayed over a large area to ensure dilution
			Changes in faunal distribution	Unknown	Unknown				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Changes in benthic species composition and an increase in opportunistic species resulting from mineral extraction can also benefit certain demersal fish as food becomes more abundant (de Jong *et al.*, 2014).	Unknown	Unknown				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artificial upwelling (which stimulates primary production)
			Decrease in abundance of meiobenthos	Unknown	Unknown				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			Increased plume dispersion during high flow periods may influence larval dispersal, while low-flow regimes with lower spreading rates and greater blanketing may adversely affect abundance and diversity	Unknown	Unknown				Restore	The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008). *
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	Unknown	Unknown				Restore	Communities in naturally high-energy areas with exposure to currents or waves are more adept at readjusting to the impacts of mineral extraction than more stable communities
			Extraction of material from the seabed changes the composition of the sediments	Unknown	Unknown				Restore	In the absence of primary production, the resource limited deep-sea communities have a lower abundance and are reliant on the phytodetrital nutrient supply from the surface (Smith *et al.*, 2008).
			The release of sulfides during sediment disturbance	Unknown	Unknown				Restore	Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks.

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Mineral extraction activities that cause topographical changes on the seabed may modify its biogeochemical processes.	Unknown	Unknown				Restore	Natural restoration through sediment settlement results in recolonisation over impacted areas
			Large pits and borrow holes created when using a suction dredger in shallow areas may trap organic matter, enriching the sediment and increasing the oxygen consumption as the organic matter decomposes	Unknown	Unknown				Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through 'set aside' areas, used exclusively as "impact reference zones" and "preservation references zones" as stipulated by the ISA (International Seabed Authority, 2010)
			The potential for trace-metal bioaccumulation	Unknown	Unknown				Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community **
		Mobilisation of sediments (creation of sediment plumes)	Suspended loads will travel laterally over vast distances causing clogging of fliter feeding appartus of benthic organisms in the area.	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Direct impacts along the track of the collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Loss of ecosystem function through occulsion and smothering of benthos	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P	Avoid	Apply the precautionary principle - avoid impacts as with limited information on the physiology of deep-sea organisms, it is currently not possible to estimate the toxic impacts from metal release from the mined material on deep-sea species (Hauton *et al.*, 2017).
			Addition of bottom sediments to the surface resulting in change in the marine ecosystem	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Minimise Sediment penetration

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	High	P	High			Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Smothering or entombment of the benthic fauna away from the site of nodule removal where sediment plume settles (if and when). Even low levels of sediment redeposition may be destructive to certain benthic organisms as increased solids in the water may smother or clog their feeding organs or gills (Ellis *et al.*, 2002), especially harming filter-feeding organisms such as mussels and other bivalves (Mestre *et al.*, 2017).	High	P				Minimise	Minimise lifting of sediments near the seafloor
			Clogging of suspenstion feeders and dilution of deposit-feeders foor resources	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Generation of turbidity in the water column over large areas affecting pelagic organisms. Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	Low	PD				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			Suspended solids and increased sedimentation as a result of harvesting the sediment may cause significant reduction in light availability (Kirk, 1977), leading to the reduced vitality or death of aquatic macrophytes (Riul *et al.*, 2008).	High	P				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	High	P				Minimise	Surface water discharge can be sprayed over a large area to ensure dilution
			Decrease in abundance of meiobenthos	High	P				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	High	P				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			The release of sulfides during sediment disturbance	High	P				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			suspended particulate matter and toxic substances from the sediment plume can potentially harm the eggs and larvae (Auld and Schubel, 1978; Partridge and Michael, 2010)	High	P				Minimise	Minimise sediment return to water column
			Dispersal is dependent on the stratification of the water column and the depth of the surface mixing layer. Sharp pycnoclines reduce vertical mixing and promote the horizontal dispersion of suspended particulate matter (Ellis, 2001).	High	P				Minimise	Mitigation strategies should aim at reducing the concentration, size and toxicity of particles in sediment plumes associated with various mining activities

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	The debris and sediment in the water column cause occlusion and potential habitat fragmentation (screens)	High	P				Minimise	Reducing the concentration, size and toxicity of particles in sediment plumes can be achieved through modifications to mining equipment or procedures. These sites should be upstream, support a similar biological community and be far enough away not to be impacted by mining, yet close enough to supply colonising larvae to the impacted site
			Increased nutrient concentrations in the water column due to sediment resuspension (Klump and Martens, 1981; Lohrer and Wetz, 2003) may result in phytoplankton blooms	High	P				Minimise	Design the suction/retrieval mouth of the seafloor mining tool for minimal escape of suspended material during exploitation
			In oligotrophic waters, the intrusion of nutrient rich bottom water and sediment may drastically increase primary production (Hyun *et al.*, 1998).	High	P					
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High	P					
		Reduction of biomass around disturbance area	Loss of biodiversity and changes to the marine ecosystem and foodwebs with potential consequences to fisheries, ocean health and function and the biological (carbon and nutrient) pump	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Avoid areas of high biodiversity
									Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through ‘set aside’ areas, used exclusively as “impact reference zones” and “preservation references zones” as stipulated by the ISA (International Seabed Authority, 2010)
									Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
									Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community
		Mobilisation and removal from oceans of key geochemical nutrients	The potential for trace-metal bioaccumulation	High	P					No mitigations have been identified currently
			Suspended loads will remain over very long periods	High	P					No mitigations have been identified currently
			Disruption of the Biological (carbon and nutrient) pump of the oceans	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Changes in the physic-chemical conditions around disturbance area	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
			Mining activities will change the ocean chemistry and have consequential impact on ecological processes. A major disruption of the chemical conditions that permit microbial chemosynthesis could have significant consequences for all animals in that ecosystem			Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently
			The release of sulfides during sediment disturbance	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P		No mitigations have been identified currently
			The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	High	P					No mitigations have been identified currently
		Removal of polymetallic crusts as substrates	Changes in environmental conditions may alter metal partitioning and bioavailability (Calmano *et al.*, 1993; Cantwell *et al.*, 2002).	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Avoid areas of high biodiversity
			Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Unknown	Unknown	Loss of ecosystem function	High	P		No mitigations have been identified currently
			Removal of species associated with polymetallic formation (high species diversity)	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species. Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
			Mining process will release metal ions into the water column, either in the benthic plume created by mining vehicles or, following dewatering on the surface vessel, in a mid-water plume	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Removal of polymetallic crusts as substrates (cont.)	Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process.	Unknown	Unknown					No known mitigations currently
			Sediment dispersion changes both the chemical properties of the water and the seafloor sediment composition (Newell *et al.*, 1999; Desprez *et al.*, 2009)	Unknown	Unknown					No known mitigations currently
		Deposition of sediments near surface following processing	Introduction of debris and sediment in the water column	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never deposit sediment at surface
			Considerable quantities of organic contaminants and heavy metals may be released from the seabed sediments when they are disturbed (Latimer *et al.*, 1999).	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		
			Increased turbidity causes occlusion and reduced availability of sunlight photsynthesis causing long term effects on biological productivity	Medium	T	Disruption to fishery through reduction of fish populations	Medium	?		
			The potential for trace-metal bioaccumulation	Medium	P					
			Reduction in primary productivity due to shading of phytoplanton	Medium	T					
			Impacts on marine mammal behaviour	Medium	T					
		Introduction of bottom water at the surface	Introduction of bottom water with its higher nutrient values could result in artificial upwelline increasing the surface productivity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never introduce or deposit bottom water at surface
		Discharge of tailings and effluent below the oxygen-minium zone	May cause some environmental harm to pelagic fauna	Unknown	Unknown	Disruption to fishery through reduction of fish populations	Unknown	Unknown	Avoid	Never discharge of tailings and effluent below the oxygen-minium zone
			Mortality and change in species composition of zooplankton	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown		
			Effects on meso- and bathypelagic fishes and other nekton	Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Unknown	Unknown		
			Impacts on deep diving marine mammals	Unknown	Unknown	Disruption of the ocean biological pump	Unknown	Unknown		
			Impacts to bacterioplankton	Unknown	Unknown					
			Depletion of oxygen by bacterial growth on suspended particles	Unknown	Unknown					
			Effects on fish behaviour and mortality caused by sediments or trace metals	Unknown	Unknown					

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport	Mining Operations	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to bird species resulting in species range restrictions	High	PD					
		Light	Impacts of light on biodiversity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Medium	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Medium	T				Minimise	Only use lighting where necessary
			Disturbance from support ship to bird species resulting in species range restrictions	Medium	T					
At sea processing, ore transfer and transport (cont.)	Mining Operations (cont.)	Chemical Spills	The potential for trace-metal bioaccumulation	Medium	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T	Minimise	In the event of an incident, ensure application of best pro-active mitigation practices to ensure containment and remediation are expedited
			Impacts on marine mammals	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		
			Impacts and mortality of pelagic fish	Medium	T					
			May cause some environmental harm to pelagic fauna	Medium	T	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Mortality and change in species composition of zooplankton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T		No mitigations have been identified currently
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
			Effects on meso- and bathypelagic fishes and other nekton	Medium	T					
			Impacts on marine mammals	Medium	T					
			Depletion of oxygen by bacterial growth on suspended particles	Medium	T					
			Effects on fish behaviour and mortality caused by sediments or trace metals	Medium	T					
Mine Closure and Decommissioning	Abandonment of machinery on seabed	Machinery and infrastructure left on seabed	The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	Medium	P				Avoid	Ensure machinery does not degrade in deep seabed envrionments
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	Medium	P				Avoid	Ensure materials used do not leach toxic substances over time
			Alteration of habitats and substrate (niche for biodiversity)	Medium	P				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
	Removal of seabed mining infrastructure	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
			Disturbance to bird species resulting in species range restrictions	Low	T					
		Light	Impacts of light on biodiversity	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Use directional lighting

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
			Disturbance to benthic species resulting in species range restrictions	Low	T					No mitigations have been identified currently
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T					No mitigations have been identified currently
		Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Loss of habitat of benthic fauna	Low	P	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Minimise lifting of sediments near the seafloor
			Permanent alteration of the benthic geomorphology	Low	P					No mitigations have been identified currently
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Minimise	Minimise Sediment penetration
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Ensure minimal interaction of the collector system with the sea floor to minimise disturbance to benthic habitats
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P	Disruption to fishery through reduction of fish populations (mortality)	Low	T	Minimise	Minimise lifting of sediments near the seafloor

* The original community structure may not be able to recover due to habitat loss as a result of substrate alteration (Desprez, 2000).

** Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

11.4.4 Applying the mitigation hierarchy

Mineral extraction is currently the only proposed enterprise that could have major, local, impacts on vent ecosystems; the impact of a single mining event is arguably expected to be on the scale of a volcanic eruption. Avoidance, minimisation, and restoration measures during and following mining of active vent systems can mitigate impacts, and may be especially effective in systems that are naturally resilient, as in the case of hydrothermal vent ecosystems. These approaches must be informed by baseline data and monitoring efforts.

Mitigations relating to the mining of active hydrothermal vents in the deep sea are summarised below and a full assessment of preventative mitigations is presented in Table 12.

11.4.4.1 Avoidance

Avoidance is the first and most important step in the mitigation hierarchy. Avoidance of impacts to deep-sea hydrothermal vents can be considered in three broad categories, each of which is briefly discussed below:

1. Avoidance during exploration and scientific study through application of voluntary codes

Over-sampling and both unintentional and intentional damage to sulphide structures are among the impacts to vent ecosystems resulting from exploration and scientific research. Concern about these impacts prompted development of a voluntary code of conduct for scientific research at vents that emphasises avoidance of activities that might have long-lasting and deleterious effects (Devey, Fisher and Scott, 2007).

2. Avoidance through creating strictly protected areas representative of the biodiversity and ecosystem services occurring within the mining area

Marine Protected Areas can contribute to mitigation for biodiversity and ecosystem services by establishing avoidance zones. To date, a number of countries have created Marine Protected Areas for hydrothermal vent ecosystems (Van Dover, 2011), including Canada (Endeavour Hydrothermal Vents Marine Protected Area), Mexico (Guaymas Basin and Eastern Pacific Rise Hydrothermal Vents Sanctuary), Portugal (Azores Hydrothermal Vent Marine Protected Areas), and the United States (Mariana Trench National Monument). There are currently no hydrothermal vent Marine Protected Areas in international waters, but hydrothermal vent ecosystems are frequently cited as meeting several of the criteria of Ecologically or Biologically Significant Areas (EBSAs) in areas beyond national jurisdiction and in need of protection (Ardron *et al.*, 2009; Taranto *et al.*, 2012).

3. Avoidance through agreements not to mine active hydrothermal vents

Establishment of networks of chemosynthetic ecosystem reserves as part of mining regulations has been recommended to the International Seabed Authority as a measure to address issues of population maintenance and gene flow for systems where mineral extraction or other human activities might put vent ecosystems at risk (Van Dover, 2011, 2012). Such an approach is modelled after the proposal for protection of Areas of Particular Environmental Interest (APEIs) for manganese nodule beds under the jurisdiction of the International Seabed Authority (Wedding *et al.*, 2013).

In addition to the broad categories above, best practice principles for avoidance include:

- Establishment of un-mined biological corridors (temporary refuges) within a mine site to aid in recovery of the biota and site rehabilitation, as described in the voluntary Code for Environmental Management of Marine Mining (International Marine Minerals Society, 2011 https://www.immsoc.org/).
- Establishment of an unmined area that can serve as both a reference site for comparative studies (Jones *et al.*, 2019) and as a source of colonists.
- Networks of permanent and temporary set-aside areas within the mine site that can also serve as sources of colonists (Mullineaux *et al.*, 2010).
- Avoid removal of brood stock by avoidance of breeding/nursery areas and setting aside areas where brood stocks can provide stock to recruit to other areas.

- Avoidance through staggering of mining and other human activities through both time and space could reduce the likelihood and degree of cumulative impacts within a region. Such a temporal strategy would require the ecosystem to recover at an impacted vent field before activity at another vent field is permitted.
- Avoiding mining activities on active hydrothermal vents altogether has been discussed as an acceptable approach to some contractors (Van Dover *et al*, 2018).

11.4.4.2 Minimisation

Approaches to minimise impacts of mineral extraction and their application to a future extractive operation are presented in (Nautilus Minerals Inc., 2015). These approaches include:

- Relocation of animals within the site to facilitate re-establishment of characteristic invertebrates.
- Engineering design (Nautilus Minerals Niugini Limited, 2008; Boschen *et al.*, 2013) including, in the case of deep-seabed mining, systems and approaches that minimise noise and sediment plumes, biodegradable lubricants, etc.

11.4.4.3 Restoration

- Restoration or rehabilitation of vent ecosystems should be considered to address unavoidable residual impacts as part of the application of the mitigation hierarchy, undertaken only after all effort has been made to avoid and minimise impacts (Van Dover, 2014).
- Given the apparent natural resilience of vent ecosystems, and observed recovery following disturbance events (Box 28), the scope for unassisted recovery - sometimes referred to as ‘passive restoration’ - should also be carefully assessed and considered.
- Naturally occurring physico-chemical disturbances characterise hydrothermal vents. These range in severity and origin and include:
  - Periodic tidal fluctuations in fluid flow and plume fall-out that have negligible impact on the ecosystem;
  - Chronic impacts and disturbances associated with mineralisation and clogging of conduits;
  - Systematic disturbances associated with the hydrothermal cycle;
  - Unpredictable and catastrophic disturbances resulting from collapse of structures either through inherent instability of mineralised structures or as a result of tectonic activity; or
  - Infrequent catastrophic volcanism that paves over vent fields and results in local extinctions.
- There is scope for developing mitigation actions that time mining activities (e.g., to reproductive seasons, tidal calendar or periodicity) to minimise impacts, in addition to spatial set-asides. We do not yet have a sophisticated understanding of rates of natural recovery for most vent systems or of temporal variability in larval supply at vents, but building this knowledge will help to determine whether mitigation opportunities exist that may be timed to, for example, periods of minimal larval supply.
- Deep-sea vents are therefore habitually disturbed and regeneration and recolonisation tends to occur successfully under conducive conditions.
- Restoration is likely to occur naturally with recolonisation of species composition and structure over time, however thresholds to recoverability and resilience need to be established. It is very likely that once a threshold of impact to a vent field has been reached, the ability for that system to naturally recover will be significantly reduced.
- Restoration is unlikely if substrates are totally removed, as in mineral exploitation, though likelihood of success may improve through the deployment of three-dimensional structures (artificial substrates) to provide topographic relief and structural stability for developing sulphide deposits following mining.

BOX 28

Example of natural restoration following a "reset event" volcanic eruption in the East Pacific Rise (Shank *et al.,* 1998)

At the 9°N vent field on the East Pacific Rise, where the hydrothermal cycle was reset by a 1991 eruption, community response to changing physico-chemical conditions was documented during a multi-year period. Subsea floor bacterial productivity increased immediately following the eruption (a phenomenon observed on other ridge systems as well); and bacterial mats and grazers on bacterial mats predominated immediately following the eruption.

The vestimentiferan tubeworm *Tevnia jerichonana* blanketed the study sites within one year and was inferred to be a pioneer species that tolerates higher temperature and sulphide conditions than giant tubeworms *(Riftia pachyptila)*. Sulphide concentrations at study sites decreased 50% within two years of the eruption, and *T. jerichonana* was replaced by dense aggregations of *R. pachyptila.*

Sulphide concentrations continued to decline in subsequent years and mussels began to colonise the seafloor diffuse flow vents along with increasing numbers of associated invertebrate taxa. A similar hydrothermal cycle was observed in the same area following a 2005-2006 eruption. Biological responses to eruptions at Co-Axial Volcano and Axial Volcano on the Juan de Fuca Ridge have also been monitored, and a relatively rapid succession of taxa responding to biotic and abiotic factors is reported.

- Opportunities to enhance the likelihood of successful ecological restoration – assisted natural regeneration – should also be explored and the following key characteristics of vent ecosystems need to be taken into consideration:
  - Once an impact has occurred, recovery of a vent ecosystem is dependent on both immigration of mobile species and successful colonization by larvae (Adams, Arellano and Govenar, 2012).
  - There is gathering evidence that, at least for some hydrothermal-vent systems, invertebrate populations are maintained by local larval supply and retention during periods of habitat stability (Metaxas, 2004, 2011; Adams and Mullineaux, 2008), even while gene flow may be high from one site to another (Vrijenhoek, 2010).
  - Characteristics that facilitate local larval supply include behavioural or other processes that retain larvae near the seafloor, effectively minimising dilution and transport (Mullineaux *et al.*, 1996; Kim and Mullineaux, 1998). For example, topographic basins formed by deep axial valleys (e.g., Juan de Fuca Ridge, NE Pacific) constrain circulation and trap and mix larvae (Thomson *et al.*, 2003; Mcgillicuddy *et al.*, 2010).
  - A few studies (Mullineaux *et al.*, 2005; Khripounoff *et al.*, 2006) suggest that supply of larvae is discontinuous and that timing of maximal supply of larval taxa varies from one taxon to another.
  - Behavioural interactions with turbulence produced by black smokers could increase residence time (Mullineaux and France, 1995; Mullineaux *et al.*, 2005), flow conditions modulated by tidal variations and tectonic activity.
  - Larvae of marine invertebrate taxa are selective in where they settle and they respond to inducement and deterrent cues, including those associated with chemical and physical characters of the environment and odours from conspecifics or other organisms (microbial and otherwise) in the environment (Hadfield and Paul, 2001; Steinberg and de Nys, 2002; Hadfield, 2010).
  - Observations of gregarious settlement in two species of vestimentiferan tubeworms indicate there can be pulsed, gregarious settlement of larvae in vent habitats.

11.4.4.4 Offsetting

Offsetting is not considered to be possible for deep-sea hydrothermal vent ecosystems. See Section 13.4.2 for further details.

11.4.5 Knowledge gaps relating to chemosynthetic ecosystems (vents and seeps)

Through four decades of research, scientists have learned much about the basic properties of vent and seep ecosystems, but from a management perspective there are critical knowledge gaps. Key gaps include:

1. The degree of **connectivity** (including larval dispersal, settlement, recruitment and gene flow) among vent sites. Knowledge of connectivity is critical if we are to understand the sensitivity of populations to the removal of one or more sources of larvae. Adaptive management allows for learning by doing, without ever knowing such details, but responsible management practices will be informed by interdisciplinary studies of larval ecology, ocean circulation and population genetics, but these studies are in their infancy.
2. The **resilience** of vent and seep systems to cumulative disturbance.
   Knowledge of the resilience of chemosynthetic ecosystems, that is, their ability to sustain and recover from a perturbation and from cumulative impacts. Recovery times and trajectories following major disturbances are poorly known for most vent systems and especially for seep systems. Exceptions are observations of relatively rapid recoveries on the scale of years following volcanic eruptions at vent sites on the East Pacific Rise (9 50’N) and Juan de Fuca Ridge (Axial Volcano), (Box 28).
3. The **effectiveness of mitigation and restoration** strategies.
   The deep sea remains a relatively inaccessible place; strategies for mitigating loss of ecosystem structure and function or, once the persistence of an ecosystem has been compromised, effective means of restoring habitat structure and function, have scarcely been considered or evaluated for their cost-effectiveness.

At present, for example, there is very little understanding of source-sink dynamics and of what an effective network of protected areas might look like, except that the optimal network size and spacing will be different for vents and seeps, and within vent and seep bioregions. These unknowns should not prevent emplacement of management strategies; rather they provide strong argument in support of a precautionary and adaptive approach to management.

11.5 Mining of polymetallic massive sulphides at inactive vents: impacts and mitigation

11.5.1 Seafloor (polymetallic) massive sulphides

This section investigates the impacts of potential mining activity upon polymetallic massive sulphides which are the deposits found at inactive hydrothermal vent systems. Users of this document are also referred to section 11.4.1 (Mining of active hydrothermal vents) which includes relevant content and considerations for the mining of polymetallic massive sulphides at inactive vents.

Since 1979, polymetallic massive sulphide deposits have been found at water depths up to 3,700 metres in a variety of tectonic settings at the modern seafloor including mid-ocean ridges, back-arc rifts, and seamounts. Well-known examples of polymetallic massive sulphide deposits have been described from mature back-arc spreading centres such as the North Fiji Basin, along propagating back-arc rifts such as the Valu Fa Ridge in the southern Lau Basin, and in nascent back arc rifts such as the Okinawa Trough. In 1991, extensive sulphide deposits were found to be associated with felsic volcanism in the Eastern Manus Basin, and hydrothermal deposits have also been located in the western Woodlark Basin, where seafloor spreading propagates into the continental crust of Papua New Guinea.

Many of the sulphide deposits consist of a black smoker complex on top of a sulphide mound which commonly is underlain by a stockwork zone. It has been widely established that circulating seawater which is modified in a reaction zone close to a subaxial magma chamber is the principal carrier of metals and sulphur which are leached out of the oceanic basement. Precipitation of massive and stockwork sulphides at and beneath the seafloor takes place in response to mixing of the high temperature (up to 400°C) metal-rich hydrothermal seawater fluid with ambient seawater. Polymetallic seafloor sulphide deposits can reach a considerable size (up to 100 million tonnes) and often carry high concentrations of copper (chalcopyrite), zinc (sphalerite), and lead (galena) in addition to gold and silver.

Extremely high concentrations of gold have recently been found in a new type of seafloor mineral deposit previously only known as epithermal (magmatic) gold deposits on the continents. Due to the high concentration of base and precious metals, seafloor polymetallic sulphide deposits have recently attracted the interest of the international mining industry. The recovery of those deposits appears to be both economically and environmentally feasible due to certain advantages over land-based deposits and will likely become reality within this decade. For logistical and technical reasons, future mining operations will largely focus on deposits in national rather than international waters.

Today, more than 100 sites of hydrothermal mineralisation are known at the modern seafloor including at least 25 sites with high-temperature (350-400°C) black smoker venting. The majority of sites so far have been located at the East Pacific Rise, the Southeast Pacific Rise, and the Northeast Pacific Rise, mainly because the first discovery of an active high-temperature hydrothermal system was made at 21°N at the East Pacific Rise off shore Baja California. Only one site has so far been located at the ridge system of the Indian Ocean, close to the Rodriguez Triple Junction. The scarcity of sulphide deposits on the Mid-Atlantic Ridge and in the Indian Ocean is, at least to a large extent, a function of restricted exploration activity in these areas. It has been assumed that today only about 5% of the 60,000 kilometres of oceanic ridges worldwide have been surveyed and investigated in some detail.

It remains premature to comment on the economic significance of seafloor massive sulphides. A large number of seafloor sulphides are recovered during submersible operations. A bias in the analytical data arises, because sulphide chimneys which are relatively easy to sample are often the focus of study. However, they are unlikely to be representative of the bulk composition of the deposits as a whole (e.g., 11 analysed samples from the Southern Juan de Fuca site have an average zinc content of greater than 34 wt.% (weight percentage)) and little is known about the interiors of larger sulphide mounds and the underlying stockwork zones.

Systematic sampling of both high- and low-temperature assemblages across the surfaces of some large active areas (e.g., TAG hydrothermal field, Explorer Ridge, Galapagos Rift) are more representative of the range of sulphide precipitates which comprise large deposits. Sufficient sampling, which has led to potentially realistic estimates of metal concentrations, has been achieved at only a few sites (e.g., Middle Valley, Explorer Ridge, Galapagos Rift) while quantitative assessment of contained metals has been possible only for the Atlantis II Deep in the Red Sea.

The metal content of massive sulphide occurrences varies depending on geological processes and location. Some examples are summarised in the Table 13 below:

Table 13: Examples of metals found in massive sulphide deposits

Location	Metal					
	Zinc (Zn)	Copper (Cu)	Lead (Pb)	Barium (Ba)	Iron (Fe)	Other
Escanaba Trough, Guaymas Basin	4.7%	1.3%	1.1%			
Explorer Ridge, Endeavour Ridge, Galapagos Rift, TAG, East Pacific Rise	8.5%	4.8%	0.1%			
Mariana Trough, Manus Basin, North Fiji Basin, Lau Basin	16.5%		0,4%	12.6%	13.%	As, Au, As
Okinawa Trough	20.2%		11.8%		6.2%	
Atlantis II Deep, Red Sea	2.0%	0.5%			As, Au, As	Other

Out of the more than 200 sites of hydrothermal mineralisation currently known at the modern seafloor, only about 10 deposits may have sufficient size and grade to be considered for future mining, although information on the thickness of most of those sulphide deposits is not yet available.

These potential mine sites include the Atlantis II Deep in the Red Sea, Middle Valley, Explorer Ridge, Galapagos Rift, and the East Pacific Rise 13°N in the Pacific Ocean, the TAG hydrothermal field in the Atlantic Ocean, as well as the Manus Basin, the Lau Basin, the Okinawa Trough, and the North Fiji Basin in the western and south-western Pacific. All of these sites except two (East Pacific Rise 13°N and TAG hydrothermal field) are located in the Exclusive Economic Zones of coastal states including Saudi Arabia, Sudan, Canada, Ecuador, Papua New Guinea, Tonga, Japan, and Fiji. The Atlantis II Deep is still the only deposit that has been evaluated by a commercial company (Preussag, Germany).

Marine sulphide massive mining appears to be feasible under specific conditions that include:

- High gold and base metal grades;
- Site location close to land, i.e., commonly within the territorial waters (200 nautical mile Exclusive Economic Zone or even 12 nautical mile zone) of a coastal state; and
- Shallow water depth not significantly exceeding 2,000 m (although the technology exists for mining in deeper water).

Under those circumstances, massive sulphide mining can be economically attractive considering that the entire mining system is portable and can be moved from mine site to mine site. An investment into mining systems and ships is thus not tied to a certain location as is the case on land, where a typical mine development in a remote area including all infrastructure requires an initial investment of US$350-500 million.

11.5.2 Exploitation of seafloor massive sulphide deposits

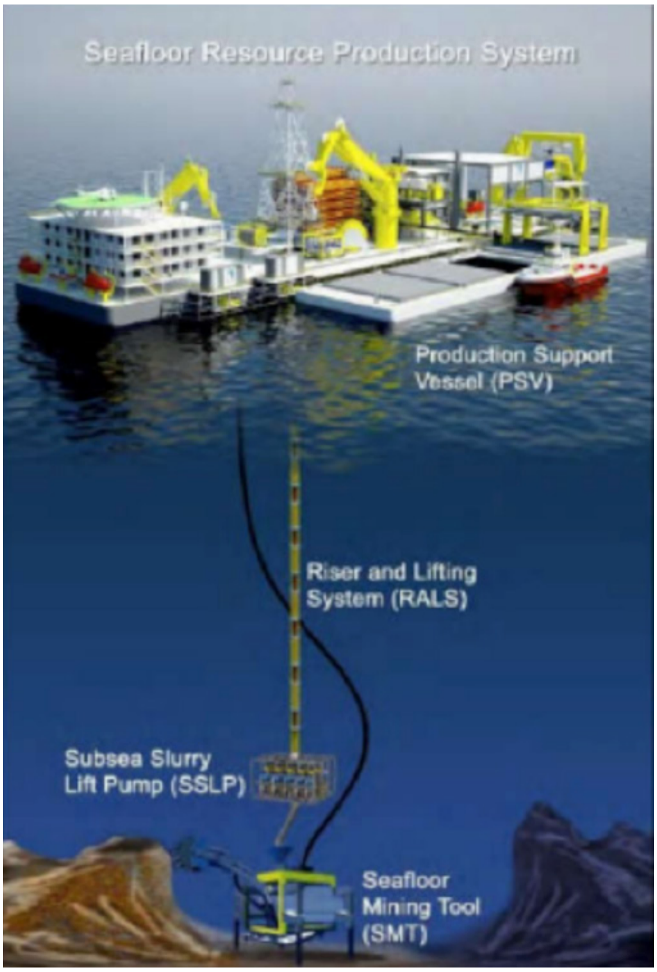


Figure 49: Illustrates the entire production system for mining seafloor massive sulphides. Source: SRK Consulting, (2010)

The proposed engineering system for seafloor massive sulphide deposits based on the system originally proposed by Nautilus (see Box 27 in Section 11.4.2, and Figure 49, below). The system starts with a production support vessel, which is the source of power for the entire mining operation, and serves as the platform by which the mining operations are controlled. The production support vessel is connected to the seafloor mining cutter and collection tools, and riser and lift system, which allows for the excavation of ores from the seabed and their transport up the riser to the vessel. Wastewater from the pre-processing steps is transported back down the riser pipe to be discharged near the seafloor. The pre-processed ore is transferred to a shuttle barge which delivers it to a processor.

Seafloor mining tools to excavate the seafloor massive sulphide deposit includes a cutter / collect system to remove and collect the hard seabed rock in which the metal ores are found. Based on the topography of the mine site (steep slopes and numerous chimneys), Nautilus is proposing the use of three different mining machines known as an auxiliary cutter, a bulk cutter and a collection or gathering machine (Figure 50). In the mining process, the auxiliary cutter is the first to be deployed in order to prepare and level the mine site for the bulk cutter. The bulk cutter is the workhorse of the system, which cuts, grinds and sizes the mineral. Finally, the collection machine removes the cut ore from the seafloor and transfers it to the riser and lift system. Ore deposits are transported to the production support vessel using a subsea lift pump and vertical riser system. The ore collected by the collection machine is pumped into the life pump at the base of the riser and an ore/water slurry is then pumped to the surface (SRK Consulting, 2010).

Before being transported to the processor, the ore is run through a ship-based ore dewatering plant (Figure 51) on board the production support vessel. After the water is removed, the ore is loaded onto barges adjacent to the vessel that will deliver ore to the processing facility at a rate of one barge per day.

Figure 50: Ore collection and extraction machinery. Credit: Nautilus Minerals

Figure 51: Dewatering machinery. Credit: Nautilus Minerals

11.5.3 Risks and impacts of mining seafloor massive sulphide deposits

Seafloor massive sulphide mining will likely focus on relatively small areas of the seafloor and largely be restricted to the seafloor surface (strip mining) and shallow subsurface (open cast mining) to recover sulphide mounds and chimney fields and replacement ore bodies just below the seafloor.

Environmental impact studies are yet to be carried out for the mining of massive sulphide deposits at inactive vents. However, based on available information key risks and impacts are assessed in detail in Table 14 and summarised here:

- Loss or modification of benthic habitat through removal of ore and associated organisms, leading to faunal mortality, reduction in available habitat, modification and fragmentation of habitat
- Degradation of habitat quality (altered topography, substrata) through reshaping of the seabed
- Modification of fluid flux regimes (flow rates, distribution, chemistry)
- Bottom water directly affected by sediment disturbance due to mining equipment.
- Sediment plumes and their transport by currents could create a major hazard for marine fauna both within the water column and at the surface.
- Disruption to ecosystem services that subsurface microbial communities provide including impacts to primary production, secondary production, element cycling, and loss of unique genetic resources.
- A major concern is that disruption of natural microbial communities and stimulation of heavy metal-metabolizing microbes will have far-reaching consequences for trace element cycling in the deep sea (see also Figure 24 and Section 6.2 for information on trace element cycles).
- Acid mine drainage (as termed in terrestrial environments) is a potential systemic problem for mined sulphide massives.
  - Pyrite – an iron sulphide mineral – is the main constituent of massive sulphide deposits, and the overall oxidation reaction that occurs when this mineral is exposed to oxygen and water generates protons.
  - Where the local environmental buffering capacity is unable to absorb these additional protons, a feedback system takes effect that causes a pH decrease.
  - A change in pH causes changes in the type and speed of chemical reactions that occur (Bethke *et al.*, 2011; Jin and Kirk, 2018), leading to changes in metal and oxygen dissolution properties in addition to changes in biology.

- The exposure of massive sulphide deposits will potentially initiate a cascade of abiotic and microbially catalysed reactions, due to the exposure of the deposits to oxygenated seawater (this is similar to the acid rock drainage issues of terrestrial mining). These cascade (open ended) processes are difficult to stabilise or stop and are limited only by the exhaustion of reactants in the process. The consequences of this could be massive, with potential disruption of ocean nutrient balances and ocean chemistry. Imbalances in ocean chemistry have implications for climate mitigation and primary productivity of the oceans.
- Changes in seafloor topography where there is local recharge of bottom seawater into ocean crust (Wheat *et al.*, 2010), causing changes in fluid dynamics and flows which would have implications on both larval/species dispersal and nutrient dissolution.
- Loss of ecosystem services from smothering of hydrothermal vent systems associated with sulphide massives.
- Tailings waste stream, consisting of rock/ore fragments of small size and initial treatment chemicals as well as elevated concentrations of dissolved metals from the mining process, will create plumes of debris in the water column (Nagender Nath *et al.*, 2012; Boschen *et al.*, 2013; Fallon *et al.*, 2017); potential for ecotoxicological effects to marine fauna.
- The sediment plumes in suspension could create anoxic zones and oxygen depletion, interfering with primary productivity in the oceans.

Compared to the mining of other polymetallic formations in the deep-sea, some impacts for biodiversity and ecosystem services may be comparatively less. For example, the high density of the sulphide particles (about 4 grams per cubic centimetre) will cause immediate redeposition of any sulphide debris produced by mining equipment. Due to the large surface exposed to seawater, some of the liberated sulphide debris will oxidise in a way which is similar to the oxidation of inactive massive sulphides in many of the seafloor deposits described.

11.5.4 Applying the mitigation hierarchy

Mitigations relating to the mining of seafloor massive sulphide deposits in the deep sea are briefly summarised below and a full assessment of preventative mitigations is presented in Table 14.

11.5.4.1 Avoidance

Avoidance is the first and most important step in the mitigation hierarchy. Avoidance of seafloor massive sulphide occurrences would avoid the risk and impacts described above. Application of the Precautionary Principle is strongly advised to ensure biogeochemical systems and ocean chemistry are not disrupted.

Avoidance of impacts to seafloor massive sulphide systems can be considered in three broad categories, each of which is briefly discussed below:

1. **Avoidance during exploration and scientific study through application of voluntary codes**

   Over-sampling and both unintentional and intentional damage to sulphide structures are among the impacts to vent ecosystems resulting from exploration and scientific research. Concern about these impacts prompted development of a voluntary code of conduct for scientific research at vents that emphasises avoidance of activities that might have long-lasting and deleterious effects (Devey, Fisher and Scott, 2007).

2. **Avoidance through creating strictly protected areas representative of the biodiversity and ecosystem services occurring within the mining area**
   Marine Protected Areas can contribute to mitigation for biodiversity and ecosystem services by establishing avoidance zones. To date, a number of countries have created Marine Protected Areas for hydrothermal vent ecosystems (Van Dover, 2011), including Canada (Endeavour Hydrothermal Vents Marine Protected Area), Mexico (Guaymas Basin and Eastern Pacific Rise Hydrothermal Vents Sanctuary), Portugal (Azores Hydrothermal Vent Marine Protected Areas), and the United States (Mariana Trench National Monument). There are currently no hydrothermal vent Marine Protected Areas in international waters, but hydrothermal vent ecosystems are frequently cited as meeting several of the criteria of Ecologically or Biologically Significant Areas (EBSAs) in areas beyond national jurisdiction and in need of protection (Ardron *et al.*, 2009; Taranto *et al.*, 2012).

3. **Avoidance through agreements not to mine active hydrothermal vents**
   Establishment of networks of chemosynthetic ecosystem reserves as part of mining regulations has been recommended to the International Seabed Authority as a measure to address issues of population maintenance and gene flow for systems where mineral extraction or other human activities might put vent ecosystems at risk (Van Dover, 2011, 2012).

Best practice principles for avoidance include:

- Establishment of unmined biological corridors (temporary refuges) within a mine site to aid in recovery of the biota and site rehabilitation, as described in the voluntary Code for Environmental Management of Marine Mining (Verlaan, 2011).
- Establishment of an un-mined area that can serve as both a reference site for comparative studies and as a source of colonists (Collins, Kennedy and Dover, 2012).
- Networks of permanent and temporary set-aside areas within the mine site that can also serve as sources of colonists (Mullineaux *et al.*, 2010).
- Avoid removal of brood stock by avoidance of breeding/nursery areas and setting aside areas where brood stocks can provide stock to recruit to other areas.
- Avoidance through staggering of mining and other human activities through both time and space could reduce the likelihood and degree of cumulative impacts within a region. Such a temporal strategy would require the ecosystem to recover at an impacted vent field before activity at another vent field is permitted.

11.5.4.2 Minimisation

- Design and operational practices to minimise impacts to sulphide massive deposit ecosystems need to consider the biogeochemical implications of exposure of minerals to oxidation at depth. The degree to which acidic mining pits might influence surrounding ecosystems and the roles of microbial communities in these acid-generating reactions requires investigation, however predictions are that run-away acid mine generation could occur unless capped. How do you do that at such depth and with no extant technology?
- Minimisation of exposure of acid-generating mineralisation – even during the exploration phase – is strongly advised.
- Additional good practice approaches to minimise impacts of mineral extraction and their application to a future extractive operation are presented in (Systems, 2008) and include:
  - Relocation of animals within the site to facilitate re-establishment of characteristic invertebrates.
  - Engineering design (Nautilus Minerals Niugini Limited, 2008; Boschen *et al.*, 2013), including, in the case of deep-seabed mining, systems and approaches that minimise noise and sediment plumes, biodegradable lubricants, etc.
  - Reduction of lighting and use of directional lighting wherever possible.

11.5.4.3 Restoration and Offsetting

- No active restoration nor offsetting are possible. Indeed, recent scientific research and review suggests offsetting is scientifically, legally and economically questionable (Van Dover *et al.*, 2017; Niner *et al.*, 2018). See Section 13.4.2 for further details.

11.5.5 Knowledge gaps relating to mining of sulphide massive deposits

Information is required regarding underlying hydrology and microbial colonisation patterns before any predictions can be made regarding the potential unintended consequences of disturbing the microbial communities and related ecosystem function of seafloor massive sulphide systems. However, there are likely to be impacts to nutrient availability and transfer resulting from biogeochemical cycling and disruption to natural processes.

- Many animal taxa in inactive vent fields obtain their nutrition in association with chemoautotrophic microbial symbionts (Erickson *et al*, 2009).
- Very few studies have attempted to characterize the microbial communities of sulphide massive deposit fields, their roles in local and global biogeochemical cycling, or as refugia and seed banks for the more dynamic active deep-sea vent fields.
- Inactive hydrothermal systems may lack vigorous hydrothermal venting, but they nevertheless contain complex subsurface habitats with unknown microbial ecosystems.

Table 14 : Impacts to biodiversity and ecosystem services of mining seafloor massive sulphide deposits at inactive vent sites and suitable mitigations, with further opportunities for research / experimentation identified

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	Low	T				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T				Minimise	Establish effective recycling programs and find alternative technologies that reduce, or eliminate, the use of supply constrained metals
									Restore	Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	Low	P				Minimise	Minimse sampling area
			Permanent alteration of the benthic geomorphology	Low	P					
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Loss of ecosystem function through occulsion and smothering of benthos	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Low	T	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P				Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Disruption of th Biological (carbon and nutrient) pump of the oceans	Low	P				Minimise	Minimise lifting of sediments near the seafloor
	Removal of polymetallic samples	Removal of substrates	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Low	P	Avoid	Avoid areas of high biodiversity
			Removal of species associated with polymetallic formation (high species diversity)	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	P	Minimise	Use machinery and technology designed to Best Practice Standards to reduce the impacts of nodule removal
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown				Minimise	Sample with minimum viable sample size
									Minimise	Ensure Scientific study to establish the formation of and relevance of the micro-organisms of polymetallic nodules
Resource Development	Use of Large Extractive Machinery designed to be mobile of seabed	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Noise (cont.)	Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	High	PD				Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	High	PD				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Understand the total area that will be affected including the total water volume (3D)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Integrated Approach - take into account stressors such as ocean acidification, climate change and pollution. Such an approach could help to avoid fragmented, inconsistent approaches to regulating activities in different regions, though some level of systematic and permanent damage to ecosystems would be unavoidable.
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	Avoid areas of high biodiversity
			Disturbance to benthic species resulting in species range restrictions	High	PD				Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance from support ship to bird species resulting in species range restrictions	High	PD				Minimise	Only use lighting where necessary
		Loss or modification to benthic habitat	Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	habitat loss and the modification of seabed morphology, physiological disturbance to organisms, and changes in the intra- and interspecific competition patterns affecting food web structures	High	P	Disruption of the ocean biological pump	High	P	Minimise	Minimise lifting of sediments near the seafloor
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999).	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification						Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge. Surface water discharge can be sprayed over a large area to ensure dilution
			The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008).						Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column
			Changes in faunal distribution						Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Changes in benthic species composition and an increase in opportunistic species resulting from mineral extraction can also benefit certain demersal fish as food becomes more abundant (de Jong *et al.*, 2014).						Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			Decrease in abundance of meiobenthos						Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			Increased plume dispersion during high flow periods may influence larval dispersal, while low-flow regimes with lower spreading rates and greater blanketing may adversely affect abundance and diversity.						Restore	The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008).
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)						Restore	Communities in naturally high-energy areas with exposure to currents or waves are more adept at readjusting to the impacts of mineral extraction than more stable communities
			Extraction of material from the seabed changes the composition of the sediments						Restore	In the absence of primary production, the resource limited deep-sea communities have a lower abundance and are reliant on the phytodetrital nutrient supply from the surface (Smith *et al.*, 2008).
			The release of sulfides during sediment disturbance						Restore	Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks.

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Mineral extraction activities that cause topographical changes on the seabed may modify its biogeochemical processes.						Restore	Natural restoration through sediment settlement results in recolonisation over impacted areas
			Large pits and borrow holes created when using a suction dredger in shallow areas may trap organic matter, enriching the sediment and increasing the oxygen consumption as the organic matter decomposes						Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through ‘set aside’ areas, used exclusively as “impact reference zones” and “preservation references zones” as stipulated by the ISA (International Seabed Authority, 2010)
			The potential for trace-metal bioaccumulation						Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
			Disruption of th Biological (carbon and nutrient) pump of the oceans	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community **
		Mobilisation of sediments (creation of sediment plumes)	Suspended loads will travel laterally over vast distances causing clogging of fliter feeding appartus of benthic organisms in the area.	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes)	Loss of ecosystem function through occulsion and smothering of benthos	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P	Avoid	Apply the precautionary principle - avoid impacts as with limited information on the physiology of deep-sea organisms, it is currently not possible to estimate the toxic impacts from metal release from the mined material on deep-sea species (Hauton *et al.*, 2017).
			Addition of bottom sediments to the surface resulting in change in the marine ecosystem	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	High	P				Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Smothering or entombment of the benthic fauna away from the site of nodule removal where sediment plume settles (if and when). Even low levels of sediment redeposition may be destructive to certain benthic organisms as increased solids in the water may smother or clog their feeding organs or gills (Ellis *et al.*, 2002), especially harming filter-feeding organisms such as mussels and other bivalves (Mestre *et al.*, 2017).	High	P				Minimise	Minimise lifting of sediments near the seafloor
			Clogging of suspenstion feeders and dilution of deposit-feeders foor resources	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Generation of turbidity in the water column over large areas affecting pelagic organisms. Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	Unknown	Unknown				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			Suspended solids and increased sedimentation as a result of harvesting the sediment may cause significant reduction in light availability (Kirk, 1977), leading to the reduced vitality or death of aquatic macrophytes (Riul *et al.*, 2008).	High	P				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	High	P				Minimise	Surface water discharge can be sprayed over a large area to ensure dilution
			Decrease in abundance of meiobenthos	High	P				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	High	P				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			The release of sulfides during sediment disturbance	High	P				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes) (cont.)	Suspended particulate matter and toxic substances from the sediment plume can potentially harm the eggs and larvae (Auld and Schubel, 1978; Partridge and Michael, 2010)	High	P				Minimise	Minimise sediment return to water column [†]
			Dispersal is dependent on the stratification of the water column and the depth of the surface mixing layer. Sharp pycnoclines reduce vertical mixing and promote the horizontal dispersion of suspended particulate matter (Ellis, 2001).	High	P				Minimise	mitigation strategies should aim at reducing the concentration, size and toxicity of particles in sediment plumes associated with various mining activities
			The debris and sediment in the water column cause occlusion and potential habitat fragmentation (screens)	High	P				Minimise	Reducing the concentration, size and toxicity of particles in sediment plumes can be achieved through modifications to mining equipment or procedures. These sites should be upstream, support a similar biological community and be far enough away not to be impacted by mining, yet close enough to supply colonising larvae to the impacted site
			Increased nutrient concentrations in the water column due to sediment resuspension (Klump and Martens, 1981; Lohrer and Wetz, 2003) may result in phytoplankton blooms	High	P				Minimise	Design the suction/retrieval mouth of the seafloor mining tool for minimal escape of suspended material during exploitation
			In oligotrophic waters, the intrusion of nutrient rich bottom water and sediment may drastically increase primary production (Hyun *et al.*, 1998).	High	P					
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High	P					
		Reduction of biomass around disturbance area	Loss of biodiversity and changes to the marine ecosystem and foodwebs with potential consequences to fisheries, ocean health and function and the biological (carbon and nutrient) pump	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Avoid areas of high biodiversity
									Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through 'set aside' areas, used exclusively as "impact reference zones" and "preservation references zones" as stipulated by the ISA (International Seabed Authority, 2010)
									Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
									Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community [††]

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation and removal from oceans of key geochemical nutrients	The potential for trace-metal bioaccumulation	High	P					No mitigations have been identified currently
			Suspended loads will remain over very long periods	High	P					No mitigations have been identified currently
			Disruption of the Biological (carbon and nutrient) pump of the oceans	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
		Changes in the physic-chemical conditions around disturbance area	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
						Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently
			The release of sulfides during sediment disturbance	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P		No mitigations have been identified currently
			The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	High	P					No mitigations have been identified currently
		Removal of polymetallic nodules as substrates	Changes in environmental conditions mayalter metal partitioning and bioavailability (Calmano *et al.*, 1993; Cantwell *et al.*, 2002).	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
			For every tonne of Mn nodule mined 2.5-5.5 tonnes of sediment with be resuspended ~ 40,000 metric tonnes per day sedminet disturbed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently
		Estimate disturbance of 300-600km^2 per year through mining for 1.5-3 million metric tonnes of nodules per year	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Unknown	Unknown	Loss of ecosystem function	High	P		No mitigations have been identified currently
			Removal of species associated with polymetallic formation (high species diversity)	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Estimate disturbance of 300-600km^2 per year through mining for 1.5-3 million metric tonnes of nodules per year (cont.)	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
			Mining process will release metal ions into the water column, either in the benthic plume created by mining vehicles or, following dewatering on the surface vessel, in a mid-water plume	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently
		Nodules may be collected whole,the transfer of nodules up the riser pipe will likely result in them also turning to slurry requiring processing at surface	Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process.	Unknown	Unknown					No mitigations have been identified currently
			Sediment dispersion changes both the chemical properties of the water and the seafloor sediment composition (Newell *et al.*, 1999; Desprez *et al.*, 2009)	Unknown	Unknown					No mitigations have been identified currently
		Deposition of sediments near surface following processing	Introduction of debris and sediment in the water column	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never deposit sediment at surface
			Considerable quantities of organic contaminants and heavy metals may be released from the seabed sediments when they are disturbed (Latimer *et al.*, 1999).	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Increased turbidity causes occlusion and reduced availability of sunlight photsynthesis causing long term effects on biological productivity	Medium	T	Disruption to fishery through reduction of fish populations	Medium	Unknown		No mitigations have been identified currently
			The potential for trace-metal bioaccumulation	Medium	P					No mitigations have been identified currently
			Reduction in primary productivity due to shading of phytoplanton	Medium	T					No mitigations have been identified currently
			Impacts on marine mammal behaviour	Medium	T					No mitigations have been identified currently
		Introduction of bottom water at the surface	Introduction of bottom water with its higher nutrient values could result in artificial upwelline increasing the surface productivity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never introduce or deposit bottom water at surface
			Ecological disturbances and imbalances through dissolution of heavy metals (Cu and Pb) within the oxygen minimum zone	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
		Discharge of tailings and effluent below the oxygen-minium zone	May cause some environmental harm to pelagic fauna	Unknown	Unknown	Disruption to fishery through reduction of fish populations	Unknown	Unknown	Avoid	Never discharge of tailings and effluent below the oxygen-minium zone
			Mortality and change in species composition of zooplankton	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown		No mitigations have been identified currently
			Effects on meso- and bathypelagic fishes and other nekton	Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Unknown	Unknown		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Discharge of tailings and effluent below the oxygen-minium zone	May cause some environmental harm to pelagic fauna	Unknown	Unknown	Disruption to fishery through reduction of fish populations	Unknown	Unknown	Avoid	Never discharge of tailings and effluent below the oxygen-minium zone
			Mortality and change in species composition of zooplankton	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown		No mitigations have been identified currently
			Effects on meso- and bathypelagic fishes and other nekton	Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Unknown	Unknown		No mitigations have been identified currently
			Impacts on deep diving marine mammals	Unknown	Unknown	Disruption of the ocean biological pump	Unknown	Unknown		No mitigations have been identified currently
			Impacts to bacterioplankton	Unknown	Unknown					No mitigations have been identified currently
			Depletion of oxygen by bacterial growth on suspended particles	Unknown	Unknown					No mitigations have been identified currently
			Effects on fish behaviour and mortality caused by sediments or trace metals	Unknown	Unknown					No mitigations have been identified currently
At sea processing, ore transfer and transport		Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
		Light	Disturbance to bird species resulting in species range restrictions	High	PD					No mitigations have been identified currently
			Impacts of light on biodiversity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Medium	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Medium	T				Minimise	void lighting where possible
			Disturbance from support ship to bird species resulting in species range restrictions	Medium	T					No mitigations have been identified currently
		Chemical Spills	The potential for trace-metal bioaccumulation	Medium	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T	Minimise	In the event of an incident, ensure application of best pro-active mitigation practices to ensure containment and remediation are expedited

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport		Chemical Spills	Impacts on marine mammals	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T	Minimise	In the event of an incident, ensure application of best pro-active mitigation practices to ensure containment and remediation are expedited
			Impacts and mortality of pelagic fish	Medium	T					
		Waste Disposal	May cause some environmental harm to pelagic fauna	Medium	T	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			mortality and change in species composition of zooplankton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T		No mitigations have been identified currently
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		No mitigations have been identified currently
			Effects on meso- and bathypelagic fishes and other nekton	Medium	T					No mitigations have been identified currently
At sea processing, ore transfer and transport (cont.)		Waste Disposal (cont.)	Impacts on marine mammals	Medium	T					No mitigations have been identified currently
			Depletion of oxygen by bacterial growth on suspended particles	Medium	T					No mitigations have been identified currently
			Effects on fish behaviour and mortality caused by sediments or trace metals	Medium	T					No mitigations have been identified currently
Mine Closure and Decommissioning	Abandonment of machinery on seabed	Machinery and infrastructure left on seabed	The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	Medium	P				Avoid	Ensure machinery do not degrade in deep seabed envrionments
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	Medium	P				Avoid	Ensure materials used do not leach toxic substances over time
			Alteration of habitats and substrate (niche for biodiversity)	Medium	P				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
	Removal of seabed mining infrastructure	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Mine Closure and Decommissioning	Removal of seabed mining infrastructure	Noise	Disturbance to bird species resulting in species range restrictions	Low	T				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
			Disturbance to bird species resulting in species range restrictions	Low	T					
		Light	Impacts of light on biodiversity	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Use directional lighting
			Disturbance to benthic species resulting in species range restrictions	Low	T					
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T					
		Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Loss of habitat of benthic fauna	Low	P	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Minimise lifting of sediments near the seafloor
			Permanent alteration of the benthic geomorphology	Low	P					
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Minimise	Minimise Sediment penetration
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P	Disruption to fishery through reduction of fish populations (mortality)	Low	T	Minimise	Minimise lifting of sediments near the seafloor

* The original community structure may not be able to recover due to habitat loss as a result of substrate alteration (Desprez, 2000).

** Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

† Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.

†† Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

11.6 Cobalt-rich ferromanganese crusts: impacts and mitigation

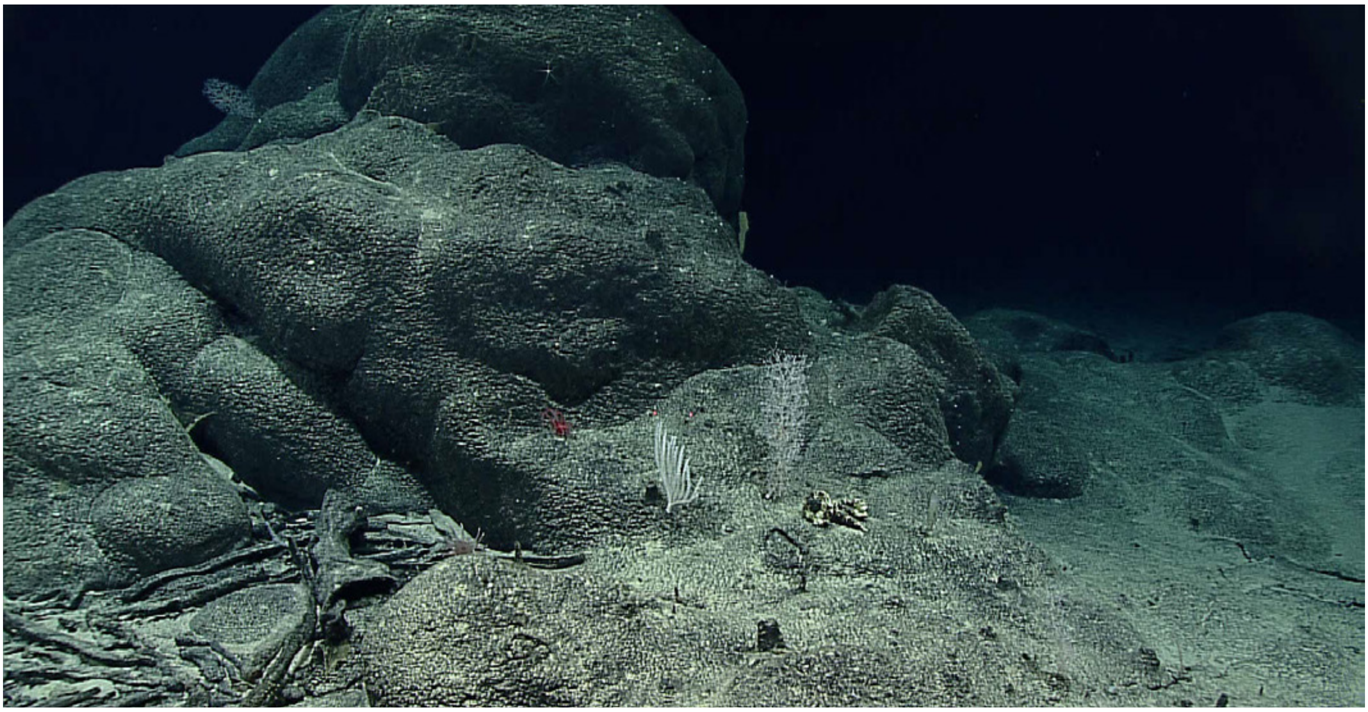
11.6.1 Cobalt-rich ferromanganese crusts

Cobalt-rich ferromanganese (polymetallic) crusts (Figure 52) occur throughout the global ocean on seamounts, ridges, and plateaus where currents have kept the rocks swept clean of sediments for millions of years. Crusts precipitate out of cold ambient seawater onto hard-rock substrates forming pavements up to 250 mm thick. Crusts are important as a potential resource for primarily cobalt, but also for titanium, cerium, nickel, platinum, manganese, thallium, tellurium, and others. Crusts form at water depths of about 400 to 4,000 metres, and most commonly occur at depths from about 1,000 and 3,000 metres. The thickest and most cobalt-rich crusts occur at depths of about 800 to 2,200 metres, , which mostly encompasses the oxygen minimum zone.

The water depths of thick high cobalt content crusts vary regionally. Gravity processes, sediment cover, submerged and emergent reefs, and currents control the distribution and thickness of crusts. Crusts are generally shallower in the South Pacific where the oxygen minimum zone is less well developed; there, the maximum cobalt contents and thickest crusts occur at about 1,000 - 1,500 metres. Crusts become thinner with increasing water depth because of mass movements and reworking of the deposits on the seamount flanks. Most ferromanganese crusts on the middle and lower seamount flanks consist of encrusted talus rather than encrusted rock outcrop, the latter typically having thicker crusts. Crusts occur on a wide variety of substrate rocks, which makes it difficult to distinguish the crusts from the substrate using remotely sensed data, such as geophysical measurements.

Crusts generally grow at rates of 1-6 millimetres per million years. Ferromanganese crusts form by precipitation from cold ambient bottom waters (hydrogenetic), or by a combination of hydrogenetic and hydrothermal precipitation in regions where hydrothermal venting occurs, such as near oceanic spreading axes, volcanic arcs, and hotspot volcanoes.

Figure 52: Ferromanganese crusts. Credit: Nautilus Expedition - NOAA, 2018



Elements most commonly associated with the vernadite phase include manganese, cobalt, nickel, cadmium, and molybdenum, and with the iron oxyhydroxide, iron and arsenic. Bulk crusts contain cobalt contents up to 1.7%, nickel to 1.1%, and platinum to 1.3 parts per million, with mean iron/manganese ratios of 0.4 to 1.2. Cobalt, nickel, titanium, and platinum decrease, whereas iron/manganese, silicon, and aluminium increase in continental margin crusts and in crusts with proximity to west Pacific volcanic arcs.

Iron, copper, and detrital-related elements increase with increasing water depth of crust occurrence. Cobalt, cerium, thallium, and maybe also titanium, lead, tellurium, and platinum are strongly concentrated in crusts over other metals because they are incorporated by oxidation reactions. Total rare-earth elements (REEs) commonly vary between 0.1% and 0.3% and are derived from seawater along with other hydrogenetic elements, cobalt, manganese, nickel, etc. Platinum-group elements are also derived from seawater, except palladium, which is derived from detrital minerals.

Seamounts obstruct the flow of oceanic water masses, thereby creating a wide array of seamount-generated currents of generally enhanced energy relative to flow away from the seamounts. The effects of these currents are strongest at the outer rim of the summit region of seamounts, the area where the thickest crusts are found. Those seamount-specific currents also enhance turbulent mixing and produce upwelling, which increases primary productivity. These physical processes also affect seamount biological communities, which vary from seamount to seamount.

Rowden *et al.* (2010) describe seamounts as oases on the abyssal plains because they often support higher epibenthic species diversity and biomass than nearby slopes (Figure 53). In some circumstances, seamounts can connect benthic and pelagic ecosystems. For example, fish and marine mammals are known to aggregate over seamounts, using them either for foraging or resting (Garrigue *et al.*, 2015; Morato *et al.*, 2015). Reisinger *et al.* (2015) tagged and tracked killer whales (Orcinus orca) and found that they spent time hunting over certain seamounts, suggesting that these oceanic features are a source of prey for these mammals. As well as supporting marine fauna including cetaceans, pinnipeds, and turtles for feeding, seamounts may be navigational features during migrations and as breeding grounds (Yesson *et al.*, 2011).

Figure 53: Brittle starts on seamount. Credit: Ocean Exploration Trust

Seamount communities are characterized by relatively low density and low diversity where the ferromanganese crusts are thickest and cobalt-rich. The make-up of the seamount communities, and population density and diversity, are determined by current patterns, topography, bottom sediment and rock types and coverage, seamount size, water depth, and size and magnitude of the oxygen-minimum zone. About 48 research cruises have been dedicated to the study of cobalt-rich crusts.

Research and development on the technology of mining crusts are only in their infancy. Detailed maps of crust deposits and a better understanding of small-scale seamount topography are required to develop the most appropriate mining strategies. Based on grade, tonnage, and oceanographic conditions, the central-equatorial Pacific offers the best potential for crust mining, particularly the EEZ of Johnston Island (USA), the Marshall Islands, and international waters in the Mid-Pacific Mountains, although the EEZs of French Polynesia, Kiribati, and the Federated States of Micronesia must also be considered.

There are two practical interests in ferromanganese crusts, the first being their economic potential for cobalt, but also for manganese, nickel, and platinum, and possibly also titanium, rare earth elements (REEs), tellurium, thallium, phosphorus, and others. The second interest is the use of crusts as recorders of the past 60 million years of oceanic and climatic history. Besides the high cobalt contents compared to abyssal ferromanganese nodules, exploitation of crusts was viewed as advantageous because most high quality crusts occur within the EEZ of island nations and, therefore, are not subject to some of the perceived challenges of exploiting mineral resources occurring in international waters.

Ferromanganese crusts have been recovered from seamounts and ridges as far north as the Aleutian Trench in the Pacific and Iceland in the Atlantic and as far south as the Circum-Antarctic Ridge in the Pacific, Atlantic, and Indian Oceans. However, the most detailed studies have concerned seamounts in the equatorial Pacific, mostly from the EEZ (200 nautical miles) of island nations including the Federated States of Micronesia, Marshall Islands, Kiribati, as well as in the EEZ of the USA (Hawaii, Johnston Island), but also from international waters in the Mid-Pacific Mountains.

Compared to the estimated 50,000 or so seamounts that occur in the Pacific, the Atlantic and Indian oceans contain fewer seamounts and most ferromanganese crusts are associated with the spreading ridges. Crusts associated with those spreading ridges usually have a hydrothermal component that may be large near active venting, but which is regionally generally a small (<30%) component of the crusts formed along most of the ridges. Those types of hydrogenetic-hydrothermal crusts are also common along the active volcanic arcs in the west Pacific, the spreading ridges in back-arc basins of the west and southwest Pacific, spreading centres in the south and east Pacific, and active hotspots in the central (Hawaii) and south (Pitcairn) Pacific. Very few (<15%) of the approximate 50,000 seamounts in the Pacific have been mapped and sampled in detail, and none of the larger ones have been so studied, some of which are comparable in size to continental mountain ranges. Thick crusts are rarely found in the Atlantic and Indian Oceans, with the thickest (up to 125 millimetres) being recovered from the New England seamount chain (NW Atlantic), and a 72 millimetre-thick crust being recovered from a seamount in the Central Indian Basin.

Many seamounts and ridges are capped by pelagic sediments and therefore do not appear to support the growth of crusts on the summit. The thickest crusts occur on summit outer-rim terraces and on broad saddles on the summits. Estimates of sediment cover on various seamounts range from 15% to 75%, and likely averages about 50%. Crusts are commonly covered by a thin blanket of sediments in the summit region and on flank terraces. It is not known how much sediment can accumulate before crusts stop growing. Crusts have been recovered from under as much as 2 metres of sediment without apparent dissolution. Based on coring results, Yamazaki estimated that there are 2-5 times more ferromanganese crust deposits on seamounts than estimates based on exposed crust outcrops because of their coverage by a thin blanket of sediment. Those thinly veiled crusts would be within reach of mining operations.

Ferromanganese crusts are enriched over seawater in all elements except bromine, chlorine, and sodium; enrichments over seawater between 108 and 1010 times include bismuth, cobalt, manganese, titanium, iron, tellurium, lead, and thorium, and between 106 and 108 times include tin, hafnium, zirconium, aluminium, yttrium, scandium, thallium, nickel, calcium, niobium, indium, copper, germanium, zinc, tungsten, and tantalum. Crusts are enriched over lithospheric concentrations about five thousand times for tellurium and a hundred to five hundred times for molybdenum, thallium, antimony, cobalt, manganese, bismuth, arsenic, selenium, and lead. Crusts may have an economic potential not only for cobalt, nickel, manganese, and platinum, but also for titanium, cerium, tellurium, thallium, zirconium, and phosphorus.

Hydrogenetic ferromanganese crusts grow at incredibly slow rates of <1 to about 11 millimetres per million years, with the most common rates being from 1-6 millimetres per million years.

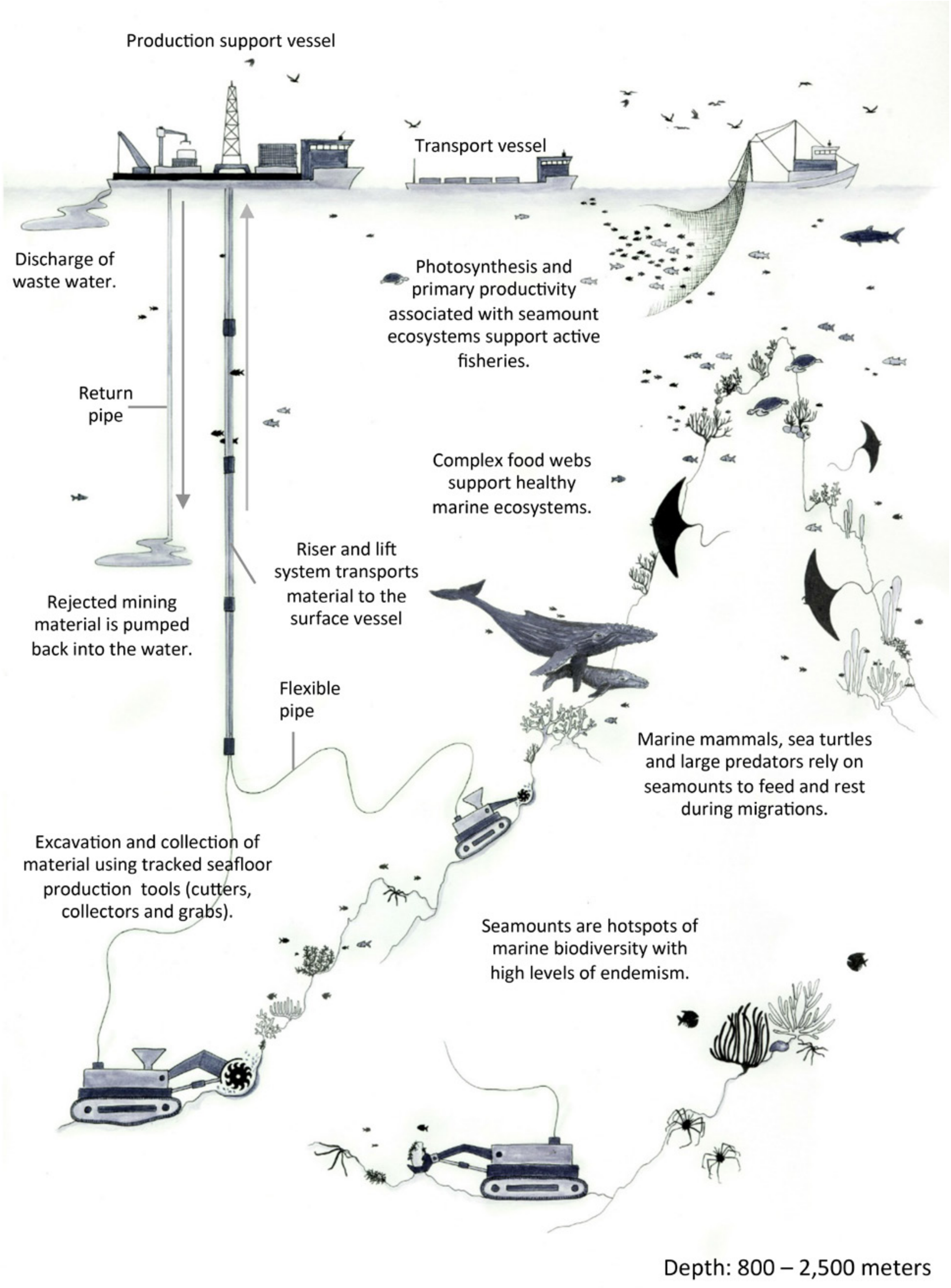
11.6.2 Exploitation of polymetallic crusts

Crust mining is considered technically much more difficult than manganese-nodule mining. Recovery of nodules is easier because they sit on a soft-sediment substrate, whereas crusts are weakly to strongly attached to substrate rock. For successful crust mining, it is essential to recover the crusts without collecting too much substrate, which would substantially dilute the ore quality. The basic mode of exploitation would be to remove the seamount skin without including too much of the less valuable rock beneath it. The skinning operation is likely to result in a large impact area.

The method of crust recovery is likely to be similar to that for seafloor massive sulphides, consisting of a bottom-crawling vehicle attached to a surface vessel by a hydraulic-pipe lift system and an electrical umbilical (Figure 54). The crawler would have articulated cutters to fragment the crusts while minimising the amount of substrate rock collected.

Other innovative systems that have been suggested include water-jet stripping of crusts from the rock, chemical leaching of the crusts while they are still on the seamounts and sonic separation of crusts. Most research and development on mining technologies for crusts has been undertaken by Japan. Although various ideas have been floated, research and development for crust mining is in its infancy.

Figure 54: Mining of ferromanganese crusts on slopes and summits of seamounts. Illustration not to scale.
Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

11.6.3 Risks and impacts of mining ferromanganese crusts from seamounts

The exploitation of ferromanganese crusts of seamounts poses significant long-term disturbances and potentially severe impacts to both ecosystem structure and functioning, as well as associated ecosystem services. Most seamounts are understudied areas, with very little knowledge on either local or regional scales. Most detailed knowledge available is centred on highly localised geological information and interpolated and/or modelled environmental data, while high-resolution data on biogeography, ecosystem processes and functioning are lacking. Seamounts are characterised by highly diverse range of seascapes, from soft sediment to carbonate pavement and cobalt crust outcrops.

The cobalt crust substrata are inhabited by diverse benthic communities, dominated by sessile organisms, presenting three-dimensional structural heterogeneity and with associated vertebrate and invertebrate animals. Cobalt-rich crusts appear to grow at an extremely slow rate (several millimetres per million years) in the deep ocean where biological and ecological processes such as reproduction, growth and recolonisation are characterised by slow dynamics. Many seamount species, such as the sessile corals, are thought to be slow growing (<1 millimetre per year), long-lived (up to millennia), and susceptible to physical disturbance and for these reasons it has been suggested that seamounts be globally managed as Vulnerable Marine Ecosystems (Clark and Tittensor, 2010; Fallon, Thresher and Adkins, 2014; Watling and Auster, 2017). These characteristics of seamount ecosystems and their associated biodiversity underlie the sensitivity and vulnerability of these systems to mining impacts.

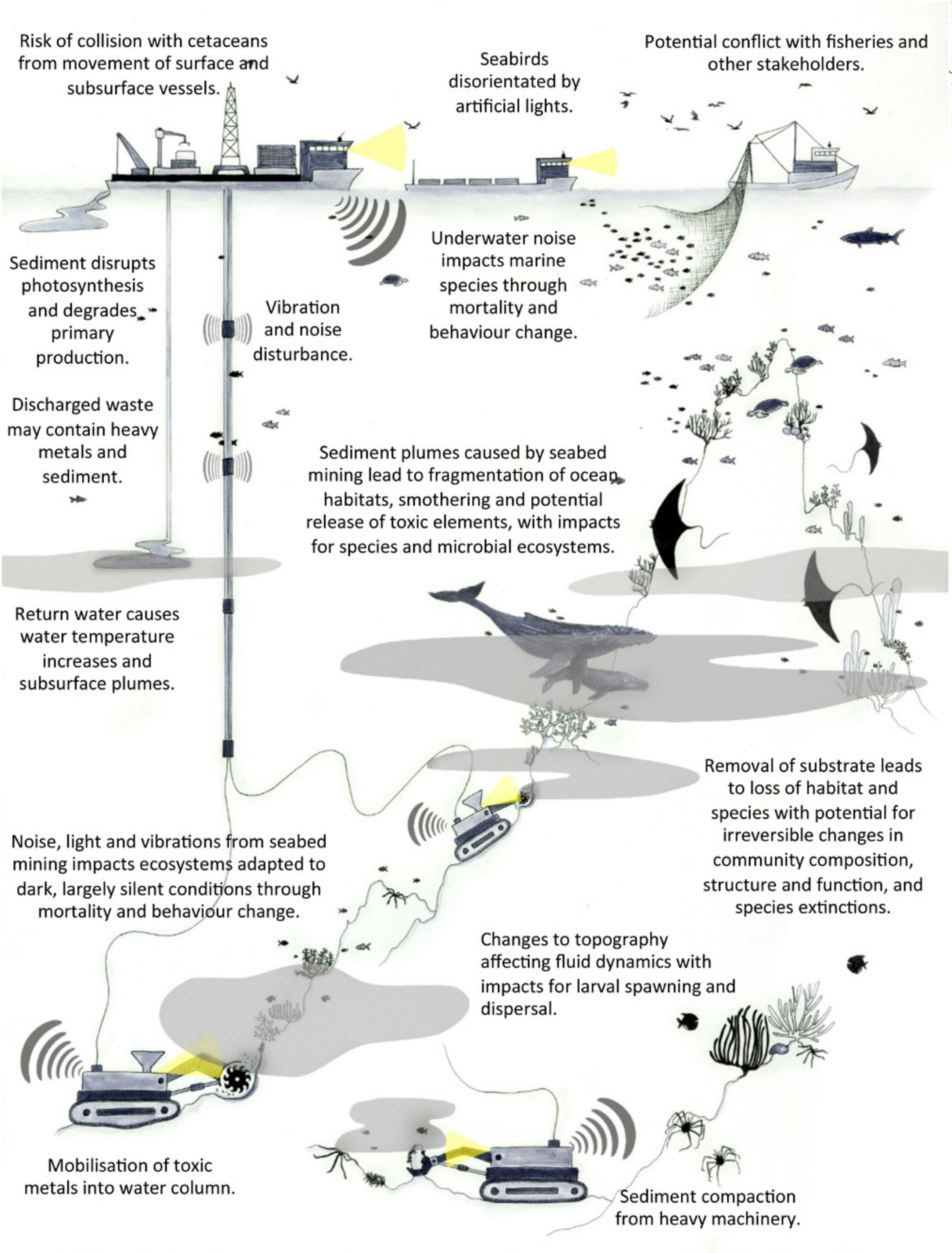
Gollner *et al.* (2017) discuss the potential impacts of mining crusts by borrowing from activities such as fisheries, in particular trawling, that remove substrate and associated organisms from seamounts. Though there are few data on recovery of species after intensive periods of trawling, the negative impact of deep-sea fisheries on seamounts is well-documented, with noted declines in faunal biodiversity, cover, and abundance (Clark *et al.*, 2016). The impact of seabed mining may be more intensive than trawling because the removal of substrata will be complete. Such removal on a commercial scale accompanied by slow species recovery rates will likely lead to irreversible changes in benthic (and possibly pelagic) community structure on and around seamounts (Gollner *et al.*, 2017).

The main impacts posed by deep-seabed mining of cobalt-rich ferromanganese crusts are summarised below and illustrated in Figure 55. Risks and impacts are assessed in detail in Table 15. These impacts will likely change the deep-sea ecosystem and its functioning for time scales in the order of decades to centuries.

The main impacts of mining the cobalt-rich ferromanganese crusts of seamounts include:

- Complete removal of substrate with its particular benthic communities, causing direct mortality to sessile organisms.
- Mining may also cause benthic, mesopelagic (200 –1,000 metres depth) and bathypelagic (1,000 – 4,000 metres depth) fish mortality (Mengerink *et al.*, 2016)
- Strong localised increases in suspended particulate matter, causing smothering of breathing apparatus and dilution of food particles.
- Crushing of organisms by tailings and overburden
- Toxicity effects by released metals and other toxic substances, likely to be increased under high pressure.
- Intensive mining could disrupt pelagic species aggregations due to the removal of benthic fauna, the presence of machinery and disruption as a result of noise, light and suspended sediments in the water column.

Figure 55. Impacts of mining cobalt crusts on slopes and summits of seamounts. Illustration not to scale. Adapted from Miller, Thompson, Johnston & Santillo (2018): doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Full impacts of mining on seamount ecosystems are unknown - changes are likely to be irreversible.

Credit: Nicky Jenner/FFI

11.6.4 Applying the mitigation hierarchy

Mitigations relating to the mining of polymetallic crusts of seamounts are briefly summarised below and a full assessment of preventative mitigations is presented in Table 15.

11.6.4.1 Avoidance

- Avoidance is the first and most important step in the mitigation hierarchy.
- Impacts to seamount biodiversity and ecosystem services from mining will be most effectively avoided by establishing avoidance areas that protect a representative assemblage of biodiversity and physical habitats.
- Given that there is a high variation in benthic assemblages found between seamounts located within the same area (Schlacher *et al.*, 2014), protecting one seamount to enable mining at an adjacent seamount may not be a suitable strategy, and it may be necessary to protect multiple seamounts or a network of sites to conserve the suite of assemblages present (Boschen *et al.*, 2015).Given the pronounced link between seamount and pelagic biodiversity (Morato *et al.*, 2010), any avoidance areas should be extended into the neighbouring water column. These could be protected through seasonal closure of mining and fisheries, in order to take into account migratory patterns and nursery function or reproduction areas for fish and other large marine predators (Cuvelier *et al.*, 2019).
- Creation of protected areas representative of seamounts.

11.6.4.2 Minimisation

As for other forms of seabed mining, good practice approaches to minimise impacts of mineral extraction and their application to a future extractive operation are presented in Nautilus Minerals Niugini Limited (2008). These approaches include:

- Relocation of animals within the site to facilitate re-establishment of characteristic invertebrates. This may include transplanting animals (extremely long lived or other key species) before mining operations to nearby sites with similar characteristics not to be affected by any mining.
- Engineering design (Nautilus Minerals Niugini Limited, 2008) including, in the case of deep-seabed mining, systems and approaches that minimise noise and sediment plumes, biodegradable lubricants, etc. (Boschen *et al.*, 2015)
- Reduction of lighting and use of directional lighting wherever possible.

11.6.4.3 Restoration

There are no active restoration activities in place on seamounts. For areas that have been impacted by mining, there may be several activities that improve the rate of natural restoration:

- First, research indicates that hard substrata, their rugosity and associated habitat complexity play an important role in the success of larval settlement (Rogers, 1999). The post-mining process could include a mechanistic increase of substrate roughness/complexity to promote larval settlement and recruitment (Cuvelier *et al.*, 2019). Advantages of this action would be to promote early colonisation stages.

Seamounts are characterised by long-lived species, hence transplant actions might be of particular interest in this specific ecosystem. This could include transplanting fauna (larvae and adults) and Sediments to the pot-mined environment (Cuvelier *et al.*, 2019).

11.6.4.4 Offsetting

No active offsetting is possible in such scenarios. See section 13.4.2 for further details.

11.6.5 Knowledge gaps relating to the mining of ferromanganese crusts

- State-of-the-art geological, environmental and ecological modelling, complemented with high-quality, fine-resolution data are needed to provide a detailed evaluation of the impacts of cobalt-rich ferromanganese crust mining, with the goal to formulate strategic environmental management plans (Montserrat *et al.*, 2019).
- The implications to hydrographic characteristics (water flows and upwelling) of topographical change to seamounts resulting from mining needs to be ascertained. Changes in fluid dynamics may have impacts on nutrient exchange and connectivity, and on the ecological function of seamounts. Consequences to pelagic fisheries and marine biodiversity need to be better understood.

Table 15: Impacts to biodiversity and ecosystem services of cobalt crust mining and suitable mitigations, with further opportunities for research / experimentation identified

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Exploration	Use of ROVs for sampling	Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions
			Disturbance to benthic species resulting in species range restrictions	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	Low	T				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T				Minimise	Establish effective recycling programs and find alternative technologies that reduce, or eliminate, the use of supply constrained metals

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Exploration (cont.)	Use of ROVs for sampling (cont.)	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	Low	P				Minimise	Minimse sampling area
			Permanent alteration of the benthic geomorphology	Low	P					
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Loss of ecosystem function through occulsion and smothering of benthos	Low	T	Avoid	Avoid areas of high biodiversity
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Low	T	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P				Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Disruption of th Biological (carbon and nutrient) pump of the oceans	Low	P				Minimise	Minimise lifting of sediments near the seafloor
	Removal of polymetallic nodule samples	Removal of substrates	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Low	P	Avoid	Avoid areas of high biodiversity
			Removal of species associated with polymetallic formation (high species diversity)	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	P	Minimise	Use machinery and technology designed to Best Practice Standards to reduce the impacts of nodule removal
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown				Minimise	Sample with minimum viable sample size
									Minimise	Ensure Scientific study to establish the formation of and relevance of the micro-organisms of polymetallic nodules
Resource Development	Use of Large Extractive Machinery designed to be mobile of seabed	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Establishing MPAs before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018)
			disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Ensure full baselines are established to imform biodiversity and ecosystem values prior to granting contracts and prior to establishing MPAs to ensure values are protected and avoided
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	When developing the proposed international legally binding instrument on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, consideration will also need to be given to ensure at least equivalent levels of protection within national jurisdictions

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Noise (cont.)	Disturbance to benthic species resulting in species range restrictions	High	PD				Avoid	Exploitation contracts should not be issued until MPA networks are implemented
			Disturbance to bird species resulting in species range restrictions	High	PD				Avoid	Support the application of the precautionary principle
									Avoid	Create marine protected areas and no go (no mining) areas in both national and international waters
									Avoid	Avoid areas of high biodiversity
									Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
									Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
		Light	Impacts of light on biodiversity	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Understand the total area that will be affected including the total water volume (3D)
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Integrated Approach - take into account stressors such as ocean acidification, climate change and pollution. Such an approach could help to avoid fragmented, inconsistent approaches to regulating activities in different regions, though some level of systematic and permanent damage to ecosystems would be unavoidable.
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Avoid	Avoid areas of high biodiversity
			Disturbance to benthic species resulting in species range restrictions	High	PD				Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance from support ship to bird species resulting in species range restrictions	High	PD				Minimise	Only use lighting where necessary
		Loss or modification to benthic habitat	Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Avoid areas of high biodiversity
			Loss of habitat of benthic fauna	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Habitat loss and the modification of seabed morphology, physiological disturbance to organisms, and changes in the intra- and interspecific competition patterns affecting food web structures	High	P	Disruption of the ocean biological pump	High	P	Minimise	Minimise lifting of sediments near the seafloor

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999).	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification	Unknown	Unknown				Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008).	Unknown	Unknown				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	Unknown	Unknown				Minimise	Surface water discharge can be sprayed over a large area to ensure dilution
			Changes in faunal distribution	Unknown	Unknown				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Changes in benthic species composition and an increase in opportunistic species resulting from mineral extraction can also benefit certain demersal fish as food becomes more abundant (de Jong *et al.*, 2014).	Unknown	Unknown				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			Decrease in abundance of meiobenthos	Unknown	Unknown				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			Increased plume dispersion during high flow periods may influence larval dispersal, while low-flow regimes with lower spreading rates and greater blanketing may adversely affect abundance and diversity.	Unknown	Unknown				Restore	The recovery of seabed communities is dependent on both the arrival of mobile species and successful recolonization by larvae, which in itself is dependent on neighboring habitats and connectivity (Thrush *et al.*, 2008). *
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)						Restore	Communities in naturally high-energy areas with exposure to currents or waves are more adept at readjusting to the impacts of mineral extraction than more stable communities
			Extraction of material from the seabed changes the composition of the sediments						Restore	In the absence of primary production, the resource limited deep-sea communities have a lower abundance and are reliant on the phytodetrital nutrient supply from the surface (Smith *et al.*, 2008).
			The release of sulfides during sediment disturbance						Restore	Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone (CCZ) in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based MPA networks.

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Loss or modification to benthic habitat (cont.)	Mineral extraction activities that cause topographical changes on the seabed may modify its biogeochemical processes.						Restore	Natural restoration through sediment settlement results in recolonisation over impacted areas
			Large pits and borrow holes created when using a suction dredger in shallow areas may trap organic matter, enriching the sediment and increasing the oxygen consumption as the organic matter decomposes						Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through ‘set aside’ areas, used exclusively as “impact reference zones” and “preservation references zones” as stipulated by the ISA (International Seabed Authority, 2010)
			The potential for trace-metal bioaccumulation						Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
			Disruption of th Biological (carbon and nutrient) pump of the oceans	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
									Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community **
		Mobilisation of sediments (creation of sediment plumes)	Suspended loads will travel laterally over vast distances causing clogging of fliter feeding appartus of benthic organisms in the area.	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P	Avoid	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Direct impacts along the track of the nodule collector, where sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Minimise	Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.
			Loss of ecosystem function through occulsion and smothering of benthos	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P	Avoid	Apply the precautionary Principles - avoid impacts as with limited information on the physiology of deep-sea organisms, it is currently not possible to estimate the toxic impacts from metal release from the mined material on deep-sea species (Hauton *et al.*, 2017).

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes) (cont.)	Addition of bottom sediments to the surface resulting in change in the marine ecosystem	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P	Minimise	Minimise Sediment penetration
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	High	P				Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Smothering or entombment of the benthic fauna away from the site of nodule removal where sediment plume settles (if and when). Even low levels of sediment redeposition may be destructive to certain benthic organisms as increased solids in the water may smother or clog their feeding organs or gills (Ellis *et al.*, 2002), especially harming filter-feeding organisms such as mussels and other bivalves (Mestre *et al.*, 2017).	High	P				Minimise	Minimise lifting of sediments near the seafloor
			Clogging of suspenstion feeders and dilution of deposit-feeders foor resources	High	P				Minimise	Strip-wise mining to be carried out, leaving alternative strips of undisturbed seafloor to allow repopulation by organisms from adjacent areas
			Generation of turbidity in the water column over large areas affecting pelagic organisms. Fish and other fauna can be affected by the indirect effects of reduced food sources and habitat modification						Minimise	The separation of minerals from sediments (or other debris) should be as close as possible to the seafloor to minimise water column impacts affected by discharge
			Suspended solids and increased sedimentation as a result of harvesting the sediment may cause significant reduction in light availability (Kirk, 1977), leading to the reduced vitality or death of aquatic macrophytes (Riul *et al.*, 2008).	High	P				Minimise	Discharge of bottom waters should be at different levels of the water column instead of only at the surface. There should be unifrm distribution of the discharge in the entire water column
			Changes in sediment grain size and loss of the original substrate can reduce optimal spawning and nursery grounds for certain fish species (Foden *et al.*, 2009), particularly demersal egg-laying teleosts (de Groot, 1980, Kaiser *et al.*, 1999)	High	P				Minimise	Surface water discharge can be sprayed over a large area to ensure dilution
			Decrease in abundance of meiobenthos	High	P				Minimise	Sediment discharge should be minimised at the surface to allow sufficent sunlight to penetrate for photosynthetic activity
			Increase in abundance of macrobenthos due to increased nutrient availability (disturbance of sediments)	High	P				Minimise	The concentration of discharge material should be such that it will have a positive effect e.g. artifical upwelling (which stimulates primary production)
			The release of sulfides during sediment disturbance	High	P				Minimise	Proper treatment of waste disposal to be carried out before discharging. Biodegradable methods should be used for treatment of discharge
			Suspended particulate matter and toxic substances from the sediment plume can potentially harm the eggs and larvae (Auld and Schubel, 1978; Partridge and Michael, 2010)	High	P				Minimise	Minimise sediment return to water column[†]

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation of sediments (creation of sediment plumes) (cont.)	Dispersal is dependent on the stratification of the water column and the depth of the surface mixing layer. Sharp pycnoclines reduce vertical mixing and promote the horizontal dispersion of suspended particulate matter (Ellis, 2001).	High	P				Minimise	Mitigation strategies should aim at reducing the concentration, size and toxicity of particles in sediment plumes associated with various mining activities
			The debris and sediment in the water column cause occlusion and potential habitat fragmentation (screens)	High	P				Minimise	Reducing the concentration, size and toxicity of particles in sediment plumes can be achieved through modifications to mining equipment or procedures. These sites should be upstream, support a similar biological community and be far enough away not to be impacted by mining, yet close enough to supply colonising larvae to the impacted site
			Increased nutrient concentrations in the water column due to sediment resuspension (Klump and Martens, 1981; Lohrer and Wetz, 2003) may result in phytoplankton blooms	High	P				Minimise	Design the suction/retrieval mouth of the seafloor mining tool for minimal escape of suspended material during exploitation
			In oligotrophic waters, the intrusion of nutrient rich bottom water and sediment may drastically increase primary production (Hyun *et al.*, 1998).	High	P					
			Disruption of the Biological (carbon and nutrient) pump of the oceans	High	P					
		Reduction of biomass around disturbance area	Loss of biodiversity and changes to the marine ecosystem and foodwebs with potential consequences to fisheries, ocean health and function and the biological (carbon and nutrient) pump	High	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Avoid areas of high biodiversity
									Restore	Enhancing the recruitment and re-establishment of biota following mining is one of the recommendations of the IMMS Code (International Marine Minerals Society, 2011). This can be achieved through 'set aside' areas, used exclusively as "impact reference zones" and "preservation references zones" as stipulated by the ISA (International Seabed Authority, 2010)
									Restore	Temporary refuge sites will not be mined until there are signs of recovery from mining activity at other sites, enabling local retention of organisms that could supply recently mined zones
									Restore	Re-locate fauna from mined sites to temporary refuges or even outside of the mining area to help retain an adult spawning population that would aid recolonisation. In addition
		Mobilisation and removal from oceans of key geochemical nutrients	The potential for trace-metal bioaccumulation	High	P				Restore	Maximise the potential for recolonisation of areas impacted by mining from surrounding populations and the preservation of undisturbed communities similar to the impacted community [††]

Project cycle	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (Temporary (T)/ Project Duration (PD) or Permanent (P))	**Mitigation hierarchy stage** (A, M, R)	**Mitigation activity**
									BES Impact mitigation	
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Mobilisation and removal from oceans of key geochemical nutrients	Suspended loads will remain over very long periods	High	P					No mitigations have been identified currently
			Disruption of the Biological (carbon and nutrient) pump of the oceans	Low	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
		Changes in the physic-chemical conditions around disturbance area	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
						Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently
			The release of sulfides during sediment disturbance	High	P	Loss of ecosystem function through occulsion and smothering of benthos	High	P		No mitigations have been identified currently
			The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	High	P					No mitigations have been identified currently
		Removal of polymetallic substrate	Changes in environmental conditions may alter metal partitioning and bioavailability (Calmano *et al.*, 1993; Cantwell *et al.*, 2002).	High	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
		Estimate disturbance of 300-600km2 per year through mining for 1.5-3 million metric tonnes of nodules per year	Removal of P, N, Fe, Si which are key biochemical nutrients fundamental to the function of marine biodiversity causing loss of ecological function, patterns and processes and decline in biomass, species composition and ecosystem services	Unknown	?	Loss of ecosystem function	High	P		No mitigations have been identified currently
			Removal of species associated with polymetallic formation (high species diversity)	High	P	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
			Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Unknown	Unknown	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	High	P		No mitigations have been identified currently
			Mining process will release metal ions into the water column, either in the benthic plume created by mining vehicles or, following dewatering on the surface vessel, in a mid-water plume	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
		Crusts may be collected whole, the transfer of nodules up the riser pipe will likely result in them also turning to slurry requiring processing at surface	Deep-sea ore deposits comprise complex mixtures of potentially toxic elements, which may be released into the sea during different stages of the mining process.	Unknown	Unknown					No mitigations have been identified currently
			Sediment dispersion changes both the chemical properties of the water and the seafloor sediment composition (Newell *et al.*, 1999; Desprez *et al.*, 2009)	Unknown	Unknown					No mitigations have been identified currently
		Deposition of sediments near surface following processing	Introduction of debris and sediment in the water column	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	P	Avoid	Never deposit sediment at surface
			Considerable quantities of organic contaminants and heavy metals may be released from the seabed sediments when they are disturbed (Latimer *et al.*, 1999).	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Medium	P		No mitigations have been identified currently
			Increased turbidity causes occlusion and reduced availability of sunlight photsynthesis causing long term effects on biological productivity	Medium	T	Disruption to fishery through reduction of fish populations	Medium	Unknown		No mitigations have been identified currently
			The potential for trace-metal bioaccumulation	Medium	P					No mitigations have been identified currently
			Reduction in primary productivity due to shading of phytoplanton	Medium	T					No mitigations have been identified currently
			Impacts on marine mammal behaviour	Medium	T					No mitigations have been identified currently
Resource Development (cont.)	Use of Large Extractive Machinery designed to be mobile of seabed (cont.)	Introduction of bottom water at the surface	Introduction of bottom water with its higher nutrient values could result in artificial upwelline increasing the surface productivity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	High	P	Avoid	Never introduce or deposit bottom water at surface
			Ecological disturbances and imbalances through dissolution of heavy metals (Cu and Pb) within the oxygen minimum zone	Medium	T	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	High	P		No mitigations have been identified currently
		discharge of tailings and effluent below the oxygen-minium zone	May cause some environmental harm to pelagic fauna	Unknown	Unknown	Disruption to fishery through reduction of fish populations	Unknown	Unknown	Avoid	Never discharge of tailings and effluent below the oxygen-minium zone
			Mortality and change in species composition of zooplankton	Unknown	Unknown	Disruption to ecosystem function through loss of primary producers and function of foodweb	Unknown	Unknown		No mitigations have been identified currently
			Effects on meso- and bathypelagic fishes and other nekton	Unknown	Unknown	Climate Change implications as oceans ability to absorb and cycle carbon in reduced	Unknown	Unknown		No mitigations have been identified currently
			Impacts on deep diving marine mammals	Unknown	Unknown	Disruption of the ocean biological pump	Unknown	Unknown		No mitigations have been identified currently
			Impacts to bacterioplankton	Unknown	Unknown					No mitigations have been identified currently
			Depletion of oxygen by bacterial growth on suspended particles	Unknown	Unknown					No mitigations have been identified currently
			Effects on fish behaviour and mortality caused by sediments or trace metals	Unknown	Unknown					No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport	Mining operations	Noise	The impacts of noise remain uncertain however need to learn from Marine sound and life information and note that sound can impact all marine life, including physical and behavioural impacts	High	PD	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	High	PD	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	High	PD				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to bird species resulting in species range restrictions	High	PD					No mitigations have been identified currently
		Light	Impacts of light on biodiversity	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Medium	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Medium	T				Minimise	Only use lighting where necessary
			Disturbance from support ship to bird species resulting in species range restrictions	Medium	T					No mitigations have been identified currently
		Chemical Spills	The potential for trace-metal bioaccumulation	Medium	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T	Minimise	in the event of an incident, ensure application of best pro-active mitigation practices to ensure containment and remediation are expedited
			Impacts on marine mammals	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		
			Impacts and mortality of pelagic fish	Medium	T					
		Waste Disposal	May cause some environmental harm to pelagic fauna	Medium	T	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Avoid	Apply MARPOL and IMO regulations - avoid disposal of wastes to sea
			Mortality and change in species composition of zooplankton	Medium	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Medium	T		No mitigations have been identified currently
			Reduction in primary productivity due to mortality of phytoplanton	Medium	T	Disruption to fishery through reduction of fish populations (mortality)	Medium	T		No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
At sea processing, ore transfer and transport	Mining operations	Waste Disposal	Effects on meso- and bathypelagic fishes and other nekton	Medium	T					No mitigations have been identified currently
			Impacts on marine mammals	Medium	T					No mitigations have been identified currently
			Depletion of oxygen by bacterial growth on suspended particles	Medium	T					No mitigations have been identified currently
			Effects on fish behaviour and mortality caused by sediments or trace metals	Medium	T					No mitigations have been identified currently
Mine Closure and Decommissioning	Abandonment of machinery on seabed	Machinery and infrastructure left on seabed	The release of metals and harmful substances from the sediment and through the weathering of solid mineral material may exert sublethal effects on both benthic and pelagic organisms (Simpson and Spadaro, 2016).	Medium	P				Avoid	Ensure machinery does not degrade in deep seabed envrionments
			Aquatic organisms may be exposed to harmful substances via the ingestion of contaminated particles, passive diffusion, or active transport through membranes	Medium	P				Avoid	Ensure materials used do not leach toxic substances over time
			Alteration of habitats and substrate (niche for biodiversity)	Medium	P				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
		Noise	Impacts of noise on biodiversity	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Apply Industry best practice Db thresholds for noise taking into account the species of concern (NOTE: micro-organisms are extremely sensitive to noise and noise can cause mortalities aof eggs, microorganisms and disrupt beviour etc.)
			Disturbance to benthic species resulting in species range restrictions	Low	T				Minimise	Sometimes leaving infrastructure on the seabed can result in lower impacts than removal (c.f. Brent Spar oil platform in North Sea) - ascertain whether leaving on seabed is less harmful than removal through EIA.
			Disturbance to bird species resulting in species range restrictions	Low	T					No mitigations have been identified currently
		Light	Impacts of light on biodiversity	Low	T	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Avoid	Avoid areas of high biodiversity
			Disturbance affecting breeding and/or behaviour of animals	Low	T	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Reduce temporal and spatial impacts of operations through efficient planning and execution of duties
			Disturbance to pelagic species resulting in species range restrictions	Low	T				Minimise	Only use lighting where necessary
			Disturbance to benthic species resulting in species range restrictions	Low	T					No mitigations have been identified currently
			Disturbance from support ship to bird species resulting in species range restrictions	Low	T					No mitigations have been identified currently

Project cycle	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (Temporary (T)/ Project Duration (PD) or Permanent (P))	Mitigation hierarchy stage (A, M, R)	Mitigation activity
									BES Impact mitigation	
Mine Closure and Decommissioning	Abandonment of machinery on seabed	Loss or modification to benthic habitat	Mortality of benthic fauna	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Loss of habitat of benthic fauna	Low	P	Disruption to fishery through reduction of fish populations	Low	T	Minimise	Minimise lifting of sediments near the seafloor
			Permanent alteration of the benthic geomorphology	Low	P		Low	Low		No mitigations have been identified currently
		Mobilisation of sediments (creation of sediment plumes)	Injury and mortality to benthic creatures	Low	P	Disruption to the biogeochemical processes of deep ocean ecosystem with potential consequences to the nutrient balance and associated life cycle of species	Medium	T	Minimise	Minimise Sediment penetration
			Loss of ecosystem function through occulsion and smothering of benthos	Low	P	Disruption to ecosystem function through loss of primary producers and function of foodweb	Low	T	Minimise	There should be minimum interaction of the collector system with the seafloor environment to keep it disturbance free
			Permanent alteration of the benthic geomorphology through deposition of sediments resulting in niche alteration and potential smothering of benthic species	Low	P	Disruption to fishery through reduction of fish populations (mortality)	Low	T	Minimise	Minimise lifting of sediments near the seafloor

* The original community structure may not be able to recover due to habitat loss as a result of substrate alteration (Desprez, 2000).

** Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

† Recommended approach to prediction and environmental assessment of plume development duringmineral harvesting would be to nest a fully-operational short-term forecasting model within eddy-resolving regional/global ocean (e.g. HYCOM58) and atmospheric (e.g. GFS59) simulations. These models would ideally be able to assimilate sea surface and water column data provided by altimetry, autonomous gliders, Argo floats or similar measuring platforms, and would be accompanied by a sediment-transport model which takes into account the cohesive properties and aggregation of fine-grained sediments.

†† Population connectivity (defined here in terms of genetic connectivity as opposed to demographic connectivity) is controlled by a suite of factors, including the local hydrographic regime, the distance between sites, small spatial-scale habitat suitability, the evolutionary history of the population in question, and life history characteristics - this makes restoration and recovery (natural) difficult and unlikely

12. UNCLOS and the commons – how do we deal with the need to apply precautionary principles and no harm in the deep sea?

The potential impacts and options to apply the mitigation hierarchy have been described above, with clear identification of gaps and uncertainties in baseline data and knowledge and in the cause and consequence of impacts from mining. More scientific data would better inform these assertions. Application of a precautionary approach would provide opportunity to avoid and minimise potential impacts.

In the interests of ensuring equitable, rational and sustainable development of seabed mineral resources, UNCLOS designates the seabed Area and its resources as the "common heritage of mankind" (UNCLOS, Part XI, Art. 136). The term "resources" is defined in the context of UNCLOS Part XI on the Area as "all solid, liquid or gaseous mineral resources in situ in the Area at or beneath the seabed, including polymetallic nodules".

All rights to the resources of the Area are vested in mankind as a whole, on whose behalf the International Seabed Authority is to act (UNCLOS Art. 137.2). Activities in the Area are to be carried out for the benefit of mankind, taking into particular consideration the interests and needs of developing States (UNCLOS Art. 140). Developing States are to benefit not only through a share in the financial and other economic benefits derived from mining activities in the Area, but also through provisions designed to promote capacity building, technology transfer, and access to and participation in marine scientific research and mining-related activities in the Area (UNCLOS Art. 140, 143, 144, 148) including training programs conducted by the contractors (UNCLOS Annex III Article 15).

An equally important objective, and legal obligation under UNCLOS, for both States and the International Seabed Authority is to ensure "effective protection" of the marine environment from "harmful effects" which may arise from seabed mining activities (Article 145). For this purpose the International Seabed Authority is required to adopt "appropriate rules, regulations and procedures for inter alia, (a) the prevention, reduction and control of pollution and other hazards to the marine environment, including the coastline, and of interference with the ecological balance of the marine environment … and (b) the protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment" (UNCLOS Art. 145 (a) and (b)). This is in addition to other obligations in UNCLOS that call for, inter alia, the protection and preservation of the marine environment," and the taking of measures "necessary to protect and preserve rare or fragile ecosystems as well as the habitats of depleted, threatened or endangered species and other forms of marine life" (UNCLOS Art. 192, 194(5)).

Global communities must fully understand the implications of mining because large parts of the seabed are legally the 'common heritage of mankind'. A precautionary approach, as envisaged by (Durden *et al*, 2017), would incorporate routine reviews to prevent – rather than assess the likelihood of – harm. Weaver and Billett, (2016) suggest that uncertainties such as lack of baseline ecological data warrant the use of the precautionary approach. The precautionary approach aims to ensure a high level of environmental protection through the use of smart, risk-averting decisions, but the term can be interpreted in different ways by different stakeholders.

Many aspects of deep-sea species biology are unknown – it is impossible to predict genetic or demographic connectivity for species that have yet to be described. Mining could lead to widespread habitat loss and to species extinction.

12.1 Defining no-harm/acceptable harm versus serious harm

Existing International Seabed Authority regulations for deep-seabed mineral exploration of manganese nodules, seafloor massive sulphides, and cobalt-rich crusts provide only a definition for "serious harm". Under these regulations, "serious harm to the marine environment" is defined to mean "any effect from activities in the Area on the marine environment which represents a significant adverse change in the marine environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally recognised standards and practices" (International Seabed Authority Regulations (nodules), [12]; (sulphides), [13]; (crusts), [14]).

Such standards, as spelled out in the regulations and an Advisory Opinion by the International Tribunal for the Law of the Sea, are to ensure the application of "best environmental practices and the precautionary approach" (Regulations 31(2)). The potential for serious harm entails serious consequences. As required by UNCLOS Article 165(2)(l), the Legal and Technical Commission, the International Seabed Authority's advisory body, is to, among other tasks, develop recommendations to the Council, the International Seabed Authority's executive body, to disapprove mining in areas where "substantial evidence indicates the risk of serious harm to the marine environment". The Legal and Technical Commission is also empowered to develop recommendations for emergency orders during mining operations to "prevent serious harm to the marine environment" (UNCLOS Art. 165 (k)). In turn, the International Seabed Authority Council is required to issue emergency orders, which may include orders for the suspension or adjustment of operations, to prevent serious harm to the marine environment arising out of activities in the Area (UNCLOS, Art. 162(2) (w)).

Unless mining proponents and permitting decision-makers have clear and comprehensive parameters for what constitutes both "effective protection" as well as "serious harm" and associated significant adverse change to the marine environment, there will be a risk that seabed mining could cause unacceptable impacts.

Some helpful guidance for defining serious harm may be drawn from the definition of "significant adverse impact" in the International Guidelines adopted in the context of deep-sea bottom fishing on the High Seas by the FAO in 2009. These guidelines were developed to help states and regional fisheries management organizations implement a UN General Assembly Resolution of 2006 which called upon them to, among other things, "assess, on the basis of the best available scientific information, whether individual bottom fishing activities would have significant adverse impacts on vulnerable marine ecosystems and to ensure that, if it is assessed that these activities would have significant adverse impacts, they are managed to prevent such impacts, or not authorized to proceed" (UN General Assembly Resolution 61/105 para 83(a)).

This FAO definition is particularly relevant as the International Seabed Authority Mining Code contains a similar formulation with respect to exploration impacts, which provide that: "The Commission shall develop and implement procedures for determining, on the basis of the best available scientific and technical information…., whether proposed exploration activities in the Area would have serious harmful effects on vulnerable marine ecosystems, including seamounts and hydrothermal vents], and ensure that, if it is determined that certain proposed exploration activities would have serious harmful effects on vulnerable marine ecosystems, those activities are managed to prevent such effects or not authorized to proceed." (International Seabed Authority, https://www.isa.org.jm/legal-instruments).

The FAO Guidelines provide that significant adverse impacts are "those that compromise ecosystem integrity" (FAO, 2009, para 17). It lists six factors to consider:

1. intensity and severity of the impact;
2. spatial extent of the impact relative to habitat availability;
3. sensitivity and vulnerability of the ecosystem to the impact;
4. ability for the ecosystem to recover;
5. the extent of ecosystem alteration; and
6. the timing and duration of the impact relative to species and habitat needs (para 18).

It further considers duration and frequency of impacts as metrics for determining significance (para 19–20). In addition, the authors recommend including the concepts of:

7. the probability of impacts occurring;
8. cumulative effects of impacts, and
9. scientific uncertainty related to impacts, when determining what deep-seabed mining impacts should be considered “significant”.

The FAO Guidelines also provide criteria for identifying “vulnerable marine ecosystems” in the context of deep-seabed bottom fishing, but their applicability to seabed mining is beyond the scope of this report.

In reality, assessing any changes to deep-sea ecosystems induced by mining activities is challenging at best. The remoteness and expense of studying these ecosystems has resulted in major knowledge gaps concerning habitat distribution (regionally and globally), ecosystem structure and function. These gaps include species identities (most deep-sea species are undescribed), biodiversity, distribution patterns and biogeography, community distributions, dynamics, trophic relationships, population connectivity, physiological tolerances, ecosystem tolerances, and resilience. Without this baseline information, it is difficult to assess the impacts of any human activity in space and time, to determine whether these impacts are enduring or transitory.

The use of a systematic approach based on a robust ecological assessment of the key physical, biogeographic, ecological, and biodiversity features of the deep-seafloor will be important when dealing with the challenges of managing a large underexplored area such as the deep-sea. Cumulative impacts of multiple mining actions (in space and time) and additive perturbations from direct human activities (e.g., fishing activities, contaminants and spills), and climate-change related stressors (e.g., warming, ocean acidification and deoxygenation) must also be considered when evaluating the significance of changes to and/or impacts on deep-sea ecosystems.

Environmental protection regulations to be enacted and implemented by the International Seabed Authority in the future, including functional distinctions and definitions of “harmful effects” and “serious harm,” will have far-reaching consequences both beyond and within national jurisdictions.

Under UNCLOS, where mining activities may cause serious harm, the International Seabed Authority has the power to:

- set-aside areas where mining will not be permitted,
- deny a new application for a contract to conduct seabed mineral activities;
- suspend, alter or even terminate operations, and
- hold the contractor and its sponsoring state liable for any environmental harm if it ensues (UNCLOS Art. 162((2)(w) and (x) and 165 (2)(k) and (l) and Annex III Article 18).

Such standards will also inform national laws and regulations for mining activities within national jurisdiction, for such rules are to be “no less effective than” international rules, standards, recommended practices and procedures (UNCLOS Art. 208).

Fundamentally, however, designing a system to evaluate the significance of harm in the deep sea, where “serious harm” is used as the key trigger for preventive and precautionary action, we need to know:

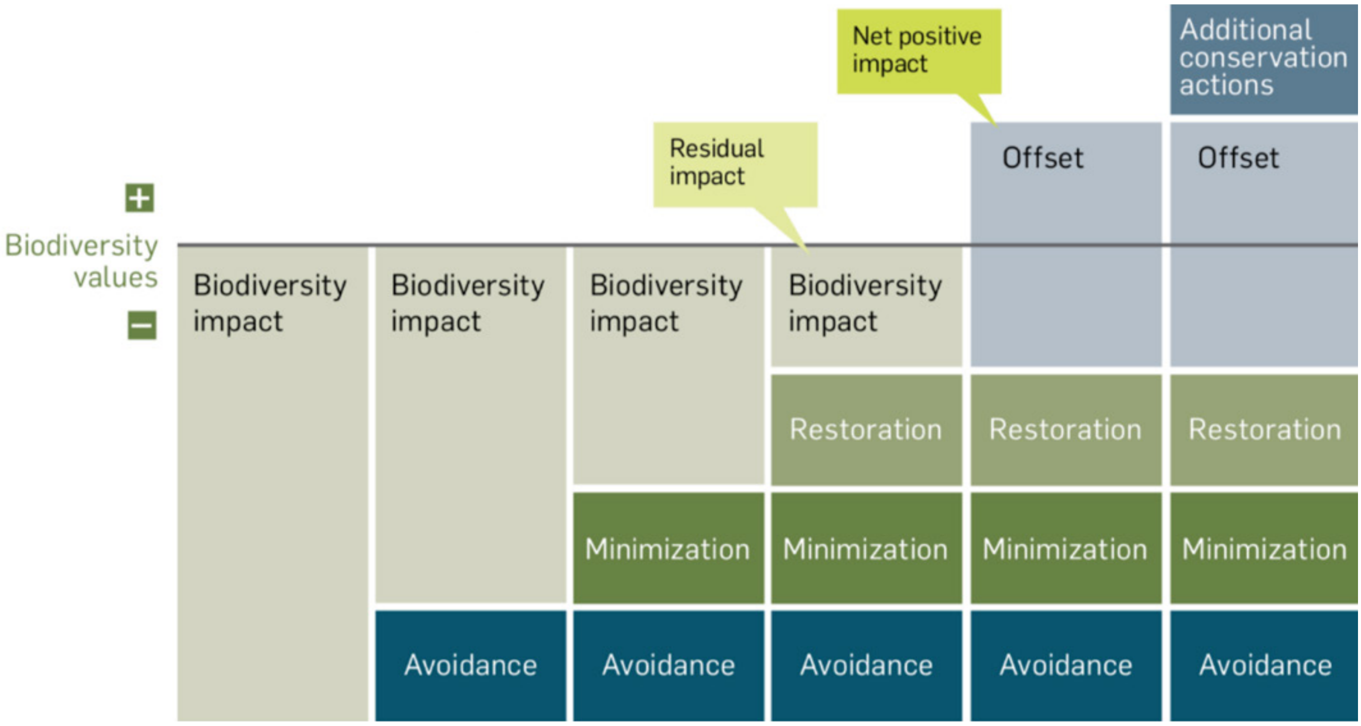
- How to define “serious harm” in the context of deep-seabed mining?
- What key factors or parameters need to be measured to inform the decision about whether an impact constitutes serious harm or not?
- What are the special features of the deep-sea habitats targeted by mining companies that affect the significance of impacts?

13. Deep-seabed mining: fundamental considerations to apply the mitigation hierarchy

Considering the evidence outlined above, the impacts of seabed mining on physical, ecological and geochemical state of the oceans are likely to be considerable. Assessment of the impacts is difficult yet needs to form the backbone of decision making to determine the acceptability of proposed exploitation and the risks to environmental receptors. This cannot be undertaken in isolation nor without consideration of the wider ocean system, as demonstrated by the extensive and complex ocean connectivity and the interdependencies of primary production and the biological pump on the microbes and biodiversity maintaining the stasis of ocean chemistry and ecological function (Part B of this report).

No net loss (Niner *et al.*, 2018) is an objective or target for development projects in which the impacts on biodiversity and ecosystem services caused by the project are balanced or outweighed by measures taken to prevent and remediate the project's impacts through the application of a mitigation hierarchy (Figure 56). Briefly described, the mitigation hierarchy is a framework comprising a series of steps that are to be applied sequentially to first **avoid** impacts, then **minimise** impacts and to undertake on-site r**ehabilitation and/or restoration** to address impacts that cannot be avoided or minimised. The final step in the hierarchy is biodiversity offsetting in which measures are taken to compensate for any residual significant, adverse impacts that cannot be avoided, minimised and / or rehabilitated or restored. Measures that address residual impacts but are not quantified to achieve No Net Loss or not secured for the long term are compensation, otherwise known as compensatory mitigation.

Figure 56: The mitigation hierarchy – avoid – minimise – restore - offset



Niner *et al.*, (2018) conclude that avoidance and minimising impacts from deep-seabed mining are the only viable means of reducing biodiversity loss. Boetius and Haeckel (2018) go further and state that managing the risks of commercial deep-seabed mining is not possible, from either a financial or ecological perspective.

13.1 Avoidance

Avoidance of impacts can be achieved through spatial, temporal and operational measures, but need to be based on and informed by science to ensure a no net loss outcome or no harm objective.

Avoidance is the first and most important step in the mitigation hierarchy and is the only way to mitigate impacts of marine ecosystems with any certainty. It is the approach advocated by the scientific community for mitigating the impacts of deep-sea research. Over-sampling and unintentional and intentional damage to sulphide structures are among the impacts to vent ecosystems resulting from scientific research. Concern about these impacts prompted development of a voluntary code of conduct for scientific research at vents that emphasizes avoidance of activities that might have long-lasting and deleterious effects (Devey, Fisher and Scott, 2007).

Avoidance of impacts requires **early intervention, proactive planning** and **recognition of biodiversity and ecosystem values to ensure no harm outcomes are achieved.** It calls for **excellent knowledge of both the baseline state and the activities proposed.** Though arguably, if applying the precautionary principles avoidance is the only way forward in the absence of knowledge and in the face of uncertainty. The current state of scientific knowledge is limited by time and spatial frames of effort, cost of data collection and analysis and complexity. Requirements for effective avoidance and challenges in application are elaborated on below:

13.1.1 Defining biodiversity values and no-go areas for deep-seabed mining

The impact of continuous and cumulative commercial-scale deep-seabed mining operations may generate interacting stressors that are very different from those associated with one single mining event (Van Dover *et al.*, 2017) and well beyond the natural variations that the seabed has experienced to date. One approach to limit biodiversity loss in deep-sea ecosystems is to establish a coherent network of Marine Protected Areas, (Van Dover *et al.*, 2014; France, 2016). Such networks can protect biodiversity from the impacts of deep-seabed mining and other anthropogenic activities. An added advantage of MPA networks is that the creation of management plans can help biologists to gather baseline data on deep-sea ecosystems (Dunn, *et al.*, 2018).

13.1.1.1 Protection for hydrothermal vents

As a first step in implementing the UNCLOS obligations outlined in Articles 145 and 194, the International Seabed Authority's Mining Code for exploration calls for application of a precautionary approach and protection of "vulnerable marine ecosystems, in particular, hydrothermal vents…(Tunnicliffe *et al.*, 2018)" from serious harm (Regulations on Prospecting and Exploration for Polymetallic Sulphides in the Area; Regulation 33). This call for protection of vulnerable marine ecosystems is also included in draft exploitation regulations proposed by the International Seabed Authority and in a parallel discussion paper on environmental matters related to exploitation regulations.

Protection of active hydrothermal vents by the deep-seabed mining sector would be consistent with "No-Go Zones" for mining on land, where avoidance of areas characterized by high biodiversity and endemism, rare or endangered species, rare habitats, and intactness, is practiced. While a moratorium on mining of active vent ecosystems may be considered a far-reaching precautionary measure by some, it is currently the only known measure that would, with certainty, be effective in protecting ecosystems associated with active vents in accordance with UNCLOS Articles 145 and 194: Article 145 requires the International Seabed Authority to prevent "damage to the flora and fauna of the marine environment" from deep-seabed mining, and Article 194 requires States to take measures "necessary to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life".

Marine Protected Areas contribute to mitigation through the establishment of avoidance zones. To date, a number of countries have created Marine Protected Areas for hydrothermal vent ecosystems though there are currently no hydrothermal vent Marine Protected Areas in international waters. Marine Protected Areas that include hydrothermal vents and that manage human activities can implement avoidance measures with obligatory compliance (Van Dover *et al.*, 2012). Establishment of networks of chemosynthetic ecosystem reserves as part of mining regulations has also been recommended to the International Seabed Authority as a measure to address issues of population maintenance and gene flow for systems where mineral extraction or other human activities might put vent ecosystems at risk (Van Dover, 2014).

13.1.1.2 Ensuring good baseline understanding of biodiversity

Despite recent advances, much of the existing state-of-the-art technologies and methodologies are still at the pilot test stage and cannot be used on an industrial scale for rapid biodiversity assessment. There is no methodology that can rapidly assess biodiversity across the size scales from megafauna to microbes, either to give the genetic connectivity or dispersal potential of species vulnerable to impacts. Faced with such sparse data on deep-sea biodiversity and dispersal ecology, particularly where the direct observation of larvae and reproductive traits is not a possibility, molecular and modelling approaches will be required to provide valuable insights into patterns of differentiation and connectivity in marine systems. However, our lack of knowledge forces us to use many assumptions in such endeavours. A coordinated effort is needed when carrying out baseline studies on potential mining areas to fill these gaps, an effort that must bring together academic researchers, contractors and regulators. Until informed predictions on impacts of mining can be better made, a precautionary approach should be implemented to best maintain biodiversity at levels that will theoretically avoid global extinctions.

13.1.1.3 Difficult to avoid due to gaps in data and scientific knowledge

Attempts to understand the biogeography in the deep sea are hampered by: the size and volume of the deep sea; most species found there are rare and known from only a few or even a single specimen per locality; species that can be clearly differentiated using molecular techniques may look very similar morphologically - these are the so-called ‘cryptic species’. As a result, most rare species appear to be endemic, and the cosmopolitan nature of others should be challenged if they are not supported by complementary morphological and genetic information.

Despite considerable sampling and study of the deep sea over the past century, our knowledge of species distribution across most spatial and temporal scales is still very poor, with only a few areas that have been studied in some detail. Hence, our current level of biogeographic knowledge is not sufficient to make accurate predictions of the consequences of mining, which may continue for many decades. This lack of knowledge is compounded by the observation that the majority of species are only rarely sampled. Using current sampling methods and efforts, it is difficult to establish whether such species are genuinely rare and in danger of extinction or merely very widely distributed in low numbers and, therefore, at less risk.

The vast areas involved, together with the remote location of most mining areas, present logistical challenges for environmental sampling. To date, studies indicate that some species are widely distributed at scales of 100 kilometres to 1,000 kilometres. However, many species have not been collected in sufficient numbers or from across different areas, so we cannot say whether they will be impacted by mining activity. This problem can be best addressed by focused biological sampling programmes, the use of new molecular technologies, and strong and vigorous collaboration between mining contractors and scientists.

13.1.1.4 Difficult to avoid due to lack of knowledge on connectivity

Quantifying scales of population connectivity is crucial to understanding the role of the ecological processes and environmental parameters needed to predict population response to environmental disturbance, and to develop efficient conservation strategies. No baseline study or monitoring regime can be effective without the development and integration of a regional hydrodynamic model, which is ideally run over several years in order to capture inter-annual and seasonal variabilities of circulation patterns. In addition, such models need a range of reproductive and life history parameters such as: spawning time; spawning sites; feeding and prey environments; sex ratio, fecundity, reproductive mode (continuous, discontinuous, annual, etc.) and season.

13.1.1.5 Improving avoidance option through understanding reproductive traits and life histories

Further studies on the reproductive biology of the species inhabiting areas targeted for mining are crucial in order to accurately assess the potential impacts. Determination of spawning events would allow a better understanding of reproductive seasonality and would facilitate the detection of potentially crucial periods in which disturbance should be minimised. Moreover, further insights into larval biology, such as information on larval duration and dispersal, would enable us to understand the current level of connectivity among local coral populations and determine the potential impacts on their dynamics.

13.1.2 Using a risk-based approach to avoidance

TO address lack of knowledge and uncertainties, two approaches suggested here. One derived from Levin *et al* (2016) and the other a more traditional approach used in biodiversity conservation planning and management.

13.1.2.1 Significant adverse change: thresholds and triggers

An ecological threshold is a point at which changes in an important ecosystem property or phenomenon have exceeded normal ranges of variability. Such thresholds may, but will not necessarily be, “tipping points” at which a small further change will abruptly produce a large ecosystem response resulting in a regime shift (change in state). In the context of deep-seabed mining, ecological thresholds should help to inform the determination of when an adverse change and/or impact may be considered a significant one, i.e. ‘serious harm’. The identification of ecological thresholds requires, at the very least, knowledge of long-term (years to decades) average baseline conditions and natural ecological variability. Although natural variability is often determined from time series investigations of 3 to 25 years, the appropriate time period for assessment will be system-dependent. With an understanding of ecological thresholds, decision-makers can determine:

- what impacts are expected to exceed ecological thresholds and therefore should not be permitted; and
- what impacts could exceed ecological thresholds and therefore require management, monitoring and then cessation of operations if the threshold is neared.

However, one of the greatest challenges for environmental management of the deep sea is the substantial lack of data, making the use of ecological thresholds for decision making in deep-seabed mining a difficult one at best. The mandate to apply a precautionary approach and a lack of baseline data necessary to define ecological thresholds should lead to heightened restrictions, including at least slow ramping up of activities until thresholds are better characterised. Key metrics that may serve as threshold indicators are measures of biodiversity, abundance, habitat quality, population connectivity, heterogeneity levels, and community productivity.

If information is not available to set particular ecological thresholds, a suite of other indicators can be used to determine the likelihood of significant adverse change and impacts, including those that address species-, community- or ecosystem-level impacts. Here all three ecological levels are level are considered (see below). These impacts can be evaluated in local, regional or global contexts.

Ecological Level	Impact
Significant species-level changes or impacts	(i) extinction; (ii) significant decline in abundance; (iii) decline in foundation species; (iv) reduction below critical reproductive density; (v) loss of source populations; and/or (vi) loss of critical stepping-stone populations.
Community-level impacts	(i) alteration of key trophic linkages among species in a community (ii) reduction in species diversity beyond natural levels of variability (iii) regional declines in habitat heterogeneity, such as loss of entire habitats or community types
At the ecosystem-level	Impairment of important ecosystem functions such as biomass production nutrient recycling or carbon burial can lead to loss of major ecosystem services upon which society depends. They may include loss of carbon sequestration capacity, genetic resources, or fisheries production.

While the concept of ecosystem services underlies many of the above indicators and metrics, threshold levels of decline in services have yet to be identified. These services are likely to vary by habitat, and the spatial and temporal scale at which changes are significant to the ecosystem have not been defined here. Additional measures that reflect key services are needed and a quantifiable measure of lost services will need to be incorporated into significance assessment

13.1.2.2 Biodiversity and ecosystem services: risk-based approach

Corporations and some governments have revealed, in debates and discussions across the sector, a predilection for a 'risk-based' approach to biodiversity and ecosystem services, rather than by drawing 'lines on a map' to establish 'no go' areas.

In principle, a risk-based approach can ensure adequate protections for biodiversity and ecosystem services and is fully compatible with a 'no go' approach. The key to integrating the two approaches is to specify clear criteria and risk thresholds that can identify when and where the risks to biodiversity and ecosystem services are so high that mining or extraction should not proceed. Applying a risk-based approach to biodiversity and ecosystem services for mine sites would involve the following general steps:

1. Identify the biodiversity and ecosystem services values at risk, including species, ecosystems and ecosystem services, and the associated measurement endpoints.
2. Identify uncertainties in both exposure (area of impact and time) and hazard (type of activity) for the project and location in question.
3. Establish a priori assumptions, for example, assume that mining poses significant risks to biodiversity and ecosystem services except where compelling evidence shows that this is not the case or, alternatively, that mining does not pose a threat unless evidence shows it does.
4. Determine, for each biodiversity and ecosystem value at risk, the threshold weight of evidence required to overturn the presumption. For example, if it is assumed that industrial-scale cobalt crust or polymetallic nodule removal does not pose a significant risk to a particular biodiversity and ecosystem services value, what is the weight of evidence that would be required to overturn this presumption?
5. Determine, for each activity in the mining process and for each biodiversity and ecosystem services value, the acceptable risk threshold. In other words, what is the acceptable level of risk tolerance?
6. Conduct a transparent risk assessment based on hazard, exposure, risk tolerance, available evidence and a priori assumptions.
7. If the assessed risk is found to be above the threshold, it may be possible to design appropriate mitigation strategies and go back to step 1.

An illustration of potential risk criteria and thresholds related to biodiversity and ecosystem services, and potential implications for deep-seabed mining, is provided in Table 16.

Table 16: Indicative guidance for assessing risk in relation to biodiversity and ecosystem services

Risk	Biodiversity and ecosystem service (BES) context	Implications
Very high or high	Inside or directly adjacent to World Heritage site(s), and/or protected areas listed in IUCN Categories 1-6.	No go
	Where impacts to BES are irreversible and BES is irreplaceable e.g. removal of seamount crusts; removal of benthos in abyssal plains; removal of living sulphide massifs	No go
High or medium	- Inside or directly adjacent to Key Biodiversity Areas, core areas of Biosphere reserves. - Likely to affect the provision of ecosystem services of high value either locally or globally	Can only progress on a case by case basis but generally a no go for mining - In the case of Key Biodiversity Area, may be certifiable as long as the Key Biodiversity Area Guidelines are implemented effectively. - Requires a commitment to achieve a Biodiversity Net Gain (and offsets must be possible/feasible in the context under consideration (not likely in some environments see Offsets section 12) and must be implemented in accordance with the IUCN Biodiversity Offset Policy and/or the BBOP Standard). - Requires fully independent BES assessment, planning, mitigation, rehabilitation, and compensation to ensure Biodiversity Net Gain, as defined by the IUCN Biodiversity Offset Policy
Medium	- Inside or directly adjacent to habitat of endemic restricted range species. - Confirmed sightings or physical evidence of the presence of threatened or endangered species within past 20 years. - All sites of special scientific or cultural interest. - Likely to affect the provision of ecosystem services of high value locally.	- Potential to proceed with no net loss objective and application of the mitigation hierarchy - Requires fully independent BES assessment, planning, mitigation, rehabilitation, and compensation to ensure Biodiversity Net Gain, as defined by the IUCN Biodiversity Offset Policy. - Subject to $$$/ha performance bond, released upon verified completion of milestones agreed with independent commission comprising local community representatives.
Low	All other areas	- Potential to proceed with no net loss objective and application of the mitigation hierarchy - Requires fully independent BES assessment, planning, mitigation, rehabilitation, and compensation to ensure Biodiversity Net Gain, as defined by the IUCN Biodiversity Offset Policy.

13.1.3 Using spatial planning and marine protected area planning for avoidance

Niner *et al.* (2018) argue that mitigation measures should consider spatial planning, including the distribution of habitats, species ranges and connectivity, and the location and extent of proposed mining. Marine ecosystems are under increasing pressure from climate change, ocean acidification, oil and gas extraction, fishing, marine litter and shipping (United Nations [UN], 2016). Establishing Marine Protected Areas before exploration and exploitation is a priority and detailed monitoring is key (Halfar and Fujita, 2002; Van Dover *et al.*, 2017, 2018).

Much of the current available advice focuses on deep-seabed mining, but is conceptually applicable to all seabed mining. Should commercial deep-seabed mining take place, it is plausible that exploitation could occur simultaneously in multiple adjacent locations – whether on vents, on seamounts or on nodule fields. Forecasting and evaluating the effects of deep-seabed mining will involve quantifying the cumulative and interacting effects of mining combined with other stressors (Levin *et al.*, 2016; Kroeker *et al.*, 2017). A strategic environmental assessment could be a first step toward assessing the impact of multiple anthropogenic activities in the ocean (Rogers, 2018).

Wedding *et al.* (2015) support the application of the precautionary principle in relation to establishing Marine Protected Areas in deep-seabed mining regions. Lessons learned from the planning process relating to exploration claims within the Clarion Clipperton Zone in the Pacific Ocean indicate that existing and emerging claims reduced the effectiveness of proposed science-based Marine Protected Area networks. Wedding *et al.* (2015) suggest that all exploration contracts be suspended and no exploitation contracts issued until Marine Protected Area networks are fully implemented.

Giving marine scientists the opportunity to fully survey an area of the seabed and overlying waters before any permits are issued could help to protect fragile biota if the survey data are used to formulate policy. In the absence of robust baseline environmental data, contractors may otherwise simply designate no-mine areas, or preservation reference zones, in regions of their contract area that are devoid of nodules and, therefore of no financial interest (Gjerde *et al.*, 2016; Vanreusel *et al.*, 2016) rather than on the basis of informed conservation objectives. Improvements to the current International Seabed Authority could include full transparency and independent scientific reviews at all stages by observers from NGOs or institutions (Ardron *et al.*, 2018).

13.1.3.1 Defining thresholds for risk and impact significance: example for hydrothermal vents

Recognition of the ecological rarity and vulnerable status of biodiversity and the ecological significance of the ecosystem function, patterns and processes within the deepsea is fundamental and should inform decisions on where mining can be permitted. Risks of loss of such systems needs assessment.

The ecological rarity and vulnerable status of active hydrothermal vent sites is not new. Key interventions for full protection of ecosystems at active hydrothermal vents have been enacted by several coastal States through establishment and management of area-based protection. Canada recently augmented its 2003 implementation of the Endeavour Hydrothermal Vents Marine Protected Area by announcing its intention to protect all hydrothermal vents sites in its waters in a large offshore area. There exists a multitude of legal obligations, policy statements, and precedents for the protection of hydrothermal vents because of their rare and vulnerable (or “fragile”) characteristics. In 2004, the United Nations General Assembly Resolution 59/24 called for States to manage risks to the marine biodiversity of hydrothermal vents and the United Nations General Assembly also adopted Resolution 59/25, committing States to take action urgently to consider interim prohibitions on destructive fishing practices that have adverse impacts on vulnerable marine ecosystems including seamounts, hydrothermal vents and cold-water corals.

In the same year, the Conference of the Parties to the Convention on Biological Diversity, in its Decision VII/5 (paragraph 30) agreed to the “urgent need for international cooperation and action to improve conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction”, including through the establishment of Marine Protected Areas that include seamounts, hydrothermal vents, cold-water corals, and/or other vulnerable ecosystems. United Nations General Assembly Resolution 61/105 (adopted in 2006) commits States to “protect vulnerable marine ecosystems, including … hydrothermal vents …, from destructive fishing practices, recognising the immense importance and value of deep-sea ecosystems and the biodiversity they contain.” The Council of the European Union requires the protection of hydrothermal vents from bottom fishing through Council Regulation 734/2008, adopted by the EU to implement United Nations General Assembly Resolution 61/105.

In 2008, parties to the Convention on Biological Diversity recognised hydrothermal vents as meeting criteria for designation as “Ecologically and Biologically Significant Areas”, where enhanced conservation and management measures may be needed. Provisions of the Convention on Biological Diversity related to States’ activities regarding biodiversity protection apply beyond areas under national jurisdiction; States that currently sponsor exploration for polymetallic sulphides in such areas (India, Germany, France, Korea, Russia, China) are bound by the Convention on Biological Diversity.

The multilaterally negotiated International Guidelines for the Management of Deep-Sea Fisheries in the High Seas, adopted in 2008 to assist States in the implementation of UN General Assembly Resolution. While United Nations General Assembly resolutions and International Guidelines are not legally binding, key provisions of these instruments, including criteria for identifying vulnerable marine ecosystems and requirements that such ecosystems be protected from significant adverse impacts, have become binding on States in most High Seas areas through their incorporation into regulations adopted by Regional Fisheries Management Organizations, which have the legal competence to manage bottom fisheries in areas beyond national jurisdiction.

In 2016, the UN General Assembly reaffirmed and strengthened the commitment of States and Regional Fisheries Management Organizations to adopt and implement regulations to protect vulnerable deep-sea ecosystems from the adverse impacts of bottom fisheries and encouraged regulatory bodies with competence over other activities potentially impacting such ecosystems in areas beyond national jurisdiction (e.g., the International Seabed Authority) to consider doing the same (Resolution 71/123). The Oslo and Paris (OSPAR) Commission for the Convention for the Protection of the Marine Environment of the North-East Atlantic recommends protection and conservation of hydrothermal vent fields as “priority habitats” in the OSPAR maritime area (NE Atlantic). OSPAR also called for “raising awareness of the importance of hydrothermal vents/fields occurring on oceanic ridges among relevant management authorities, relevant actors including industry sectors and the general public” . Protection has also been accorded to vent ecosystems by the scientific community through responsible research practices, as outlined in the 2007 InterRidge Code of Conduct.

The UNESCO Marine World Heritage Program also recently highlighted the Lost City vent ecosystem on the Mid-Atlantic Ridge as one example of a site that meets criteria for outstanding, universal value in international waters. From these actions, it is evident that active hydrothermal vent ecosystems are recognised through multiple international, regional, and State interventions as natural areas in need of protection and conservation.

13.1.3.2 Regional Environmental Management Plans

A Regional Environmental Management Plan (REMP) lays out the goals, rules, and management tools particular to a specific region where mining could occur. Different regions and habitats require different rules and thresholds to ensure effective protection. So REMPs must be tailored to the ecosystem structure and functions for the specific area in question, as well as the different habitats, community structure, biodiversity, connectivity, and resilience of the area. In general, there are two main classes of management tools for REMPs:

- All REMPs should conserve areas of the seabed through a network of large no-mining zones. These zones are called “areas of particular environmental interest” (APEIs). APEIs should cover the full range of habitats, biodiversity, and ecosystem functions within the overall management area. Development of the APEI network should be based on scientific principles. Placement of such networks is typically based on spatial analyses of physical, geochemical, ecological, and social datasets.

- Rules-based management tools. REMPs are more than maps of where contractors cannot mine. They should also include rules for managing the areas where mining is permitted. These could be general rules such as requiring updates to baseline data, taking account of cumulative impacts, and ensuring the application of best environmental practices. Rules could also be region- or species-specific. Certain habitats could be given special protections. Mining could be suspended during key breeding or migratory seasons. Underwater sites of historical or cultural significance could also be set aside.

13.1.3.3 Defining thresholds for risk and impact significance: Areas of Particular Environmental Interest (APEI)

APEIs need to be identified and set aside and would:

- Include networks of APEIs that are representative of the range of habitats, species, and ecosystem functions in the area.
- Include in the network ecologically important areas that harbour unique biodiversity and provide important ecosystem services or functions.
- Offer connectivity for populations. In other words, APEIs should be close enough so that larvae and other dispersing life stages can travel between APEIs to maintain and/or restore population sizes.
- Replicate protections so that species, habitats, and ecological processes are covered in more than one protected area.
- Assure viable sites of the size, populations, and protections sufficient to sustain their ecological functions and maintain self-sustaining populations.
- Draw APEI networks that protect 30 to 50 percent of the total management area.2 The ISA has committed to protecting 30 to 50% of the Clarion-Clipperton Zone in the Eastern Pacific Ocean, the only area with a management plan to date.3 Scientists have called for similar safeguards in other regions.

13.2 Minimisation

In terms of minimising impacts, a key focus will be the reduction of physical footprint and both spatial and temporal implications of impacts of activities. For example, the impacts of sediment plumes. This could be achieved through investing in technology to reduce sediment emanating from the mining tool, or through modifying the means by which sediments are returned to the water column, including their release directly back into the mined area.

13.3 Restoration

Restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed and is critical for habitats where natural recovery is hindered. Uncertainties about restoration cost and feasibility can impede decisions on whether, what, how, where, and how much to restore.

Active restoration activities may be complex in the deep sea, mainly because of our limited understanding of deep sea ecosystems and the high cost of running trials in deep water. To date, the majority of case studies for restoring marine habitats come from coastal regions. A number of approaches have been proposed for deep water habitats, including restoring hard substrates, e.g. inactive vent chimneys, or rocky reefs, and transplanting or seeding organisms and larvae to the restoration areas to aid (Cuvelier *et al.*, 2019), but these approaches remain largely theoretical at this point. Below, some general points about restoration are raised, drawing mainly upon knowledge gained in shallow water ecosystems.

Restoration techniques can be used to re-establish or improve ecosystems that have been degraded, damaged or removed by project activity. The Cross-Sector Biodiversity Initiative (CSBI) defines restoration as ‘measures taken to repair degradation or damage to specific biodiversity features and ecosystem services of concern following project impacts that cannot be completely avoided and/or minimised (Cross Sector Biodiversity Initiative (CSBI), 2015). The Society for Ecological Restoration (SER) defines ecosystem or ecological restoration more broadly as “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed”(Convention on Biological Diversity (CBD), 2012). Restoration will generally occur on-site after impacts have already occurred and can be undertaken during all phases of a project. Restoration in this section should be distinguished from restoration activities required to implement offsets which generally occur off-site (Cross Sector Biodiversity Initiative (CSBI), 2015). Offsets are unlikely to be possible in deep-sea environments and are addressed separately in Section13.4.

Restoration activities should be considered early in the project life given the high uncertainty in successfully restoring certain ecosystems and the slow pace of restoration. Restoration in the marine environment is considered technically feasible in waters shallower than 100m depth, however also very challenging. Marine environmental restoration techniques, are only in developmental stages, with highly variable success rates (Statton *et al.*, 2012). For example, there are few studies which demonstrate successful large-scale seagrass rehabilitation. The main reasons for failure of seagrass restoration projects around Australia included a lack of location-specific information on seagrass growth, and insufficient development of planting techniques to ensure the success of projects (Ganassin and Gibbs, 2008). For this reason, regulatory frameworks may be unlikely to accept restoration of complex marine habitats (i.e. coral reef) as a feasible option. In this circumstance the proponent should not consider restoration as a viable option. Further consideration should be given to avoidance and reduction measures (Goreau and Hilbertz, 2005).

The cost of successfully implementing marine restoration projects is likely to be significant and should not be underestimated. For example the cost of planting seagrass was estimated at AUD $10,000-166,000 per hectare in 2005 (D. A. Lord & Associates Pty Ltd, 2005). The median and average reported costs for restoration of one hectare of marine coastal habitat were around US$80 000 (2010) and US$1 600 000 (2010), respectively, the real total costs (median) are likely to be two to four times higher (Bayraktarov *et al.*, 2015). Alternatives to direct planting or translocation includes active indirect on-site restoration techniques such as promoting the recruitment of mangroves, seagrass or coral by deploying suitable substrate and materials.

Marine restoration activities may involve field works such as rubbish removal, weed control, sedimentation control, measures to improve water quality, habitat enhancement (provision of shelter, foraging or spawning habitats, facilitate natural colonisation or active planting (Hopkins, White and Clarke, 1998). Restoration targets should be established that are socially acceptable to relevant stakeholders and will be linked to the baseline conditions prior to impacts, or to a reference site (Cross Sector Biodiversity Initiative (CSBI), 2015). Restoration planning must consider temporal time lags that occur between biodiversity and ecosystem service losses at the field development phase and subsequent restoration gains.

13.3.1 Ecosystem resilience and recovery

Future extraction of deep-seafloor minerals will have adverse effects on the benthic biota. It is thus important to examine and predict the potential for and mode of deep-sea ecosystem recovery.

Within MIDAS a variety of anthropogenic and natural disturbance events were investigated in order to estimate the impact of industrial mining on benthic organisms associated with nodules from abyssal plains, ferromanganese crusts from seamounts, seafloor massive sulphides from hydrothermal vents and gas hydrates at continental margins.

13.3.2 Faunal recovery rates

Faunal recovery rates vary greatly across ecosystems, and community composition may not return to its original state for a long time.

Following local submarine volcanic eruptions, opportunistic organisms can quickly recolonise (i.e. within months to few years) disturbed seafloor areas (Canals *et al.*, 2006). At the Palinuro seamount, rock abundances, biomass and diversity of microscopic meiofauna (animals between 32 and 300 microns in size) were fully recovered after disturbances, whereas community composition had not returned to control conditions (Roberto Danovaro *et al.*, 2017). Furthermore, following a disturbance experiment in Portmán Bay, an area severely affected by dumping of tailings from land-based mining operations, the abundance and biomass of meiofaunal assemblages did not change significantly between disturbed and undisturbed areas but food availability increased, suggesting that the particulate fallout from sediment plume settling can modify the trophic state of benthic systems.

The situation is different in polymetallic nodule areas where there was an indication that faunal densities of some taxa recovered quickly, and were almost back to pre-disturbance conditions after seven years, whereas diversity and community composition had not recovered 26 years after the impact (Gollner, Kaiser, Menzel, Jones, Brown,

C. Mestre, *et al.*, 2017). A metadata analysis on recovery rates revealed high variability between and within ecosystems, as well as across size classes and taxa (Simon-Lledó *et al.*, 2019). While densities and diversities of certain taxa can recover to pre-disturbance conditions or even exceed them, community composition remains distinct even decades after disturbance. The loss or change of hard substrate composition may cause substantial community changes persisting over geological timescales at directly mined sites (Gollner, *et al.*, 2017).

13.4 Offsetting

13.4.1 Overview

The implementation of biodiversity offsets as a way to compensate for residual loss of biodiversity should only be considered as the final ‘step’ in the mitigation hierarchy. Offset measures are taken to compensate for any residual impacts that could not be avoided, minimised, or restored on-site. It is widely held, however, that there are situations in which residual impacts cannot be fully compensated for by a biodiversity offset, and that offsetting may not be appropriate in all circumstances.

The goal of biodiversity offsets should be to achieve no net loss, and preferably a net gain, of biodiversity on the ground (Business and Biodiversity Offsets Programme (BBOP), 2013). A net gain in biodiversity is achieved where the ‘biodiversity value’ of the offset is greater than the residual impact caused by development and under current best practice guidance there are certain situations (e.g. impacts to the International Finance Corporation’s Performance Standard 6 critical habitats) in which a net gain of biodiversity is required.

Biodiversity offsets are becoming increasingly embedded in regulatory frameworks around the world. Legislation mandating compensatory biodiversity conservation mechanisms (which includes amongst other mechanisms, offsets) exists in 56 countries and is under development in another 27 countries (Madsen *et al.*, 2011). Development and application of national and subnational offset schemes has focussed on the developed world, however, international lenders, multilateral banks and corporate standards are increasingly driving the application of biodiversity offsetting in developing countries, such as Columbia, Mongolia and Namibia, within diverse political, economic and ecological contexts.

13.4.2 Offsetting is not an option

A recent paper (Niner *et al.*, 2018) addresses the challenge to achieving no net loss outcomes for biodiversity impacted by deep-seabed mining. Deep-seabed mining is likely to result in biodiversity loss, and the significance of this to ecosystem function is not known. “Out of kind” biodiversity offsets substituting one ecosystem type (e.g., coral reefs) for another (e.g., abyssal nodule fields) have been proposed to compensate for such loss. The authors conclude that the industry cannot at present deliver an outcome of no net loss. This results from the vulnerable nature of deep-sea environments to mining impacts, currently limited technological capacity to minimise harm, significant gaps in ecological knowledge, and uncertainties of recovery potential of deep-sea ecosystems.

Avoidance and minimisation of impacts are therefore the only presently viable means of reducing biodiversity losses from deep-seabed mining. Because of these constraints, when and if deep-seabed mining proceeds, it must be approached in a precautionary and step-wise manner to integrate new and developing knowledge. Each step should be subject to explicit environmental management goals, monitoring protocols, and binding standards to avoid serious environmental harm and minimise loss of biodiversity.

“Out of kind” measures, an option for compensation currently proposed, cannot replicate biodiversity and ecosystem services lost through mining of the deep seabed and thus cannot be considered true offsets. The ecosystem functions provided by deep-sea biodiversity contribute to a wide range of provisioning services (e.g., the exploitation of fish, energy, pharmaceuticals, and cosmetics), play an essential role in regulatory services (e.g., carbon sequestration) and are important culturally. The level of “acceptable” biodiversity loss in the deep sea requires public, transparent, and well-informed consideration, as well as wide agreement. If accepted, further agreement on how to assess residual losses remaining after the robust implementation of the mitigation hierarchy is also imperative. To ameliorate some of the inter-generational inequity caused by mining-associated biodiversity losses, and only after all no net loss measures have been used to the fullest extent, potential compensatory actions would need to be focused on measures to improve the knowledge and protection of the deep sea and to demonstrate benefits that will endure for future generations (Niner *et al.*, 2018).

14. Closure

All projects must consider a closure or abandonment plan as part of the environmental management of the project. Closure of Operations and Abandonment includes all the activities related to the closure of a main subsea equipment and any installations at the end of the estimated useful life and the activities related to the proper abandonment of the installations and the rehabilitation of the site. The context, considerations and responsibilities set out for closure below borrow mainly from the oil and gas industry. As compared to the oil and gas industry, with its complex seabed infrastructure, marine mining operations are likely to be less complex to decommission.

A preliminary consideration to take account of is that, in general, projects improve their mining tools, equipment and technology as the useful life of the project proceeds, in order to:

- Maintain high level of safety (that allows compliance with current legislation and the internal company guidelines) at all the operational equipment, including all the land and marine facilities;
- Increase reliability and efficiency;
- Comply with the national government and international environmental standards, as well as the project proponent's internal requirements; and
- Adjust to market demands regarding the quantity and quality of the product being delivered.

In this context the closure or abandonment[10] of the operation does not occur for technical reasons but rather for economic, strategic or other reasons.

The closure of the operation should be a programmed action that:

- ensures compliance with the legislation in the date programmed for the closure;
- in the absence of specific legislation, specifies the project proponent will confirm to the proper authorities that all the actions have been taken to protect human life and the surrounding environment; and
- requires the operating company to delimit its environmental responsibilities "before" and "after" the closure of the Project.

Under the conditions outlined above, the general approach that a project proponent should adopt upon closure of the operations of the project are outlined below:

- The project proponent should estimate a minimum useful life of the operation in years, which could be extended such that under optimum maintenance condition, the physical life of the project could extend for many more years.
- The tools, machines, vessels and equipment to be closed should be assessed and handled in an individual manner.
- Operations infrastructure that needs to be abandoned will be disconnected from all sources and supplies. This includes, for example, pipelines, metering stations, control lines, and other equipment.
- Surface equipment shall be removed and taken away.

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[10] Abandonment is understood to mean the dismantling of the project. The other possibility is that the owner sells the installations to a third party, in which case it does not constitute closure or abandonment.

For this project stage, the environmental requirements and guidelines for marine biodiversity established for the project development stage will apply. During these tasks the various environmental aspects generated by the dismantling work will be managed in an environmentally correct manner, namely:

- Generation of solid waste;
- Generation of liquid effluents;
- Gaseous emissions;
- Particulate matter emissions;
- Generation of noise and vibrations; and
- Physical presence.

Once the decommissioning tasks are completed the environmental conditions in the occupied area will be re-established, by performing at least the following:

- As far as possible the areas affected by the physical presence of the structures will be restored returning them to their initial condition. This includes the reconstitution of the benthic surface affected and the landscape of the area in order to not alter the natural run-off of the shorelands.
- The areas affected during the decommissioning will be restored as much as possible, returning them to their initial condition.
- In the event that any feature will be an improvement for the environment, it may be left with the agreement with the relevant authorities.

Figure 57: Octopus and sponges on seabed. Credit: NOAA, Nautilus Expedition

Table 17: Impacts associated with decommissioning on marine biodiversity and ecosystem services, and recommended activities to avoid and minimise impacts

Source of impact & application in phase	Outcome of activity	Potential pre-mitigation impact on biodiversity and ecosystem services	Mitigation Hierarchy Step	Mitigation Activity
			Biodiversity and Ecosystem Services (BES) Impact Mitigation	
Decommissioning of umbilicals	Disturbance of benthic environment	• Displacement of benthic species • Injury or death of benthic species	Minimise	Assess different options for the decommissioning of pipelines, which can include backfill in-situ, leave in-situ or total removal. Complete removal is generally not required.
Subsea facilities - Decommissioning of subsea facilities	Decommissioning of subsea facilities, some of which may be embedded in the seafloor, can create heavy disturbance to the seafloor	• Displacement of benthic species • Injury or death of sessile species unable to move away from areas where subsea facilities are removed • Smothering of organisms, resulting in reduced ability to feed, and potential ill health and mortality	Minimise	Assess different options for the decommissioning of subsea structures, considering that total removal could create more disturbance to the marine environment than partial decommissioning in-situ.
			Avoid	Leave clean steel and concrete structures in-situ, as remaining subsea structures can benefit the local ecology by providing an artificial habitat to marine species.
Explosives (potentially applicable to deep-seabed mining only)	Heavy disturbance of benthic environment	• Direct injury and mortality of marine species, particularly benthic species • Destruction of benthic environment	Avoid	Determine what marine mammal species are likely to be present in the detonation area and assess if there are any seasonal considerations that need to be taken in to account, e.g. migration, breeding and calving
			Minimise	Determine the distance at which the explosive detonations could cause physical injury to marine mammals and establish suitable mitigation zone. Default mitigation zone for marine mammal observation mitigation should be 1km, measured from the explosive source, 360 degrees circular coverage. This radius can be increased/ decreased if there is supporting evidence to do so.
			Minimise	Only commence explosive detonations during the hours of daylight and good visibility (observers should be able to monitor the full extent of the mitigation zone). If marine mammals are observed, delay detonation (dedicated and trained Marine Mammal Observers (MMOs) should carry out observations). Delay should last for at least 20 minutes of a marine mammal leaving the mitigation zone.

Source of impact & application in phase	Outcome of activity	Potential pre-mitigation impact on biodiversity and ecosystem services	Mitigation Hierarchy Step	Mitigation Activity
			Biodiversity and Ecosystem Services (BES) Impact Mitigation	
			Minimise	Use Active Acoustic Monitoring (AAM) to supplement visual observations and PAM as mitigation measures. AAM can detect animal presence in all conditions regardless of whether animals are vocalising.
			Minimise	Conduct pre-detonation searches for marine mammals at least 1 hour before any type of detonation. Visual and acoustic monitoring should be conducted by a trained Marine Mammal Observer (MMO) in the mitigation zone and should continue until the MMO advises that the mitigation zone is clear.
			Minimise	Plan the sequence of multiple explosive charges so that, where possible, smaller charges are detonated first to maximise a 'soft-start' effect.

15. Monitoring and evaluation

Monitoring programmes produce evidence for effective management of marine habitats and communities, and enable conclusions to be drawn about the cause and direction of natural and anthropogenic change (Noble-James, Jesus and McBreen, 2018).

Monitoring and Evaluation (M&E) for shallow seabed mining and aggregate dredging is well developed and examples of long-term M&E programme are documented e.g. (Newell and Woodcock, 2013) and by the UK Crown Estate in their Good Practice Guidance, or the Joint Nature Conservation Committee Guide on Monitoring Benthic habitats. The UK now has multiple national and international requirements for marine biodiversity monitoring and assessment, and it is primarily the EU Marine Strategy Framework Directive which requires monitoring programmes to be in place across the whole marine environment.

There is little advice specifically designed for M&E of biodiversity and ecosystem services in the context of deep-seabed mining. The deep-seabed mining industry faces some unique challenges on this front: there is a particular lack of knowledge of deep-sea environments, and very little information on the potential effects of mining activities (Jones *et al.*, 2017).

The deep-seabed mining industry has the opportunity to learn from developments in safety and environmental management practices from other marine industries. Many of the key environmental management issues (e.g. environmental impact assessment, environmental management planning (EMP), baseline assessment, monitoring and mitigation) have been documented in detail already (Jones *et al.*, 2019), and a growing body of guidance exists on biodiversity and ecosystem services monitoring from which good practice principles can be loaned. The intention of this section is not to replicate this advice, but rather to establish the general considerations for M&E of marine biodiversity and ecosystem services.

15.1 Purpose of monitoring and evaluation

The purpose of a M&E programme is to measure progress against an operation's specified targets for biodiversity and ecosystem services. M&E helps improve a project's performance and achieve results (UNDP, 2002). It involves the assessment of a project's progress against pre-defined targets to ensure the activities are on track in terms of timeline, activities and delivery. This includes tracking against higher order objectives such as no net loss or a net gain for biodiversity and ecosystem services to determine whether the desired outcomes are being achieved.

The two components of M&E are defined as follows (Sera and Beaudry, 2007) :

- **Monitoring** is a continuing function that aims primarily to provide project stakeholders with early indications of progress towards defined goals. Monitoring helps companies track achievements by a regular collection of information to assist timely decision making, ensure accountability, and provide the basis for evaluation.
- **Evaluation** is the systematic and objective assessment of a project, including its design, implementation and results. The aim is to determine the relevance and fulfilment of objectives, development efficiency, effectiveness, impact, and sustainability. An evaluation should enable the identification of lessons learned for future projects.

Put simply, monitoring tells us whether an activity is on track to achieve its intended objectives, whereas evaluation tells us whether the project as a whole is on the right track (IUCN, 2015).

A formalised system of M&E enables the measurement and monitoring of a company's impacts upon biodiversity and ecosystem services and assists the understanding, prediction, minimisation and prevention of negative impacts (The Energy & Biodiversity Initiative, 2003); enhancement of positive impacts; management of activities; and the development, monitoring and refinement of corporate policy and expected best practice standards (Durden *et al.*, 2017).

M&E enables a company and other stakeholder groups to comply with national and international laws and performance against corporate or lender standards and industry good practice. Further, the information collected can be instrumental in communicating biodiversity and ecosystem services performance both internally and to external stakeholders. Such communications and the demonstration of a clear biodiversity and ecosystem services evidence base are likely to be instrumental in companies accessing resources (Durden *et al.*, 2017), maintaining good relations with communities and attaining their social licence to operate (The Energy & Biodiversity Initiative, 2003).

M&E should be incorporated into the Environmental Management Plan of an operation and should include monitoring before, during and after testing and commercial use of collecting systems and equipment. This will require the development of relevant indicators, thresholds and responses in order to trigger timely action to prevent serious harm (Jones *et al.*, 2019).

M&E should be a continuous process throughout the life of a project, recognising that the focus of the M&E will be different for each phase of the project cycle to reflect the different impacts and priorities. For example, during seismic surveys M&E may focus upon pelagic species including fish and marine mammals likely to be affected by noise. During project development and operations, the focus may shift to benthic habitats impacted by subsea operations.

15.2 Designing a monitoring and evaluation programme

Monitoring requirements for biodiversity and ecosystem services are not currently specified in International Seabed Authority legislation for the Area. Similarly, international finance institutions lender requirements and wider marine industry good practice do not specify what elements of biodiversity and ecosystem services should be monitored (see Box 29), as each operation is essentially unique.

Box 29
International Finance Institutions and guidance on M&E

Lender standards do not prescribe which elements of biodiversity and ecosystem services an operation should monitor, due to the context-specific nature of different operations. Instead, they usually set out general requirements for monitoring. For example, IFC's PS6 states that for Critical Habitat "A robust, appropriately designed, and long-term biodiversity monitoring and evaluation program is integrated into the client's management program." Further details are provided in the Guidance Notes, which set out the following broad considerations for monitoring biodiversity:

- **in-field monitoring of species and habitats, and monitoring of the effectiveness of mitigation measures;**
- **the need for a separate monitoring programme for any biodiversity offsetting;**
- **the desire for statistically defensible results; and**
- **the need to identify thresholds for key biodiversity, in conjunction with external experts, against which success will be measured. In all cases, it is important to ensure that ecosystem function and persistence of biodiversity and ecosystem services is incorporated into the M&E programme.**

Generally, monitoring and evaluation of marine biodiversity and ecosystem services will be geared to addressing the following high-level questions (adapted from Noble-James *et al.,* 2018):

1. What is the the state of ecological components of biodiversity?
2. Are changes natural or due to anthropogenic activities?
3. Are management measures required?

If yes to 3 above, then the following question should be applied:

4. Are management measures effective in meeting their objectives?

These questions may be addressed using the three main types of monitoring identified by Noble-James *et al.* (2018), as displayed in Box 30.

BOX 30

Three types of M&E for marine biodiversity (Noble-James *et al.,* 2018)

There are three main types of monitoring for marine biodiversity:

Sentinel monitoring of long-term trends (Type 1)
This type of monitoring provides the context to distinguish directional trends from short-scale variability in space and time. To achieve this objective efficiently, a long-term commitment to regular and consistent data collection is necessary; this means time-series must be established as their power in identifying trends is far superior to any combination of independent studies. This addresses question 1 above.

Operational monitoring of pressure-state relationships (Type 2)
This type is best suited to explore the likely impacts of anthropogenic pressures on habitats and species and identify emerging problems. It relies on finding relationships between observed changes in biodiversity and observed variability in pressures and environmental factors. This addresses questions 2 & 3 above.

Investigative monitoring to determine management needs and effectiveness (Type 3)
This monitoring type provides evidence of causality. It complements the above types by testing specific hypotheses through targeted manipulative studies (i.e. excluding an impact or causing an impact for experimental purposes). It is best suited to test state/pressure relationships and the efficacy of management measures. This addresses question 4 above.

15.3 Setting objectives for monitoring and evaluation

M&E requirements will vary depending on the size and complexity of the operation, and the social and environmental sensitivity of the surrounding area. Given deep-seabed mining projects will be operating in very different contexts, and with different permitting conditions, it will be necessary for each operation to develop an M&E programme tailored to their needs. The first step is to identify the objectives for biodiversity and ecosystem services for the operation.

A M&E programme may be designed to track progress towards a high level and strategic project target of No Net Loss for biodiversity (a legislative requirement in 39 countries, and a lender standard for 32 international finance institutions). Equally, it may help assess a more specific, operational target such as ensuring the protection of a priority species, habitat or ecosystem service for a set period of time, while a specific activity such as grab sampling or sediment removal is under way.

Once the biodiversity and ecosystem services objectives have been identified, and the type of monitoring selected, the next step is to develop indicators for M&E.

15.4 Developing indicators

Central to monitoring and evaluation plans is the identification of indicators which help track progress towards objectives. Indicators should help assess changes to the integrity of biodiversity, ecosystem functions, ecosystem services and the complex relationships between these within an ecosystem.

Indicators are quantitative or qualitative variables which are measurable and can demonstrate trends over time. M&E usually involves the collection of two kinds of indicator, the first for performance and the second for impact:

- **Performance indicators** measure the progress in securing project inputs and delivering project outputs against set targets
- **Project impact indicators** reveal trends towards, or away from, biodiversity and ecosystem services conservation targets

Both are essential in tracking the overall progress of the project. Performance indicators are usually based around the delivery of specific services, for example training sessions or construction of infrastructure. Impact indicators measure elements of biodiversity (e.g. species, habitats or ecological processes) or ecosystem services that are likely to be highly impacted by the project.

Impact indicators should be carefully selected to ensure they match the stated M&E objectives. Different types of impact indicators can be selected to represent the complexities of biodiversity and ecosystem services and ecosystem function and make the linkages between abiotic and biotic variables within an ecosystem. Direct indicators can quantify the ecosystem components through a number of means, e.g. area extents, yields, abundance or value variables. Relationship or process indicators can represent the underlying links and associations between the ecosystem component and other biodiversity, ecosystem function and ecosystem services within an ecosystem and across a seascape, e.g. predator-prey interactions or nutrient cycling. These relationship indicators add value to the direct indicators by helping to understand the potential impacts that may result as the underlying related ecosystem components change.

In certain cases, it may not be possible to directly measure the desired biodiversity and ecosystem services element, for example a rare or cryptic species, and a proxy may be required, such as area of habitat or availability of prey species. Such proxy indicators must be carefully selected to ensure they are biologically meaningful. Consultation with marine biodiversity and ecosystem services experts is recommended for the selection of all impact indicators, and especially proxies.

Appropriate biodiversity and ecosystem services indicators should have the following characteristics (Brown *et al.*, 2014):

- **Relevant** to the activities of the project and objectives of the M&E program.
- **Understandable** and able to aid the interpretation of data, inform management plans and promote the communication of results.
- **Useable** for measuring progress and, in conjunction with thresholds, act as a preventative measure against negative change.
- **Scientifically sound,** equally informed by scientific information and able to be tested and measured.
- **Sensitive** to change, in that changes in responses or values can be detected.
- **Practical and affordable** to promote consistent application and ensure rigour in data over long periods of time.

15.5 Identifying thresholds

The purpose of thresholds is to represent the difference between two or more different states or responses of an indicator. Thresholds help to predict and prevent changes to the value of key biodiversity and ecosystem services components which may cause degradation or loss of biodiversity, ecosystem function and ecosystem services.

Biodiversity and ecosystem services indicators will usually be selected to track changes to a key biological trait such as population size for a species, area or quality for a habitat, interaction for a relationship or volume of offtake for a provisioning ecosystem services. For many indicators it is possible to identify thresholds which are both measurable and biologically meaningful. From a management perspective, a threshold provides a defined boundary beyond which impacts are acted upon: crossing these thresholds will trigger management actions to address the problem.

Thresholds help inform progress against targets in monitoring and evaluation plans. With any change to the environment, through operational activities or minimisation or restoration activities, the ecosystem can suffer impacts where a ‘tipping point’ may be reached, leading to a change in the ability of the ecosystem to function and produce particular ecosystem service/s. When an ecosystem reaches or passes such a tipping point, recovery can be difficult, expensive and lengthy. Degradation and loss to ecosystems can be irreversible (e.g. species extinction and state change of habitat), expensive to rectify (e.g. translocation of species and removing pollution), take significant time to rectify (e.g. restoration of mature primary forest) or require a significant input of energy and resources (e.g. active restoration of habitats and eradication of invasive species).

By evaluating and relating changes to ecosystem services against thresholds, negative trends can be determined and prevented by adapting management activities to suit. Of course, there are many impacts to ecosystem components which cannot be predicted and evaluated against thresholds (e.g. natural disaster events). Investing in a structured M&E plan which includes an understanding of tipping points and identifies biologically meaningful thresholds should minimise the risk of complex recovery programmes.

It is important that thresholds are defined in close consultation with marine biodiversity and ecosystem services specialists. It should be noted that thresholds can vary considerably and may, for some biodiversity and ecosystem services values, need to be set very low, especially where the value is highly irreplaceable and where potential losses may be irreversible. Further, thresholds may not be appropriate for all biodiversity and ecosystem services values, including some cultural ecosystem services.

15.6 Consultation

To be successful, a M&E plan must be developed in consultation with key stakeholders, including those stakeholders dependent upon potentially affected ecosystem services. This requires meaningful engagement with a range of groups, including communities local to the operation, ecosystem services user groups, marine biodiversity and ecosystem services experts and regulators. Free Prior & Informed Consent principles should always be applied. Consultation should be a continuous process which engages key stakeholders in the purpose, planning, implementation and review of M&E activities.

15.7 Independence

An operation’s M&E activities should provide objective and impartial information in order to track progress towards agreed targets. Therefore, consideration should be given to the independence of any persons or organisations collecting such information. Independence may be viewed differently for each of monitoring and evaluation: monitoring is an integrated part of management and therefore is commonly undertaken by internal teams, whereas evaluation is periodic and ‘big picture’ and may be best undertaken by an external party.

15.8 Monitoring biodiversity and ecosystem services

The process of M&E for biodiversity and ecosystem services is not as straightforward as for other environmental aspects, such as air or water quality for which there are well established global standards and benchmarks. As stated previously, marine ecosystems are dynamic, interconnected and highly complex. The diversity of life is not evenly spread through the marine system, with some areas e.g. seamounts, harbouring a concentrated diversity of life, and others, such as the mid-ocean ridge, containing a relatively low diversity of rare and highly specialised species.

Furthermore, the biodiversity and ecosystem services values of an area may undergo considerable fluctuations as a result of natural processes. For example, information on the species that are known or likely to occur within the project development and offset areas needs to take into account seasonality and annual variation: some species are only evident during a particular time of year and, in some ecosystems, certain species are only evident for short time periods over multiple years. Such natural variations need to be identified and monitored so that they can be taken into account in evaluating the results of project interventions. However, determining changes in natural systems can be a lengthy process, particularly if the relative importance of natural cycles and anthropogenic changes is to be properly understood. This requires an informed sampling strategy and regular monitoring over longer time frames, especially where pronounced seasonal variations occur.

15.9 Integrated monitoring

An ecosystem approach should be applied to M&E, as for all aspects of biodiversity and ecosystem services management. This demands an integrated approach to the assessment of biodiversity and ecosystem services.

An ecosystem approach should take into account the patterns and processes of the ecosystem, such as species abundance and richness, habitat heterogeneity and dispersal. These patterns are often underpinned by processes or functions, including genetic flow, biomass production, carbon sequestration and nutrient cycles. Ecological patterns and processes are dynamic in their variability and responses to change, often influenced by human-induced activities or abiotic and climatic changes. Such patterns and processes may not be easy to monitor, but their inclusion will enable a deeper understanding of the presence and persistence of the biodiversity and ecosystem services being monitored, and likely influencers of change within the environment.

Further, biodiversity and ecosystem services monitoring should be integrated with wider environmental monitoring. Operations will typically undertake some form of regular environmental monitoring, be this of operational discharges, physical properties of the water column, or the benthic substrate. Combining environmental monitoring with that for biodiversity and ecosystem services will provide a deeper understanding of the impacts of human activities upon ecosystems, and specifically those high value elements of biodiversity and ecosystem services being monitored.

15.10 Methods of assessment

The practicalities of collecting information on biodiversity and ecosystem services means different approaches may be required for each biodiversity and ecosystem services component. Biodiversity is usually monitored through quantification of species (e.g. population size, threat status), habitats (e.g. area, quality) or processes (e.g. decomposition) based upon information from direct field surveys, remote sensing, or in some cases, proxies.

By contrast, ecosystem services reflect the human value and use of resources and so often require a sociological approach to their assessment. This means talking to people about their ecosystem services use, asking them to identify priorities and trends in stocks and flows of ecosystem services over time, which is normally the case for provisioning and cultural ecosystem services. In some cases a quantified biological approach may also be appropriate for ecosystem services, for example habitat area x quality metrics may be applied to collection fisheries. For many ecosystem services, a blend of sociological and quantified biological approaches may be used.

Though approaches to biodiversity and ecosystem services are considered individually below, the design and assessment of surveys and interpretation of results must be integrated. This will enable a greater understanding of the relationship between biodiversity and ecosystem services, the underlying ecosystem processes that support both, and should promote understanding of human influences upon biodiversity and ecosystem services within the area of study.

15.11 Monitoring ecosystem services

Several documents provide guidance on the development of ecosystem service indicators, including UNEP-WCMC guidance, Joint Research Centre review of ecosystem services indicators, Biodiversity Information Systems for Europe indicators for marine ecosystems and World Resources Institute guidance.

Ecosystem services assessments are typically focused on investigating, within a particular location, what ecosystem services are provided, who benefits from these services, and how change – man-made or natural – might affect the delivery of these services. However, the cultural services provided by ecosystems continue to be underemphasised in many ecosystem services assessments and decisions as they are often considered complex and difficult to measure.

A wide range of indicators will typically be required to monitor ecosystem services. Indicators for provisioning ecosystem services may take the form of quantitative measures or numbers linked to yield, production, areas or financial figures, yet this may not account for the full benefit a stakeholder receives from an ecosystem service, such as accessibility and value to livelihood. Therefore, it is usual for a suite of qualitative indicators to be applied to represent the relative importance of the ecosystem service to the user, its accessibility, trends in availability and condition and its replaceability. In combination, such quantitative and qualitative indicators provide a more complete representation of ecosystem services value and of ecosystem function.

M&E for ecosystem services should be developed in consultation with a range of stakeholders and must be relevant for company management objectives and systems.

15.12 Review and revise

Any M&E programme should be reviewed on a regular basis. First, there should be ongoing quality assurance and quality control to ensure the required standards are being met and to provide assurance of quality and consistency of results. Second, M&E activities should be regularly reviewed against biodiversity and ecosystem services targets and objectives to ensure they continue to deliver the desired outputs. Targets and objectives may change through the life of an operation in response to new legislative or lender requirements, or emerging good practice. M&E methodology should also be reviewed as advances in technology may offer efficiencies in data collection. Finally, as our understanding of the relationship between people, biodiversity and ecosystem services improves, there may be the opportunity to adopt more integrated and efficient approaches to M&E.

16. Conclusions

With the increasing interest in exploration for and exploitation of seabed minerals in shallow and deep waters, rapid pace of development of the seabed mining sector, limited knowledge of deep-sea ecosystems, and the potential for adverse impacts from seabed mining, there has been an urgent need to assess whether and how seabed mining in shallow and deep waters could proceed without causing harm to ocean environments and their associated biodiversity, processes and functions.

This report sought to respond to this critical issue through a thorough assessment of the latest science and available evidence. The report highlights the remarkable complexity of ocean habitats and ecosystems, providing a system-scale insight into the connectivity of ocean chemistry, ecological function, the oceans' role in climate regulation and primary production, and the inter-dependence of all these processes to maintain a healthy, functioning and productive ocean system.

It is clear that different policy and governance regimes apply to national and international waters, and overall, governance of marine mining is fragmented and inconsistent. There are also different risks and impacts associated with different types and modes of seabed resource extraction. Some ecosystems are naturally highly dynamic and resilient to perturbations such as sediment smothering in high natural sedimentation environments (where alluvial gold, marine placer diamonds and aggregates are mined), or violent physical disturbances associated with plate tectonics and volcanic activity (e.g. metal sulphides associated with hydrothermal vents). Some extraction methods require total removal of entire substrates from the ocean environment (e.g. phosphate mining, seafloor massive sulphides, cobalt crust and polymetallic nodules, whilst others return benthic sediments through return waters (e.g. diamonds and aggregates) which may, in turn, contribute to the restoration potential of affected seabed ecosystems.

Shallow water (<200 metres) ecosystems are often highly dynamic and some may be receptive to passive recovery or restoration. Given the longer history of mining in shallow waters, the risks and impacts of shallow water seabed mining have been monitored for several decades and are better understood. In contrast, we know next to nothing about the deep oceans. Recent research reveals deep-seabed systems are highly vulnerable, comprising ancient systems and slow growing, long-lives species. Evidence from projects monitoring pilot excavations indicate that impacts to these systems are likely to be long-term (geological time frames) and widespread. We simply do not know enough about deep-sea ecosystems to predict impacts with any confidence. We are only just discovering the complexities of ecosystem function and the relationship between target mineral resources and the biogeochemistry responsible for their formation and the overall health and function of the ocean.

Given the reliance of humanity upon a wide range of ecosystem services, there remains an unattended question of social impact assessment, which must be applied to both international and national proposed projects, taking into account Free Prior and Informed Consent, the rights and participation of Indigenous Peoples, and a fully inclusive and transparent public consultation process.

Following the thorough assessment of the current state of knowledge relating to seabed mining and the marine environment, the following conclusions are drawn:

16.1 Shallow water mining

The nature and scale of potential impacts from marine aggregate dredging have been widely recognised. These include the impacts of sediment mobilised by the dredging process and transported along the seabed by the prevailing currents, as well as potential impacts of noise and disturbance to organisms that are higher in the food web such as fish, mammals and birds.

In almost all instances, aggregate dredging is reported to result in suppression of species diversity, population density and biomass of invertebrates that live in seabed deposits that have been dredged. The impacts of dredging on higher levels in the marine food web are poorly understood.

Physical recovery at aggregate sites where dredging had ceased is generally dependent on substrate type and the strength of tidal currents, with fastest restoration in fine muds and sandy deposits. Restoration of open coastal habitats subject to aggregate dredging is only possible by the removal of aggregate dredging operations, prevention of other impacts such as heavy bottom gear by fishing vessels, and then allowing the system to recover over time through natural processes. The potential for achieving no net loss of biodiversity remains debated.

Similar impacts and restoration profiles occur for marine diamond extraction, with removal of benthic sediments and return to the water column producing sediment plumes. Whilst evidence suggests a recovery in the composition, structure and function of benthic ecosystems, and the potential for no net loss of biodiversity, understanding of long-term recovery is still incomplete.

There is a growing body of evidence to suggest that, under certain conditions and contexts, some forms of shallow seabed mining could take place with no net loss of structure, composition and function of the habitats associated with shallow seabed extraction. This requires the strict adherence to best practice standards/principles throughout the life of operation, including commitment to no loss of biodiversity, an adaptive approach that is receptive and responsive to the latest advances in science and technology, and ongoing monitoring and adaptive management. The ‘net’ in no net loss acknowledges that there is an impact and there are losses but that these can be mitigated in such a way that losses can be balanced with gains elsewhere.

16.2 Deep-seabed mining

This large-scale review reveals evidence for significant, and currently non-mitigatable impacts of deep-seabed mining on biodiversity.

Phosphate and other bulk sediments have not yet been mined on a commercial scale from the seabed anywhere in the world, although a number of countries have imposed moratoria (New Zealand, Namibia). As a result, potential ecosystem impacts can at best be inferred from other types of mining operations that have taken place in similar biogeographic regions, at comparable depths and using similar tools, together with our understanding of the mining strategy and the local oceanography and ecology.

The potential effects of marine phosphate (or any similar bulk sediment) mining operations on marine ecosystems is likely to be considerable, not least because of the speed and method by which the dredgers operate. Particular concern lies in the complete bulk removal of phosphates (a key nutrient for ocean primary production) from the marine ecosystem, resulting in loss of substrate for benthic life.

As with all seabed mining, the implications of phosphate mining upon biodiversity will depend to a large degree on the extent of the habitat type in question. Certain unique habitats are extremely restricted in their spatial extent and may already be threatened by other ocean uses. A bulk sediment mining operation in or near such a habitat could provide a real threat to its persistence. Other benthic habitats may be more ubiquitous and widespread and hence mining in such habitats might threaten a small fraction of the total area covered by similar assemblages of species.

Deep-seabed mining will result in large scale habitat removal (loss of substrates) and associated biodiversity, including unknown diversity of macrofauna and microbial systems that underpin primary production, carbon dioxide and trace metal sequestration and cycling.

Deep-seabed mining activities will also produce sediment plumes which will disrupt ecological function and behavioural ecology of deep-ocean species, smothering fundamental ecological processes over vast (and difficult to predict) areas.

The report raises the importance of poorly understood biogeochemical processes that drive ocean chemistry and ocean ecological function, including primary production and trace metal fixation by chemosynthetic organisms beyond the photic zone. It further showcases recent science which builds a strong case for the important role of deep-sea biological systems in driving planetary systems of carbon sequestration.

Deep-seabed mining has the potential to cause disruption and potential collapse of these processes and could exacerbate our current crises of climate change and biodiversity loss, if it is developed without due care and consideration for knock on effects on benthic carbon cycle processes and on methane storage. Such impacts are likely to be irreversible.

The application of a mitigation hierarchy approach in this assessment reveals that the impacts of deep-seabed mining cannot currently be effectively mitigated or managed. Combined with the considerable gaps in the knowledge of ocean complexity and how this relates to earth-system processes, gaps in basic baselines of the biodiversity and ecosystem function of the ocean, and clear indications within the existing science base that impacts are likely to be considerable, there is an inadequate basis on which to grant mining exploitation contracts.

The urgent focus on deep-seabed mining is driven by two things: the self-imposed 2020 deadline of the International Seabed Authority to have complete the rules and regulations governing the exploitation of seabed minerals in the Area, and therefore the ability for contracts for exploitation to be granted; and the articulation of the argument that seabed minerals are necessary to decarbonise our economies and are fundamental to climate change mitigation is stimulating a rush for rare earth minerals and metals used in technologies associated with renewable energy and a beyond-fossil future.

In turn, this creates an unnecessary sense of urgency and a race to begin deep-seabed mining without due process and contrary to the spirit and intent of UNCLOS. In fact, current governance structures are no-where near ready, nor are they appropriately informed by science and policy practitioners. There are major flaws in the decision-making processes and procedures practiced by the International Seabed Authority where financial, legal, inspectorate, policy and enterprise objectives may be subject to the influences of pro-mining lobbies.

17. Recommendations

Based upon the evidence assessed in this report, a moratorium on deep-seabed mining is strongly recommended until at least such time as these recommendations have been fulfilled and exploitation technologies and operational practices are able to demonstrate no harm to the environment and outcomes of no net loss of biodiversity.

This report recommends and calls on the international community, the International Seabed Authority and those attempting to progress seabed mining to:

1) Ensure all decision-making associated with the exploration and exploitation of seabed minerals is driven by a **commitment to no net loss of biodiversity.**
2) Develop Standards and Principles that **require the application of the Precautionary Principle**, takes into account an **ecosystem-based approach** considering the health, function and resilience of the ocean and recognises the roles of the ocean in regulating climate.
3) Address the current applicability of the interpretation and intent of **UNCLOS** and the principle that seabed mining should be **for the good of all humankind.**
4) Promote a **globally harmonised governance system** for protecting the seabed to avoid fragmented, inconsistent approaches to regulating activities in different zones that takes into account stressors such as ocean acidification, climate change and pollution.
5) **Promote circular economy** approaches to reduce the demand of raw primary materials.
6) Incorporate minerals into **climate and energy planning.** Given the centrality for minerals and metals to the future diffusion of low-carbon technologies, materials security should be actively incorporated into formal climate planning.
7) Further develop the robust business case that recognises and **supports new technologies** such as hydrogen fuel cells and hybrid ion capacitors which are not dependent on metal-rich materials. We need to **leapfrog to new alternative low-metal futures** in addition to low-carbon futures.
8) Develop and implement a **research agenda** for addressing key scientific questions that must be **answered before commercial-scale mining** commences
9) In order to a**dequately assess the impacts of deep-seabed mining and establish the potential for effective mitigations,** address a number of **fundamental knowledge gaps** to establish levels of certainty fit to inform decision making and policy.[3]
10) **Ensure** the application of the mitigation hierarchy and **adherence to no net loss,** and ideally net gain **commitments** for biodiversity and ecosystem services for all seabed mining.
11) Develop **effective and precautionary legislation** which clearly promotes **'no-go'** status for habitats and situations where no net loss is considered unlikely and, via the r**egional environmental management planning** process, large representative areas identified according to scientific criteria are ruled off-limits to seabed mining.
12) Undertake a **full review of the International Seabed Authority** including governance and accountability, conflicts of interest, resourcing and competencies for regulatory activities, such as contract reviews, inspections, audits, environmental monitoring, and enforcement.
13) Critically review the **scope and objectives of the proposed International Seabed Authority Mining Code** to ensure incorporation of a process for protecting biodiversity and assessing and avoiding significant environmental impacts that (a) is responsive to independent scientific advice, (b) offers stakeholders a meaningful opportunity for participation, (c) enables rejection of mining proposals where the impacts are deemed too great or too uncertain, and (d) provides for the potential closure of large, ecologically important areas of the deep sea to mineral extraction.

Based upon the evidence assessed in this report, **a moratorium on deep-seabed mining (>200 metres depth) is strongly recommended** until at least such time as these recommendations have been fulfilled and exploitation technologies and operational practices are able to demonstrate no serious harm to the environment and no net loss of biodiversity.

[3] This includes but is not limited to: ongoing scientific research and monitoring of the oceans to better understand the diversity and biomass of life associated with seabed ecosystems; the life cycles of highly mobile marine organisms; nutrient cycling in deep water ecosystems; interactions between mineral deposits and biodiversity; carbon sequestration and cycling by seabed organisms; trace metal and mineral cycling; the processes and risks of runaway acidic reactions associated with sulphide minerals; deep ocean hydrography and the implications on ecosystem function of changing topography by removal of substrates; the extent and impact of sediment plumes on biodiversity and ecosystem services; the responses of seabed life to light, noise, vibration and electromagnetism.

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19. Annexes

Annex 1. Examples of national-level marine policy relating to Marine mining operations.

Legislation and policy in the United Kingdom

UK laws and regulations to govern oil and gas operations and to conserve marine biodiversity have their origins with the European Union.

The Environmental Assessment of Plans and Programmes Regulations (2004) implements the European Strategic Environmental Assessment (SEA) Directive (2001/42/EC). SEAs have been carried out for oil and gas operations since 1999 in accordance with its requirements.

The Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999 (as amended in 2007) require environmental assessments to be carried out for the following offshore oil and gas activities: the granting and renewal of production consents for field developments, the drilling of wells (deep boring) and the construction and installation of production facilities and pipelines in the UK Territorial Sea and on the UK Continental Shelf (UKCS).

The Offshore Chemicals Regulations 2002 (as amended in 2011) states that offshore operators must apply for permits for the use and/or discharge of chemicals in the course of all offshore oil and gas activities, including oil and gas production operations, well drilling, discharges from pipelines, and discharges during decommissioning activities.

T**he Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005 (as amended)** prohibit the discharge of oil to sea other than in accordance with the terms and conditions of a permit.

The Offshore Combustion Installations (Pollution Prevention and Control) Regulations 2013 specify provisions of the Industrial Emissions Directive 2010/75/EU (“the IED”) in respect to specific atmospheric pollutants from combustion installations relating to oil and gas production and gas and carbon dioxide unloading and storage.

The **Marine and Coastal Access Act (MCAA) 2009** covers those offshore energy activities such as decommissioning operations, including disturbance of the seabed, the depositing and removal of materials and the use of explosives.

The Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001 (as amended in 2007) require consent for geological surveys related to oil and gas activities undertaken on the UKCS and UK waters, and prior consent for the testing of equipment to be used in geological surveys. *A Habitats Regulation Assessment* must be made of the implications to any Natura 2000 site where impacts may occur.

The Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (as amended in 2010) came into force in 2007, implementing EU Directives on the conservation of wild birds, natural habitats and of wild fauna and flora in relation to offshore marine areas. The regulations apply in the “offshore area” beyond 12 nautical miles from the UK coast and protect marine species and wild birds by creating a number of offences that aim to prevent environmentally damaging activities. The regulations also enable the designation and protection of Special Areas of Conservation (SACs) for the protection of certain habitats and species and Special Protection Areas (SPAs) for the protection of certain wild bird species.

There are several EU Directives designed purely for the protection of the marine environment, but which affect oil and gas developments.

> The European Union's ambitious **Marine Strategy Framework Directive (Marine Directive)** is designed to protect more effectively the marine environment across Europe. The Marine Directive was adopted in 2008 and transposed into national legislation in 2010 and aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. It is the first EU legislative instrument related to the protection of marine biodiversity.
>
> The Directive lists four European marine regions – the Baltic Sea, the North-east Atlantic Ocean, the Mediterranean Sea and the Black Sea – located within the geographical boundaries of the existing Regional Sea Conventions. The UK falls under the North East Atlantic region.
>
> In order to achieve GES by 2020, each Member State is required to develop a strategy for its marine waters, which must be reviewed every 6 years. This strategy must: determine the current status of national marine waters and the impact of human activities; determine what 'good environmental status' means for national marine waters; establish suitable environmental targets and indicators to monitor progress towards GES; and finally, develop a programme to deliver GES.

The OSPAR Commission

The OSPAR Commission is the means by which 15 EU Member States (including the UK) aim to implement the EU Marine Directive in the North-East Atlantic. The role of the OSPAR Commission is to harmonise policies and strategies, including the drawing up of programmes and measures, for the protection of the marine environment. The OSPAR Commission also undertakes and publishes at regular intervals joint assessments of the quality status of the marine environment and of the effectiveness of the measures taken and planned.

On the basis of Quality Status Reports, the OSPAR Commission identifies priorities for action for the protection of the marine environment. Contracting Parties agree to take all possible steps to prevent and eliminate pollution and to take the necessary measures to protect the maritime area against adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected.

Legislation and policy in United States of America

Legislation and regulations regarding offshore oil and gas exploration, development, and production from U.S. offshore lands developed over five decades in response to a variety of concerns, currently addressing safety, equity, and the protection of marine and coastal environments. A variety of environmental risks are associated with offshore O & G exploration and production, among them such things as discharges or spills of toxic materials whether intentional or accidental, interference with marine life, damage to coastal habitats owing to construction and operations of producing infrastructure, and effects on the economic base of coastal communities. During the 1960s increasing environmental awareness set the stage for the development of numerous environmental laws, regulations, and executive orders that have affected (oil and gas) activities on Federal offshore areas. All oil and gas activities must now pass through a large number of environmental reviews by Federal, State and local agencies. Key national laws include:

> ***The National Environmental Policy Act* (NEPA), passed in 1969,** requires the Federal Government to consider the environmental impacts of any proposed actions as well as reasonable alternatives to those actions. Environmental Assessments, Environmental Impact Statements (EIS), and Categorical Exclusion Reviews are the primary tools to understand and make decisions on how to manage for environmental consequences. An EIS is prepared for every lease sale held by the Mineral Management Service (MMS).

***The Clean Air Act* (CAA) passed in 1970** states that proposed and existing natural gas and oil facilities must prepare, as part of their development plans and reporting procedures, detailed emissions data to prove compliance with the CAA. The amendments added in 1977 and 1990 set new attainment goals for ambient air quality and updated the Act to account for issues such as acid rain and ozone. The 1990 amendments established jurisdiction of offshore regions regarding regulation of air quality.

***The Coastal Zone Management Act* was passed in 1972** based on the perceived need to preserve, protect, develop, and restore or enhance the resources of U.S. coastal zones. This Act encourages coastal States to complete an individual Coastal Zone Management Plan for their coastal areas and requires State review of Federal actions that affect land and water use in these coastal areas. The consistency clause of this Act gives States the power to object to any Federal action that they deem not consistent with their approved Coastal Zone Management Plan. The Department of Commerce assists States with their coastal zone management plans, reviewing and approving the plans, and conducting continuous monitoring for compliance. NOAA, within the Department of Commerce, carries out these responsibilities but the Secretary of Commerce must grant final approval to all coastal zone management plans before implementation.

***The Endangered Species Act* (ESA) of 1973** protects and promotes the conservation of all species listed as endangered by restricting Federal actions that are likely to harm, harass, or pursue them. Under the ESA, plant and animal species (including marine species affected by offshore O & G operations) can be listed as facing potential extinction after a detailed legal process. In 1995, the U.S. Supreme Court ruled that significant habitat modification was a reasonable interpretation of the term “harm.” The ESA can therefore affect O & G operations in all areas near or where habitat considered critical to listed marine species exists.

***The Clean Water Act* (CWA) of 1977** is the primary law governing the discharge of pollutants into all U.S. surface waters. Under this law, the EPA requires that a National Pollutant Discharge Elimination System (NPDES) permit be obtained before any pollutant is released. The CWA holds oil and gas production to strict standards regarding direct pollution discharges into waterways. These standards are outlined in the NPDES permits and may be based on the age of a facility. Since the permits are issued on a 5-year basis, so oil and gas companies must renew their NPDES permits every 5 years.

Legislation and policy in Australia

1. Federal legislation – Environment Protection and Biodiversity Conservation Act

***The Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)** is the Australian Government’s principal piece of environmental legislation. One of the legislations objectives is to provide a streamlined national environmental impact assessment process. An environmental impact assessment is required for projects that have the potential to impact World Heritage properties, listed threatened species and ecological communities, migratory species protected under international agreements, Commonwealth marine areas and the Great Barrier Reef Marine Park.

The EPBC Act Environmental Offsets Policy guides the use of offsets under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The offset policy currently applies to offsetting requirements in terrestrial and aquatic (including marine) environments. However, the recent senate enquiry identified the need for a separate policy or guidance for marine ecosystemsv. This National-level policy is complemented by policy at the individual State level.

State legislation - Western Australia

Western Australia harbours significant offshore extractives activities and marine biodiversity hotspots. The state government has designed and implemented environmental management systems that are considered ‘international best practice’2. Petroleum exploration and development activities are regulated by state and federal agencies in Western Australia. Legislation that governs environmental impacts include:

- **Petroleum (Submerged Lands) (Environment) Regulations 2012**
- **Petroleum and Geothermal Energy Resources (Environment) Regulations 2012**
- **Petroleum Pipelines (Environment) Regulations 2012**

These laws establish the requirements for the submission of an Environment Plan and an Oil Spill Contingency Plan which must be submitted prior to the commencement of any petroleum activities within the State.

Appendix 2: Shipping impacts table

Project cycle	Project stage	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Avoidance	Minimisation
Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources)	Entire life cycle of shipping fleet		Impact to biodiversity from climate change and excessive resource use.								Ship ownership ensures group standards are met and applied
											Certification to ISO14001 ensures a minimum standard of environmental management, including energy and resource efficiency and waste management.
											Environmental Policy goes beyong compliance in adopting the mitigation hierarchy and aiming for a no net loss approach to biodiversity
				L	P						Shut-down and upgrade of shipping fleet every 3 years to minimise ship movements while in operation, as they stay in site for the full 3 years, so reducing fuel use and collision risk
											Maintenance facilities ensure efficent use of fresh water and impose strict waste recycling standards
											De Beers Marine's capacity for naval architecture means ships can be designed and upgraded for greater efficiency
											De Beers Marine has an internal environmental screening tool for projects which aims to minimise wastes, emissions, resource consumption and use of hazardous materials
		Sea vessel presence and movement	• Sea vessels moving to/ from the worksite to shore could collide with marine species and block feeding areas and migration pathways restricted areas for shipping prevent access to unauthorised vessels. • Minor releases of pollutants/wastes from ships. • Non-physical disturbance such as noise & visual presence.	• Injury and potential mortality of marine species including cetaceans, pinnipeds, sirenians, seals, turtles and seabirds through collision with vessel. • Disturbance to migration, feeding and breeding patterns through noise and light from vessel, e.g. where vessel is adjacent to intertidal areas used by migratory birds.	M	PD	• Impacts to cultural services (e.g. ecotourism, whale watching, reef diving) related to the frequency or timing of shipping. • Visual and aesthetic impact to seascape • Altered behaviour of species of economic (e.g. commercial fish) or cultural importance (e.g. iconic marine mammals) due to movement of vessels with implications for livelihoods and nutrition (e.g. fisheries, tourism) • Restricted access to traditional fishing grounds by local communities, reducing ability of subsistence fishers to catch fish and potentially increasing competition between fishers in surrounding waters	M	PD	Monitor for presence and movements of large cetaceans, sirenia, and turtles (using observers on ships - Marine Mammal Observers - and/ or acoustic monitoring devices) so that collisions with vessels can be avoided. This mitigation action will only be effective for vessels capable of rapid manoeuvres (e.g. vessels of a few thousand GT or less).	Maintaining vessels at site for long period of time (with periodic shut-down and upgrading of shipping fleet, e.g. every 3 years) reduces the risk of collision.

Project cycle	Project stage	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Avoidance	Minimisation
Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Sea vessel presence and movement (cont.)	• Sea vessels moving to/ from the worksite to shore could collide with marine species and block feeding areas and migration pathways restricted areas for shipping prevent access to unauthorised vessels. • Minor releases of pollutants/wastes from ships. • Non-physical disturbance such as noise & visual presence.	• Injury and potential mortality of marine species including cetaceans, pinnipeds, sirenians, seals, turtles and seabirds through collision with vessel. • Disturbance to migration, feeding and breeding patterns through noise and light from vessel, e.g. where vessel is adjacent to intertidal areas used by migratory birds.	M	PD	• Impacts to cultural services (e.g. ecotourism, whale watching, reef diving) related to the frequency or timing of shipping. • Visual and aesthetic impact to seascape • Altered behaviour of species of economic (e.g. commercial fish) or cultural importance (e.g. iconic marine mammals) due to movement of vessels with implications for livelihoods and nutrition (e.g. fisheries, tourism) • Restricted access to traditional fishing grounds by local communities, reducing ability of subsistence fishers to catch fish and potentially increasing competition between fishers in surrounding waters	M	PD	Where possible, avoid sensitive areas, e.g. Marine Protected Areas (MPAs), areas of shallow and deep water corals, areas of artisanal fisheries and the areas devoted to marine aquaculture, registered with the National Authority for fisheries and marine resources. Develop exclusion zones in consultation with key stakeholders including local fisher communities; raise awareness of exclusion zones with all stakeholders.	Meet with fishing communities to assess potential impacts for fisheries and develop plans for mitigation that are appropriate to the local context. Limit vessel speed in sensitive areas. (risk of collision with whales increases significantly at speeds of >10 knots). Design vessel routes to avoid areas of known high concentration of marine mammals and reptiles.
		Anchoring of vessels offshore	Physical damage by anchor and anchor chains to benthic habitat and species	Anchoring vessels may disturb or damage sensitive benthic communities, including mortality to sessile or slow-moving benthic organisms	H	P	• Damage or disturbance to nursery, feeding and breeding grounds for fish and shellfish that are important to commercial and local fishing communities for revenue and nutrition. • Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) through impacts of noise and vibration • Visual / aesthetic impact to seascape • Altered behaviour of species of economic (e.g. commercial fish) or cultural importance (e.g. iconic marine mammals) due to noise and vibration disturbance with implications for livelihoods and nutrition (e.g. fisheries, tourism)	H	P		Designate anchorage areas that avoid sensitive marine habitats such as coral reef which reduces the overall area of seabed affected by chronic anchor disturbance. Dynamic positioning (using thrusters) could minimise the use of anchors. Implement designated anchorages that limit interaction between anchored vessels and traditional and/ or commercial fishing activities.
		Ship and boat wash, as a result of the movement of vessels during operation	Changes in physical regime such as an increase in waves and sediment transport	Wash from vessels may cause changes to the hydrodynamic regime which result in erosion of intertidal and shallow subtidal habitats and disturbance to communities.	L	T	Increased turbidity from sedimentation impacts on the physico-chemical conditions of the water column reducing productivity of fisheries.	L	T		Implement site specific measures to minimise ships' wash in the proximity of vulnerable shores. For example zoned areas to reduce speeds. Investigate the feasibility of protecting intertidal features from ship wash by creating breakwaters where there is evidence that ships wash is causing the erosion of designated intertidal flats, where all other appropriate measures have been undertaken or as a precautionary approach.

Project cycle	Project stage	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Avoidance	Minimisation
Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Antifouling paints - Used to coat bottoms of sea vessels to prevent sea life such as algae and molluscs attaching themselves to the hull, thereby slowing down the ship and increasing fuel consumption	Antifouling paints, which can contain potent biocides (e.g. Tributyltin - TBT), are released into wider marine community.	• Deformities in oysters • Malformations in shellfish • Sex changes in whelks • Death of larvae (e.g. death of brine shrimp larvae by copper based paints).	H	PD	• Impacts to collection fisheries reliant upon shellfish and crustaceans • Impacts to human health and nutrition due to health of fish caught and consumed. • Bioaccumulation leading to impacts to health of higher predators and scavengers	H	PD	As per the International Maritime Organisation's (IMO's) International Concention on the Control of Harmful Antifouling Systems on Ships, do not use antifouling paints that contain harmful organotins; ships should not apply or re-apply organotin compounds which act as biocides in anti-fouling systems.	
										For ships that have already had antifouling paints that contain harmful organotins applied to their hulls or external parts of surfaces, a coating that forms a barrier to such compounds leaching from the anti-fouling systems into the marine environment should be applied	
		Ballast water - used to stabalise vessels at sea when cargo tanks are empty	Discharge of ballast water in different location to where it was pumped in to vessel can result in the introduction of alien (non-native) species into the marine environment. Alien species can include microorganisms, small invertebrates, eggs, cysts and larvae of various species, which can become established in their new environment to become alien invasive species (AIS) under certain conditions. Impacts from AIS offshore can be transferred to coastal areas in currents and tides.	Decline or extinction of native species through AIS competing with native species for space and food • Decline or extinction of native species through AIS preying upon native species • Decline or extinction of native species through introduction of diseases and pathogens • Alteration of food web dynamics through reduction or removal of key populations • Alteration of habitat • Alteration of environmental condition, e.g. decreased water clarity			• Impacts for provisioning services if introduced diseases and AIS negatively affect fish and other species important to commercial or subsistence fisheries			Ensure the ports used have facilities to receive and treat ballast water to manage in an environmentally safe way sediments of the ballast tanks and eliminate all organisms and pathogens.	As per the Ballast Water Management Convention, ships in international traffic are required to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan. The Ballast Water Management Plan is specific to each ship and includes a detailed description of the actions to be taken to implement the management requirements and practices. All ships must also carry a ballast water record book to record when ballast water is taken on board; circulated or treated for Ballast Water Management purposes; and discharged to sea. It should also record when ballast water is discharged to a reception facility and accidental or other exceptional discharges of ballast water. Ships must also carry an international ballast water management certificate.

Project cycle	Project stage	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Avoidance	Minimisation
Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Ballast water - used to stabalise vessels at sea when cargo tanks are empty	Discharge of ballast water in different location to where it was pumped in to vessel can result in the introduction of alien (non-native) species into the marine environment. Alien species can include microorganisms, small invertebrates, eggs, cysts and larvae of various species, which can become established in their new environment to become alien invasive species (AIS) under certain conditions. Impacts from AIS offshore can be transferred to coastal areas in currents and tides.	Decline or extinction of native species through AIS competing with native species for space and food • Decline or extinction of native species through AIS preying upon native species • Decline or extinction of native species through introduction of diseases and pathogens • Alteration of food web dynamics through reduction or removal of key populations • Alteration of habitat • Alteration of environmental condition, e.g. decreased water clarity	H	P	• Impacts for provisioning services if introduced diseases and AIS negatively affect fish and other species important to commercial or subsistence fisheries	H	P	Ensure the ports used have facilities to receive and treat ballast water to manage in an environmentally safe way sediments of the ballast tanks and eliminate all organisms and pathogens.	Wherever possible ballast water should be taken on-board outside of port waters and as far away from the coast as possible 97,98,99. The uptake of ballast water should be minimised or, where practicable, avoided in areas and situations such as: - In darkness when organisms may rise up in the water column - In very shallow water - Where propellers may stir up sediment - Areas with current large phytoplankton blooms - Nearby sewage outfalls - Where a tidal stream is known to be more turbid - Where tidal flushing is known to be poor - In areas close to aquaculture - Where dredging is being or has recently been carried out
											Tanks used for holding other purposes (e.g. grey water, treated sewage) should be cleaned prior to use for holding ballast water
											Ensure treatment of ballast water through either solid-liquid separation (the separation of suspended solid material, including the larger suspended micro-organisms, from ballast water either by sedimentation or by surface filtration) or by disinfection (removes and/or inactivates microorganisms through chemical inactivation, physiochemical inactivation or asphyxiation). Solid-liquid separation processes produce a waste stream which require appropriate management and during ballasting they can be safely discharged at the point where they were taken up.

Project cycle	Project stage	Project activity	Impact of project activity	Potential pre-mitigation impacts on biodiversity	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Potential pre-mitigation impacts on ecosystem services	Significance (Low, Medium, High)	Duration (temporary/ Project Duration or permanent)	Avoidance	Minimisation
Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Ballast water - used to stabalise vessels at sea when cargo tanks are empty	Discharge of ballast water in different location to where it was pumped in to vessel can result in the introduction of alien (non-native) species into the marine environment. Alien species can include microorganisms, small invertebrates, eggs, cysts and larvae of various species, which can become established in their new environment to become alien invasive species (AIS) under certain conditions. Impacts from AIS offshore can be transferred to coastal areas in currents and tides.	Decline or extinction of native species through AIS competing with native species for space and food • Decline or extinction of native species through AIS preying upon native species • Decline or extinction of native species through introduction of diseases and pathogens • Alteration of food web dynamics through reduction or removal of key populations • Alteration of habitat • Alteration of environmental condition, e.g. decreased water clarity	H	P	• Impacts for provisioning services if introduced diseases and AIS negatively affect fish and other species important to commercial or subsistence fisheries	H	P	Ensure the ports used have facilities to receive and treat ballast water to manage in an environmentally safe way sediments of the ballast tanks and eliminate all organisms and pathogens.	Under regulation B-4 of the Ballast Water Management Convention, all ships using ballast water exchange should, whenever possible, conduct ballast water exchange at least 200 nautical miles from the nearest land and in water at least 200 metres in depth, taking in to account Guidelines developed by IMO. In cases where this is not possible, ballast water exchange should be conducted as far from the nearest land as possible, and in all cases at least 50 nautical miles from the nearest land and in water at least 200 metres in depth. When these requirements cannot be met, ships should conduct ballast water exchange in designated areas, or conduct tank-to-tank transfer of ballast water to prevent discharge of high-risk ballast water to the marine environment.
											All ships should remove and dispose of sediments from spaces designed to carry ballast water in accordance with the provisions of the ships' ballast water management plan
		Biofoulants on sea vessels	Transportation of biofoulants, such as barnacles, that attach themselves to external surfaces of sea vessels into non-native environments. Biofoulants can become AIS if they become established in their new environment.	Decline or extinction of native species through AIS competing with native species for space and food •Decline or extinction of native species through AIS preying upon them. •Decline or extinction of native species through introduction of diseases and pathogens. Alteration of food web dynamics through reduction or removal of key populations • Alteration of habitat • Alteration of environmental condition, e.g. decreased water clarity	H	P	•Impacts for provisioning services if AIS negatively affect fish and other species important to commercial or subsistence fisheries	H	P	L	Ensure vessel(s) have a documented Biofoul Management Plan.
											Apply hot water treatments to reduce biofouling (including "thermal shock" and Hull Surface Treatment).
											Develop biofoul risk assessment and quarantine management system for all operational vessels, including supply tankers.
											Ensure anti-fouling treatments and records are up-to-date.

Project cycle	**Project stage**	**Project activity**	**Impact of project activity**	**Potential pre-mitigation impacts on biodiversity**	**Significance** (Low, Medium, High)	**Duration** (temporary/ Project Duration or permanent)	**Potential pre-mitigation impacts on ecosystem services**	**Significance** (Low, Medium, High)	**Duration** (temporary/ Project Duration or permanent)	**Avoidance**	**Minimisation**
Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Noise generated by sea vessels	Noise generated in the marine environment can include continuous, low frequency noises, and noises generated from machinery.	• Impacts of noise on marine mammals may be behavioural or physiological. Behavioural impacts for marine mammals include changes in vocalisation, resting, diving and breathing patterns, changes in mother-infant relationships, masking of biologically important sounds and avoidance of the noise sources. Physiological effects of underwater noise may include a reduction in animal hearing sensitivity or secondary effects associated with other systems including the vestibular system, reproductive system, nervous system and liver. • Noise emissions that interfere with natural sounds in the marine environment may affect the timing of social and reproductive behaviour, particularly if the disturbance to vulnerable or endangered animals coincides with very short breeding or spawning periods. This could result in reduced breeding success and possible mortality. •Impacts to communication in marine mammals and other marine organisms	L	T	• Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) through impacts of noise and vibration • Altered behaviour of species of economic (e.g. commercial fish) or cultural importance (e.g. iconic marine mammals) due to noise and vibration disturbance with implications for livelihoods and nutrition (e.g. fisheries, tourism)	L	T		Ensure gradual start-up of engines and thrusters where possible, to provide opportunity for species to take evasive action. Propeller and thruster noise: Many options for reducing noise from propellers and thrusters currently exist and have been implemented on a large number of commercial vessels. Good propeller design, including large diameter, slow turning props (reduced cavitation), as well as blade shapes optimized to flow conditions, increased skew, and hull modifications to improve flow conditions are effective ways to reduce underwater noise. Cold ironing, or shore connection, or alternative maritime power (AMP), when ships are at berth. Use hydrophones to monitor ship noises. Implement noise reduction measures (non-essential equipment shut down) when cumulative noise load exceeds 120dB@ 250m from vessel.
		Lighting - artificial lighting generated from sea vessels	Light pollution in the marine environment	• Marine species can be attracted to light source and become disorientated • Marine mammals can stop feeding, resting, travelling and/or socialising, with possible long term effects of repeated disturbance including loss of weight and condition and reduced breeding success • Disorientation and behavioural changes can result in reduction in breeding and feeding success • Fish may be attracted to ship's light source with larger aggregations increasing predation rates around sea vessels, resulting in loss of species abundance	L	PD	• Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) related to light disturbance. • Visual and aesthetic impact to seascape. • Altered behaviour of species of economic (e.g. commercial fish) or cultural importance (e.g. iconic marine mammals) due to light disturbance with implications for livelihoods and nutrition (e.g. fisheries, tourism)	L	PD		Minimise artificial lighting to that required for navigation and operational safety requirements For example, install security lights on motion- sensitive switches. Use directional lighting only to illuminate vessels as necessary. Where optional, point away from the shore. Use light shielding to focus light towards work areas and reduce light 'spill' into sensitive habitats. Investigate the effectiveness of coloured lighting and/or adapting the spectrum of lights in reducing its attraction for migratory birds and turtles

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Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Lighting - artificial lighting generated from sea vessels (cont.)	Light pollution in the marine environment	• Marine species can be attracted to light source and become disorientated • Marine mammals can stop feeding, resting, travelling and/or socialising, with possible long term effects of repeated disturbance including loss of weight and condition and reduced breeding success • Disorientation and behavioural changes can result in reduction in breeding and feeding success • Fish may be attracted to ship's light source with larger aggregations increasing predation rates around sea vessels, resulting in loss of species abundance	L	PD	• Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) related to light disturbance. • Visual and aesthetic impact to seascape. • Altered behaviour of species of economic (e.g. commercial fish) or cultural importance (e.g. iconic marine mammals) due to light disturbance with implications for livelihoods and nutrition (e.g. fisheries, tourism)	L	PD	L	For turtles - use light sources that are 'turtles friendly' including very short wavelength light sources (i.e. pure yellow and red sources). Low-pressure sodium- vapour lighting is the purest yellow light source and recommended due to being the best commercially available solution.
		Hazardous wastes -Planned or accidental release of toxic and non-toxic substances during field development	Discharge of hazardous materials (hazmats) to marine environment. Hazmats can be classified according to the hazard as explosives; compressed gases, including toxic or flammable gases; flammable liquids; flammable solids; oxidizing substances; toxic materials; radioactive material; and corrosive substances.	A wide variety of stresses and potential mortality of marine life will occur, depending on the material and amounts discharged.	H	P	• Impacts for provisioning services through reduction in the availability of species important to commercial or subsistence fisheries due to direct mortality from exposure to hazardous materials. • Impacts on regulating and maintenance services through impacts on the physico-chemical conditions of the water column from contamination by oil, solvents and additives. • Impacts to human health and nutrition due to bio-accumulation of chemicals, affecting the health of fish caught and consumed. • Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) and associated revenues gained by tour operators through direct mortality from chemical incidents.	H	P	As per MARPOL Annex II and III, do not dispose of waste chemicals overboard. Disposal at port by reputable/licensed waste management contractors only	A hazardous materials management plan must be developed and implemented to minimise impacts of each type of hazardous waste. At a minimum, IFC EHS General Guidelines should be followed. IMO Green Passport is a certification to maximise efficiency in the recycling of ships, including hazmats. It contains an inventory of all materials used in the construction of a ship that are potentially hazardous, and should accompany the ship throughout its working life. Use environmentally sensitive alternatives to harmful chemical agents when cleaning port infrastructure. For example, the use of high pressure cleaning techniques. Install permanent 'scrub-off' facilities to collect maintenance residues from operational areas.

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Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Hazardous wastes -Planned or accidental release of toxic and non-toxic substances during field developmen	Discharge of hazardous materials (hazmats) to marine environment. Hazmats can be classified according to the hazard as explosives; compressed gases, including toxic or flammable gases; flammable liquids; flammable solids; oxidizing substances; toxic materials; radioactive material; and corrosive substances.	A wide variety of stresses and potential mortality of marine life will occur, depending on the material and amounts discharged.	H	P	• Impacts for provisioning services through reduction in the availability of species important to commercial or subsistence fisheries due to direct mortality from exposure to hazardous materials. • Impacts on regulating and maintenance services through impacts on the physico-chemical conditions of the water column from contamination by oil, solvents and additives. • Impacts to human health and nutrition due to bio-accumulation of chemicals, affecting the health of fish caught and consumed. • Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) and associated revenues gained by tour operators through direct mortality from chemical incidents.	H	P	As per MARPOL Annex II and III, do not dispose of waste chemicals overboard. Disposal at port by reputable/licensed waste management contractors only	Develop a sedimentation and erosion plan to limit particulate matter entering waterways. i.e. construct a bund around maintenance areas. Collect wastes in a sump which allows debris to settle out before the water runs into the marine environment. Store all hazardous materials in suitably contained areas, in accordance with their MSDS . Limit quantities stored to a minimum level required for operational purposes. Ensure detailed control documentation and manifesting for disposal. Upgrade of vessels periodically (e.g. every 3 years) ensured that inefficient equipment is upgraded, so minimises the risk of leaks and accidental discharges. Efficienies can be applied, e.g. no painting of contact surfaces of mining tool to minimise pollution.
		Inorganic waste generated on sea vessels (e.g. plastics)	Sea vessels moving to/ from the worksite to shore could illegally dispose of inorganic waste at sea, resulting in pollution of the marine environment by waste, e.g. plastics.	• Ingestion of plastic waste can cause individuals to die of starvation or malnutrition • Diving birds can become entangled in plastic waste - can lead to infection, loss of limbs or death • Plastic waste can leach toxic substances to sediments and water where it can be absorbed by small algae and animals and cause bioaccumulation in other animals feeding on them. • Toxic plastics can be ingested directly by fish, exposing species further up the food chain to these pollutants - can lead to death from toxic poisoning. • Habitat degradation (seagrass and coral reef) due to smothering and reduced light access.	L	PD	• Impacts for provisioning services through reduction in the availability of species important to commercial or subsistence fisheries due to direct mortality and disruption of food web caused by plastics. • Impacts to cultural ecosystem services (e.g. ecotourism, whale watching, reef diving) through impact to aesthetic beauty from plastic waste and direct mortality of species important to tourism. • Impacts to human health and nutrition due to health of fish caught and consumed. • Impacts on regulating and maintenance services through impact on physico-chemical conditions of the water column due to turbidity.	L	PD	As per MARPOL Annex V, do not dispose of plastic waste overboard. Collect all plastic waste for onshore disposal by reputable waste management contractors only, and seek recycling options where available	Efforts should be made to eliminate, reduce, or recycle wastes at all times. A management plan must be developed and implemented to minimize discharge of each type of solid waste. At a minimum, IFC EHS General Guidelines must be followed. The plan should consider upland disposal of solid wastes in approved sites. Staff induction to managing solid waste for recycling and disposal.

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Shipping - occuring at all project stages of marine mining (e.g. survey vessels, mining vessels, support vessels, vessels carrying dry cargo and mined resources) (cont.)	Entire life cycle of shipping fleet (cont.)	Organic waste generated on sea vessels	Sea vessels moving to/ from the worksite to shore dispose of wastes (including kitchen waste, effluent, sewage and grey water) at sea	•In near-coastal waters or estuaries with poor flushing, can result in reduced benthic biodiversity and abundance, changes in fish behaviour, stress and acute or latent mortality of marine species through lack of oxygen. •May introduce pathogens and cause turbidity that would affect local sensitive organisms with limited mobility (benthos and eggs) •Increase in biological oxygen demand and a reduction in habitat quality. Can result in eutrophication (algal blooms).	L	PD	• Impact to regulating service of waste assimilation through inundation of waste; impacts to human health from increased waste in environment • Impact on provisioning services through impacts to changing behaviour of nektonic and other species attracted to nutrients from waste • Impacts on regulating and maintenance services through impacts on the physico-chemical conditions of the water column from increased nutrient levels and suspended matter.	L	PD	Treat all sewage and grey water (to recognised standards) prior to discharge OR no disposal at sea - disposal at port by reputable waste management contractors only. Collect and compact all domestic waste for onshore disposal. Ensure detailed documentation and manifesting. Ensure that onshore receiving and disposal companies meet local and international requirements.	Use waste segregation at source for different types (organic, inorganic industrial wastes, etc.). No disposal of untreated sewage or grey-water within 12 nautical miles of land. Treat all sewage and grey water according to MARPOL requirements prior to discharge OR no disposal at sea - disposal at port by reputable waste management contractors only. Store used cooking oils in suitably contained areas. Limit quantities stored to a minimum. Ensure detailed control documentation and manifesting for disposal.
		Sea vessel emissions	Emissions from sea vessels have constituents (NOx, SOx, CO2, VOCs, particulates) that can contribute to water acidification and nitrification, climate change (carbon emissions) and deposition of particulates on land and in water	• Loss/reduction in quality of habitat • Behavioural changes by marine species • Injury or death of marine species as a result of toxicity	L		• Impact to regulating services of waste assimilation and productivity through emissions • Impacts on regulating and maintenance services through impacts on the physico-chemical conditions of the water column • Eventual impacts for provisioning services through reduction in the availability of species important to commercial or subsistence fisheries due to direct mortality and ecological imbalances caused by emissions.	L			Fit exhaust gas cleaning systems. Implement technical and operational energy efficiency measures to reduce CO2 emissions. Burn 'clean' fuel only (<0.1% sulphur content). Minimise number of supply vessel trips to site - i.e. maximise the efficiency of supply vessel use. Maintaining vessels at site for long period of time (with periodic shut-down and upgrading of shipping fleet, e.g. every 3 years) reduces fuel use and emissions.

An assessment of the risks and impacts of seabed mining on marine ecosystems

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