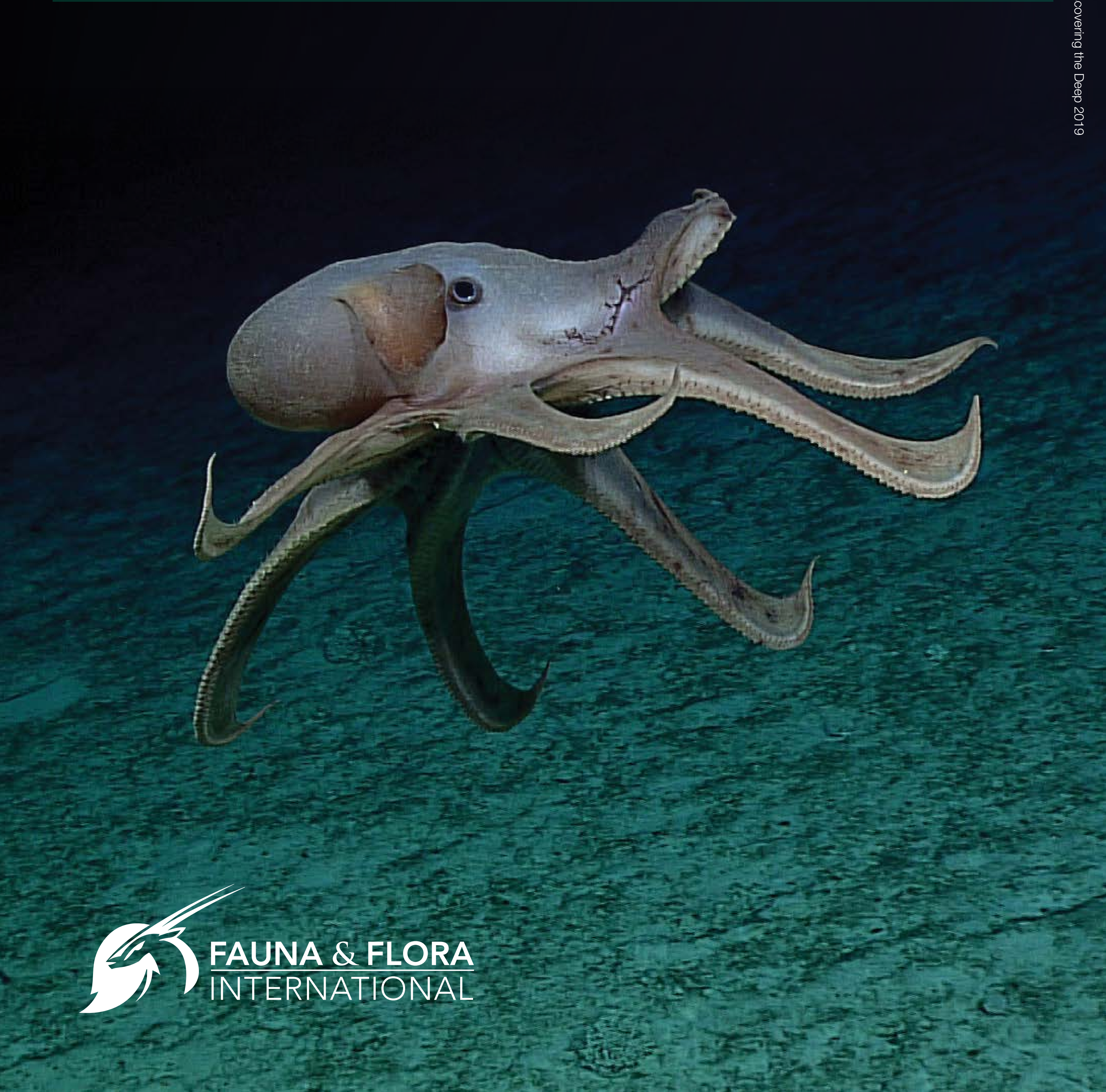
The risks and impacts of deep-seabed mining to marine ecosystems

EXECUTIVE SUMMARY



Cirrate Octopus Credit NOAA, Ocean Exploration & Research, Discovering the Deep 2019

FAUNA & FLORA INTERNATIONAL

Foreword

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.

Credit: Gary Morrisroe/FFI

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

Arctic Landscape. Credit: NOAA Ocean Exploration and Research, 2016

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, phosphorite nodules and cobalt-rich ferromanganese crusts) and rising demand for their use in high-tech industries including electronics and battery storage.

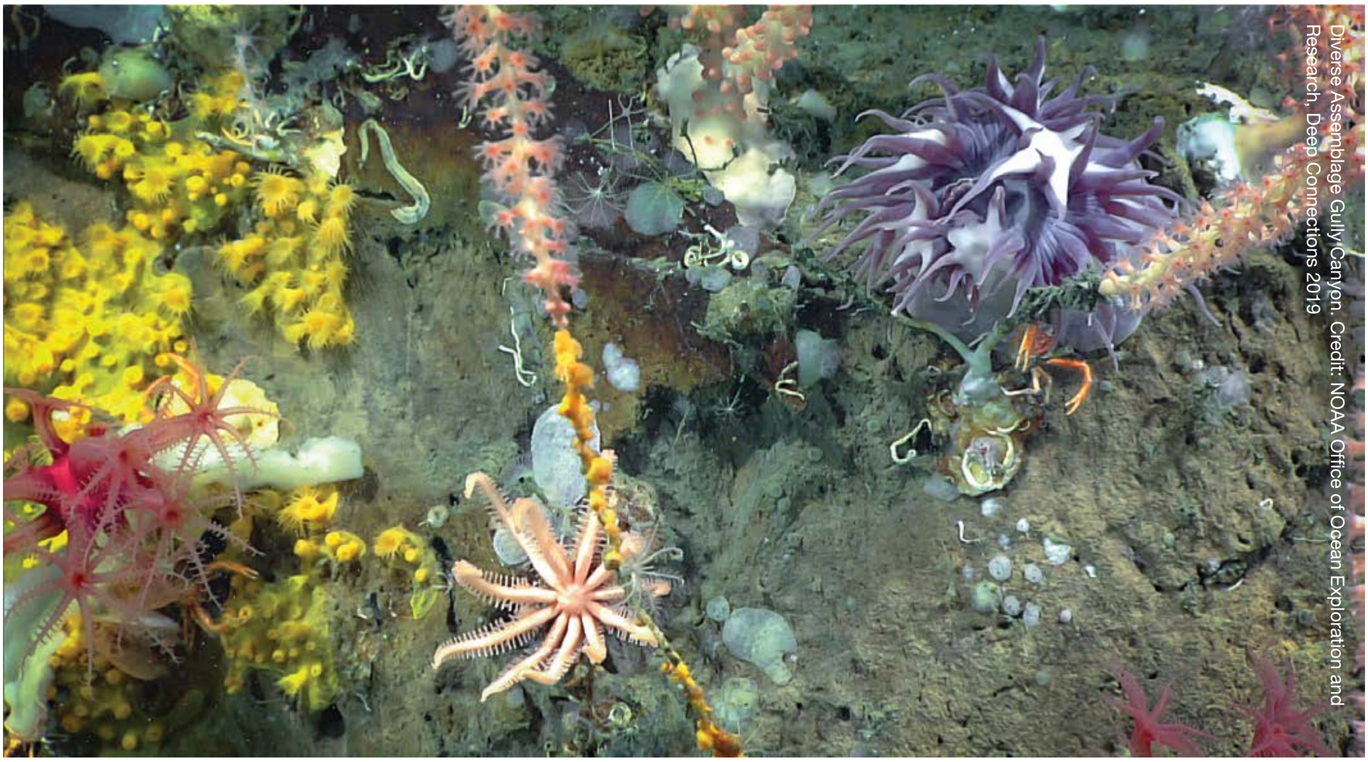
Currently there is a rush to establish rights and concessions and gain the exploration licences to start extraction of minerals from the deep sea, with key decisions about regulations permitting commercial deep-seabed mining planned for mid- to late-2020. There are 30 exploration contracts awaiting permitting 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.

However, 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 deep-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 beyond national jurisdictions, 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 minerals have been touted as essential for a decarbonised future, yet it should be noted that other sources of these minerals do exist (e.g. through untapped recycling potential) as well as new technologies for decarbonisation that are not dependent on metals.

Octopus and spnges seabed Credit: NOAA



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

Deep-sea ecosystems: a largely unexplored realm

The deep sea is a vast, pristine and largely unexplored area, with rich biodiversity and biophysical systems which are as diverse and dynamic as terrestrial ones, but far more expansive. These systems support key processes in carbon sequestration which in turn affect global carbon cycles and climate regulation.

Any changes to 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 marine biodiversity and ecosystems both complex and dependent on this 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 derived from falling organic debris (marine snow) or 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. This 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. Hotspots 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.

Riftia tubeworms 2,560m. Credit: NOAA Okeanos Explorer Programme, Galapagos Rift Expedition 2011

Growing concerns around potential impacts of deep-seabed mining

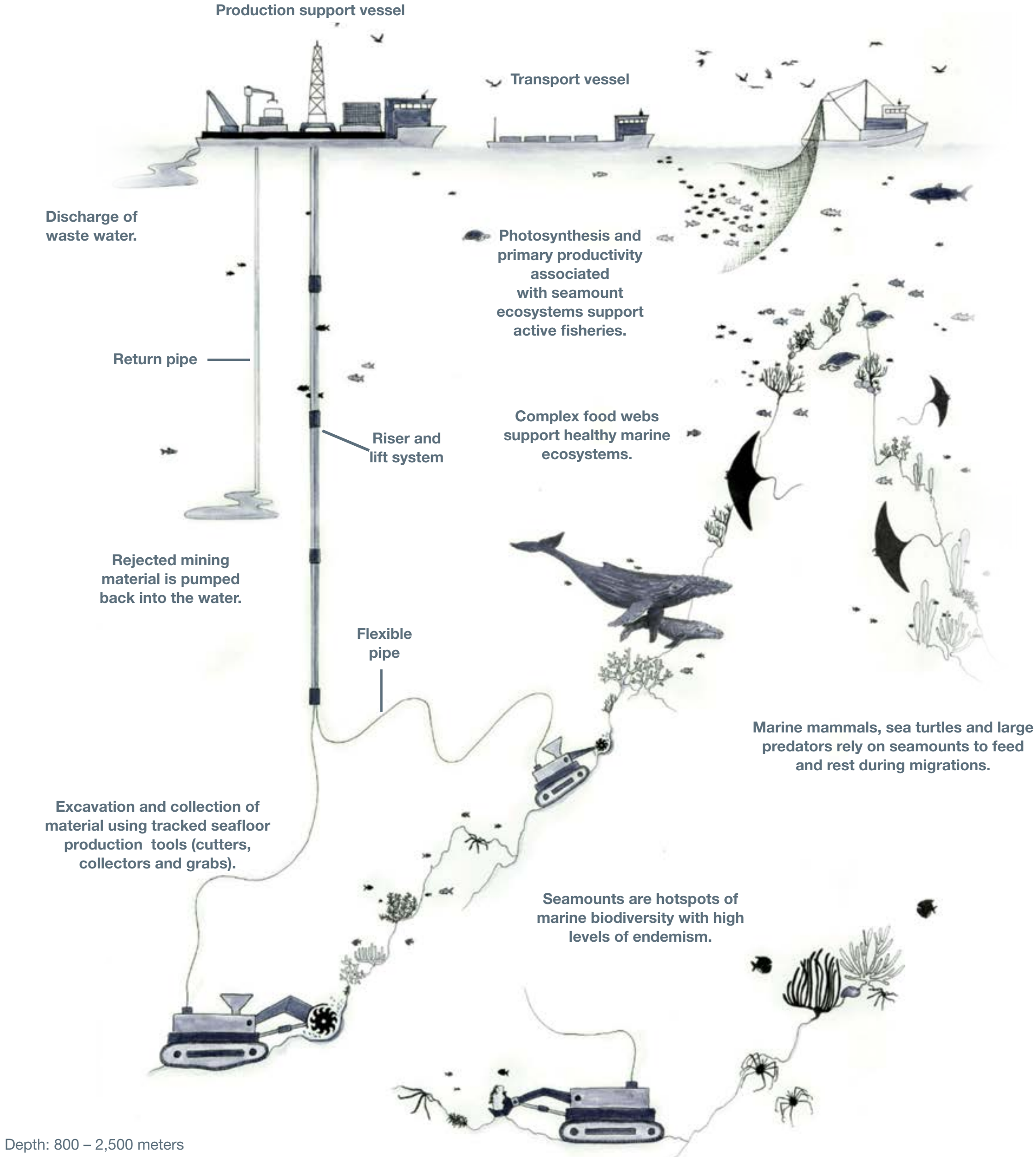
Determining the environmental risks and impacts of mineral extraction depends on the knowledge, information and data available. The deep sea remains our least explored and largest environment on the planet. A considerable level of knowledge will therefore be required to assess and manage sustainable 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[1] by a range of non-governmental and ocean science organisations, and to date a number of national governments have announced their support for a moratorium, as have representatives of other marine industries, such as fisheries[2].

Mining of ferromanganese crusts on slopes and summits of seamounts.

Drawing not to scale. Illustration adapted from Miller, Thompson, Johnston & Santillo (2018) An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. Frontiers in Marine Science: https://doi.org/10.3389/fmars.2017.00418 CC BY 4.0.



Credit: Nicky Jenner/FFI

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

Purpose and approach of this report

Given the increased interest in exploration and exploitation of deep-seabed minerals, the rapid pace of development of the 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 deep-seabed mining could proceed - using the good 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 deep-sea; 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.

The key to this approach is the application of a mitigation hierarchy, which requires prioritising 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 full report covers seabed mining, including mineral extractions in shallow waters to c. 180 metres depth and deep-seabed mining below 200 metres depth, and includes shallow marine placer diamonds and aggregates, deep-seabed phosphate and polymetallic minerals. This document does not deal with coastal or near-shore mining.

This document is divided into 3 sections.
PART A sets the context for assessing marine mining, including exploration of the key drivers of the industry and constraints to its development, a summary of existing governance structures, policy and regulation relating to the management of marine biodiversity and ecosystem service, and a strategic environmental assessment approach.

PART B contains information to describe a baseline for marine biodiversity and ecosystem services, including an overview of current knowledge on biodiversity and ecosystem services and the biophysical and ecological patterns and processes within the marine environment that drive ecological function, health and resilience.

PART C presents the major types of deep-seabed mining under development, the proposed methods for mineral extraction, and the potential risks and impacts to marine biodiversity and ecosystem services.
We provide an assessment of impact through the application of the mitigation hierarchy framework, subscribing to a no net loss outcome for biodiversity.


Flurescent jellie Credit: NOAA

Governance of deep-seabed mining

In Part A of the document, existing governance structures for deep-seabed mining are reviewed. 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 Area (beyond national jurisdiction) or on continental shelf areas (under a diversity of national jurisdictions).


Deepwater coral Credit: NOAA

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 as mandated by the United Nations General Assembly in 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.

UNCLOS dictates that the High Seas (i.e. beyond national jurisdictions) are "the common heritage of mankind" and need 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 (defined as the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction).

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, ecosystem services, and climate regulation—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.

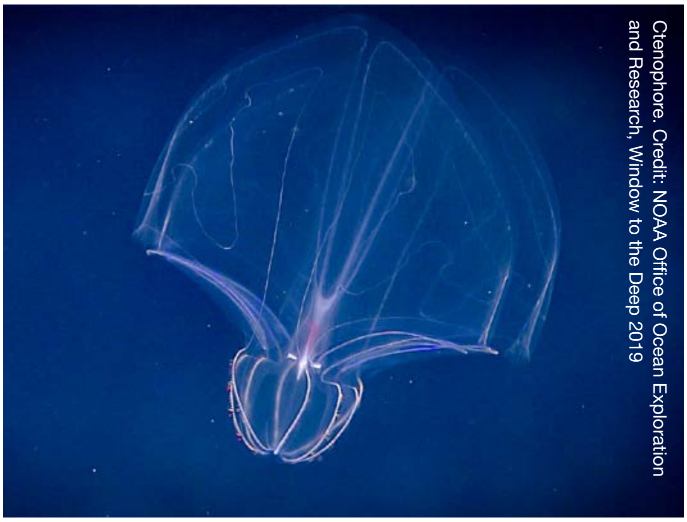
Currently, there is no robust, precautionary approach in place to safeguard against impacts to biodiversity, and regulations for deep-seabed mining in the High Seas are only in the early stages of development. Under current rules it is necessary for a mining project to conduct an Environmental Impact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

Establishing the baseline environment

In Part B, the report synthesises available information on deep-sea habitats, their associated biodiversity, mineral deposits and biophysical processes, and considers the role of deep-sea ecosystems in planetary processes.

Deep-sea ecosystems under threat from deep-seabed mining

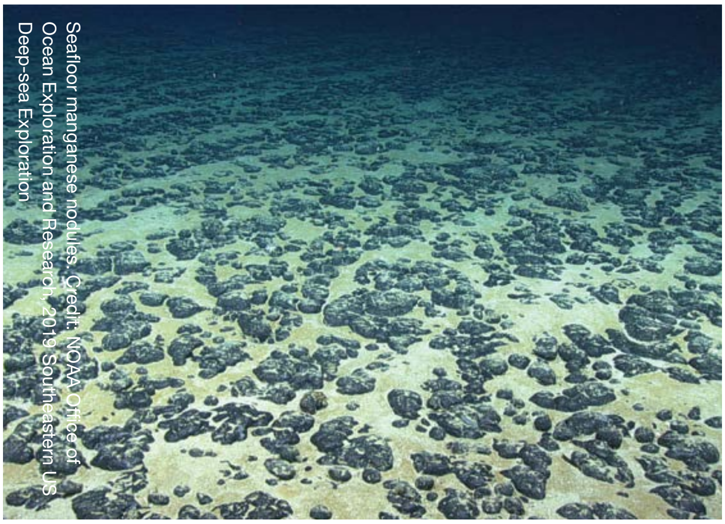
Oceans contain an astounding array of habitats, from the intertidal zone to the hadalpelagic waters more than 6,000 metres below the surface. Given the highly connected nature of the marine environment, it is important to consider the full range of marine habitats within a project's area of influence 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[4] were once assumed to be vast, desert-like environments, research shows they teem with a wide variety of microbial life and other larger creatures. Abyssal plains 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. 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 the balancing of metal-based elements and reducing potentially toxic metal compounds.



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

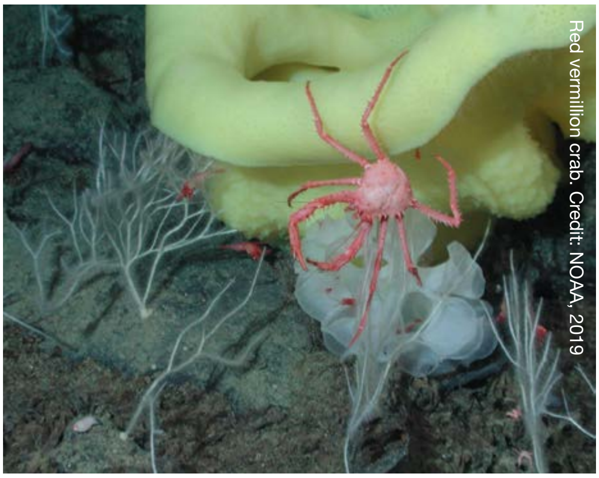
The chemosynthetic microbial communities thriving on nodules are the basis of primary production and life on the abyssal plains. They are found within the seafloor sediment, as bacterial mats on the seafloor and even within larger invertebrate organisms in the community. They act as the base of the food chain for an extensive and unique collection of organisms.

Polymetallic nodules are formed of concentric layers of manganese and iron hydroxides around a core. Nodules are targets for mining of a range of elements including cobalt, titanium, strontium, tellurium, and rare earth elements, copper, nickel, zinc, lithium, aluminium, and cadmium.

4. Abyssal plains are underwater plains on the deep seabed usually at depths of between 3,000 and 6,000 metres.

Cobalt-rich ferromanganese crusts

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 from the seafloor 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.


Red vermillion crab. Credit: NOAA, 2019

Seamounts are associated with cobalt-rich ferromanganese crusts, 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 which help to maintain the balance 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

Deep-sea 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.


Tubeworms. Credit: NOAA Office of Ocean Exploration and Research, Gulf of Mexico 2017

Globally, active hydrothermal vent ecosystems are rare habitats, comprising an estimated 50 square kilometres in total, which support highly specialised species and high levels of endemism, and hold 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. They are also central to 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,' 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. These processes balance ocean chemistry and associated key trace metals which drive 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.

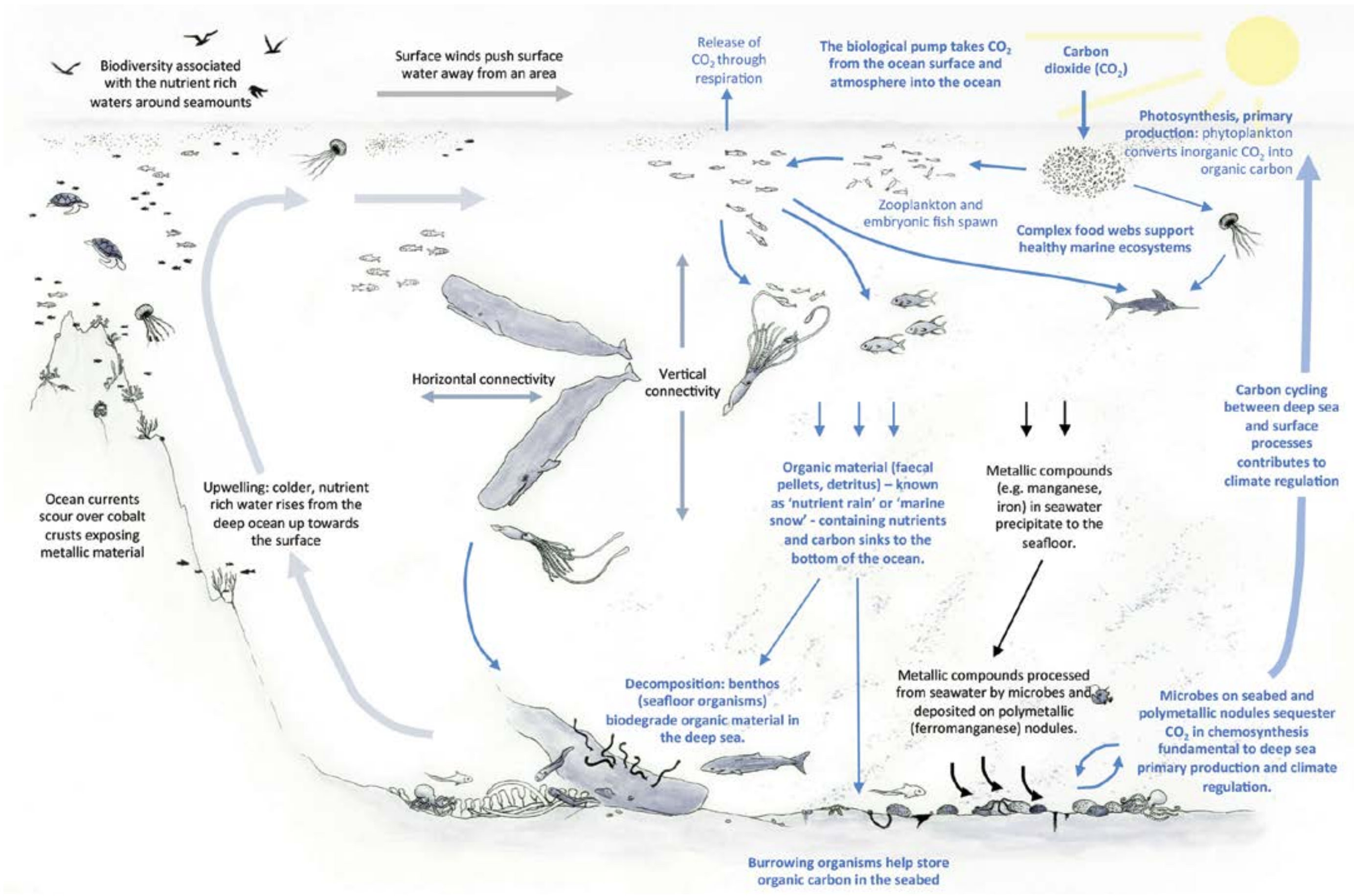
There is a relationship between the geophysical and biogeological processes that drive the trace element budgets on the planet (i.e. the amount of trace metals available for biological processes). Trace elements which are fundamental to biological processes (including ion and nutrient transport, reproduction, 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.).

The interconnected nature of the oceans mean that 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.

This interconnectedness means 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 deep-seabed mining and mining processes. Similarly, a lack of dispersion and dilution due to the absence of ocean mixing can exacerbate impacts when localised.

The bottom line is that we don't yet sufficiently understand the fundamental biological, geophysical and biochemical processes of the oceans. The implications of disruption of these processes thus requires very precautionary consideration.

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



Credit: Nicky Jenner/FFI

Risks, impacts and mitigation

Part C of the report synthesises the available science in order to assess the likely risk and impact of deep-seabed mining and determine what possible mitigation actions could be applied to avoid and reduce the extent of harm.

Risks and impacts

Most deep-sea ecosystems 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 from mining activities 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).

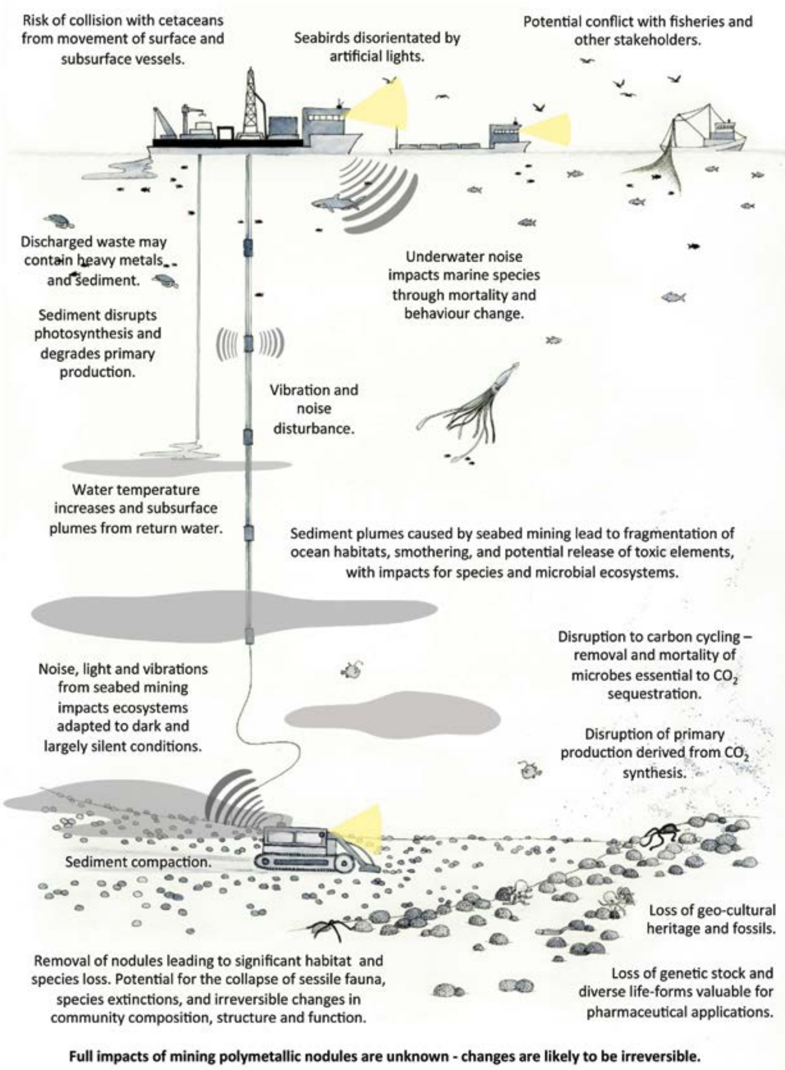
Mining activities could upset the chemical energy supplies that fuel microbial life in deep ocean ecosystems, disrupting the ecological functions that microscopic life provides and the amount and type of life that can be supported. Despite their importance, microbial organisms have been somewhat overlooked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

Furthermore, 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 as a result of 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.

Potential risks and impacts of mining polymetallic nodules on abyssal plains.

Drawing not to scale. Illustration adapted from Miller, Thompson, Johnston & Santillo (2018) An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. Frontiers in Marine Science: https://doi.org/10.3389/fmars.2017.00418 CC BY 4.0.



Credit: Nicky Jenner/FFI

Indirect impacts on the seabed and water column - both within and beyond directly mined areas – are likely to be more diffuse and difficult to predict. Impacts include smothering of habitat and biota 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.

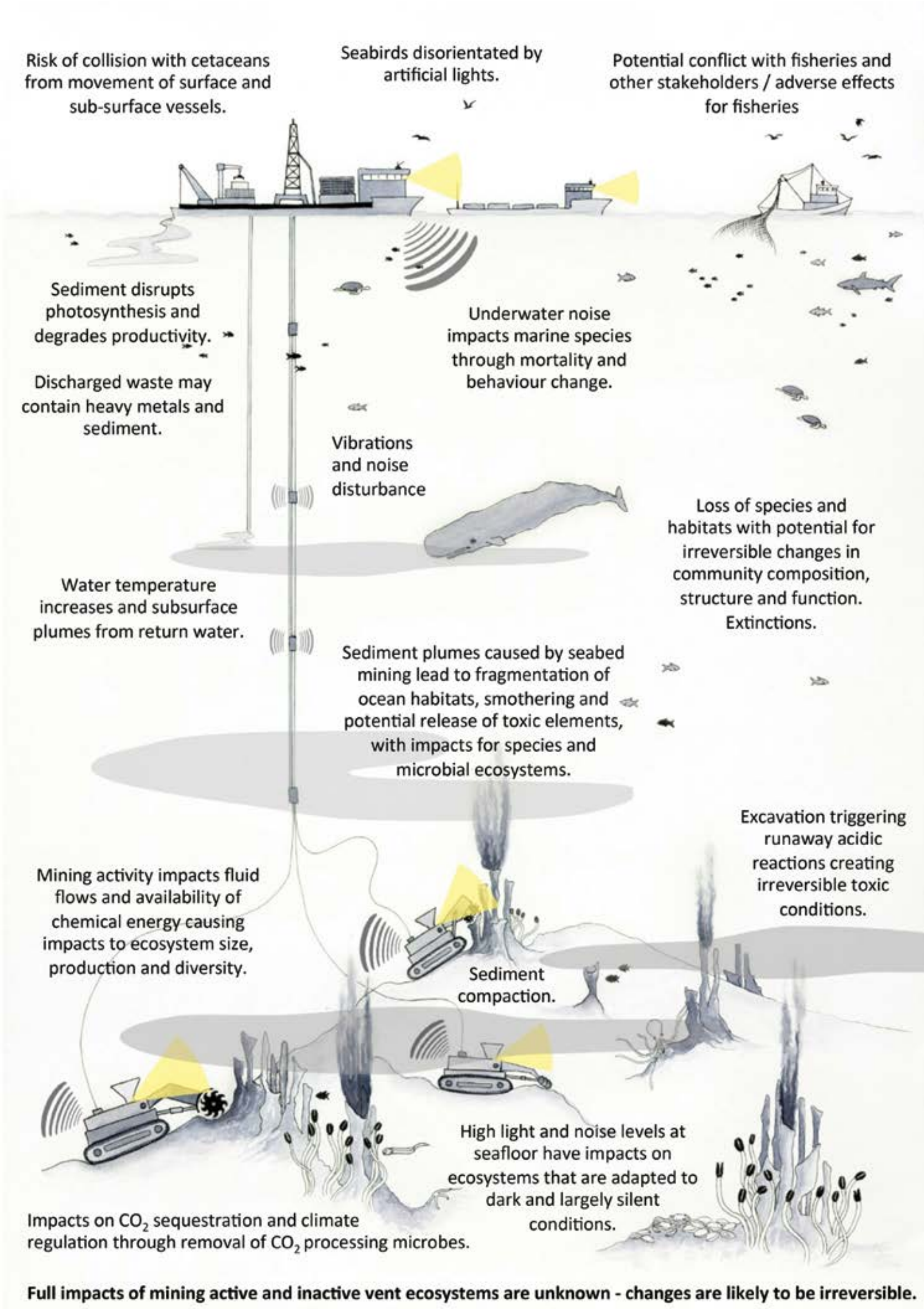
The scale over which these impacts are likely to occur is largely unknown and most of the effects remain unstudied. The highly connected and dynamic nature of the ocean and the complex biochemical and physical processes that drive ecosystem function implicate widespread impacts that are likely to be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

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. This is likely to cause ecosystem stress through disturbance of food and energy flows through deep-sea ecosystems, and by changing the ocean chemistry through depletion of nutrients fundamental to physiological processes. Consequent loss of ecosystem function through physical alteration and removal of ecosystem niche habitats and connectivity is also a real concern.

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.

Potential risks and impacts of mining seafloor massive sulphides on hydrothermal vents.

Drawing not to scale. Illustration adapted from Miller, Thompson, Johnston & Santillo (2018) An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. Frontiers in Marine Science: https://doi.org/10.3389/fmars.2017.00418 CC BY 4.0



Credit: Nicky Jenner/FFI

Application of the Mitigation Hierarchy

Deep-seabed mining is likely to result in 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 are essential.

- **Avoidance** is the only way to achieve no harm or no net loss outcomes as impacts are immitigable in time and space. The 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 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 seabed and at depth; 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 in marine environments, 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 may be over 10 million years old).

- **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

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

Conclusions

Following a thorough assessment of the current state of knowledge relating to deep-seabed mining and the marine environment, the following conclusions are drawn.

This large-scale review reveals evidence for significant, and currently immitigable impacts of deep-seabed mining on biodiversity.

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.

Given the centrality of minerals and metals to the future diffusion of low-carbon technologies, materials security and the future potential impacts of proposed deep-seabed mining should be actively incorporated into formal climate planning.

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

Recommendations

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

1) 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'.**

2) Promote a **globally harmonised governance system** for protecting the seabed to avoid fragmented, inconsistent approaches to regulating activities in different regions; one that takes into account stressors such as ocean acidification, climate change and pollution.

3) **Promote circular economy** approaches to reduce the demand for of raw primary materials.

4) 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.

5) Develop and implement a **research agenda** for addressing key scientific questions that **must be answered before commercial-scale mining** commences.

6) In order to **adequately 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.[4]

7) **Ensure** the application of the mitigation hierarchy and **adherence to no net loss**, and ideally a net gain **commitment** for biodiversity and ecosystem services for all seabed mining.

8) 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 regional environmental management planning process, large representative areas identified according to scientific criteria are ruled off-limits to seabed mining.

9) 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.

10) Critically review the **scope and objectives of the proposed 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.

4. 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.

Rough Seas. Credit Art Howard, Global Foundation for Ocean Exploration, NOAA Office of Ocean Exploration and Research, 2019

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EXECUTIVE SUMMARY

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