Decision-Making on Deep-Sea Mineral Stewardship: A Supply Chain Perspective

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Foreword

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Today, society expects stronger sustainability assurances than ever before. Accordingly – and as set out in this paper – manufacturers' success is increasingly tied to how they respond to expectations of their environmental and social performance. Every industry has a role to play in driving the transition to a more sustainable future.

At the London Metal Exchange and the World Economic Forum, we have heard from stakeholders across the metals supply chain that 2020 and 2021 have been extremely challenging years, with the effects of the COVID-19 pandemic felt universally. Given this backdrop, it would perhaps be understandable for the minerals-sourcing community to have delayed or deprioritized the sustainability agenda. However, if anything, the rare challenges faced during the pandemic have both underscored the urgency for manufacturers and markets to evolve and emboldened them to strive for sustainability with a renewed sense of determination.

The London Metal Exchange introduced responsible sourcing rules in 2019,[1] focused on human rights abuses and corruption in metal supply chains. From this experience, we have learned that there is a demand from stakeholders to understand in detail the impacts for people and planet associated with metals sourcing, and to be assured that production and processing has been achieved responsibly and sustainably.

It is clear that this demand will apply equally to industries looking to begin, including the potential exploitation of deep-sea minerals. For humanity to continuously improve, each new industry must seek to be more environmentally sustainable and socially responsible than those preceding it. Now, before the rules for this industry are set, is the right time to ask searching questions, as we contemplate the possibility of building a new industry based on sustainable foundations.

Making sound decisions about the stewardship of deep-sea minerals requires a profound understanding of the deep sea and its minerals, the societal context of mineral demand, the potential impact of deep-sea mineral exploitation on the sustainable transition and the views of a broad, inclusive range of potentially affected stakeholders. Questions surrounding the extraction of these minerals must be seen in the context of the transition to a circular economy, the drive to nature positivity in business and broader global efforts to decarbonize.

Much has been written already on the planned regulatory regimes for deep-sea mineral exploitation, and on the anticipated impacts of exploitation. This paper does not aim to judge the merits of any one standpoint. Rather, it is the first major work to contemplate the full range of potential impacts, affected stakeholders and supply-chain participants, in the context of a comprehensive decision-making ecosystem that asks how best to meet the mineral demands of our species in a real-world environment where each course of action entails note only direct intended effects but also a number of effects that may be harder to predict. The paper focuses on deep-sea mineral exploitation as a potential new industry that is being vigorously debated, but the ideas discussed within it, of inclusive decision-making on resource stewardship – not as a collection of countries and organizations but as a single human species – can and should be applied more broadly.

Manufacturers and markets are essential participants in the single-species decision-making ecosystem, and this paper calls upon them to heighten their engagement in the topic of deep-sea mineral stewardship. The challenges of the transition to a more sustainable future are immense, and the voices of responsible companies must be heard.

Executive summary

We face hard choices about the use of our planet's resources. Society must overcome unprecedented challenges, both environmental and economic, and metals and minerals will be key to these efforts. In 20 or 30 years' time, the commodities most critical to powering the global economy will not be hydrocarbons. They will be the metals that, among other applications, are used in clean energy generation, transmission and storage technologies.

It is against this backdrop that debate is taking place on the potential exploitation of deep-sea minerals: do they have a place in product supply chains as we move towards more sustainable business models and the responsible sourcing of materials? This paper attempts to build clarity on how such a question can be pragmatically posed in real-world decision-making. Its scope is broad, encompassing not just the environmental risks of mineral exploitation but other factors, too, including whether these minerals are needed to achieve societal goals. Effective decision-making must take a comprehensive approach.

This paper also expands the scope of questions on deep-sea mineral stewardship across the supply chain, bringing in the manufacturers and markets that are increasingly expected by society and regulators to source minerals responsibly. It argues that such organizations have a vital role to play in decision-making on whether, and under what circumstances, deep-sea minerals should enter supply chains.

On first impression, there is significant disagreement over such questions. While deep-sea mineral contractors draw up commercial plans and regulators draft operating frameworks, conservationists and others urge a moratorium on deep-sea mineral exploitation. However, organizations from across the spectrum of opinions use similar statements about the care and consideration that should be taken in the stewardship of deep-sea minerals.

We find that agreement between parties is hampered by a consensus gap on the meaning of terms. While general principles for sound stewardship are aligned, there are no commonly agreed benchmarks on, for instance: what approaches could be considered precautionary; when risk appreciation could be considered comprehensive; when research could be considered thorough; what environmental protections could be considered effective; or how the requirements for each might vary between phases of operations.

Arriving at such commonly agreed benchmarks requires an appreciation of the scale of the potential effects of deep-sea mineral exploitation. This paper assesses the extent to which such scale can be predicted, given the current levels of relevant knowledge. The potential effects were split into three overarching categories, covering a broad spectrum: those associated with increased metal availability; those associated with disturbance to the marine environment; and those associated with new sources of revenue from mineral exploitation. A wide range of experts was consulted on ocean science, economics, policy and regulation, mineral supply and demand projection, and technology innovation – and a literature review was conducted.

The analysis identified significant gaps in the current levels of knowledge about the scale of potential effects. Moreover, the potential effects that are currently least predictable are those that most directly affect people and planet. This underscores the need for additional knowledge-gathering before deep-sea mineral exploitation can be considered. In the ocean, for instance, the spread of sediment plumes from mineral processing and disturbances to extraction sites can be relatively well predicted based on the available knowledge, but the effects on marine ecosystems are currently less certain and the effects on communities whose livelihoods or values are tied to the sea are less certain still. Likewise, considering a potential increase in metals availability, supply quantities can currently be relatively well projected, but their disruptive effect on the clean energy transition, on the transition to circularity and on land-based mining are not as predictable based on what we currently know. The many potential knock-on effects for communities and the environment are even less predictable.

Significant research efforts are under way to close knowledge gaps, particularly in the field of ocean science, led by the deep-sea mining industry and guided by the International Seabed Authority (ISA) and other regulators. Meanwhile, a vigorous public debate is taking place on what further knowledge should be gathered before deep-sea mineral exploitation can be considered. Sufficient knowledge to enable decision-making is not the same as complete knowledge or full consensus of understanding, since real-world decisions often take place in situations where knowledge is lacking or disputed. But greater consensus should be reached on how much more knowledge is needed to make decisions.

Progress made towards knowledge of the potential effects of new mineral revenues, such as knowledge of the environmental effects, can be concretely defined and assessed, since it depends primarily on the finalization of revenue-distribution regulations by the appropriate authorities. Much less certain is the rate at which knowledge gaps can be closed on the potential effects of increased metals availability from deep-sea mineral exploitation. The simple question of "Do we really need the minerals of the deep sea?" is complex to answer. Mineral demand is widely expected to rise sharply because of the clean energy transition and other factors, but projections are subject to change as technology develops. The relative environmental and social impacts of other sourcing routes for needed minerals – from terrestrial mining – are similarly unpredictable while future extraction locations are unknown. Without significant new research on the potential effects of increased metals availability from deep-sea mineral exploitation, even with information about the potential environmental costs, the question of whether those costs can be justified for the overall good still cannot be conclusively answered.

Mapping the potential effects of deep-sea mineral extraction leads to the identification of potentially affected stakeholder groups. These include communities with traditional, cultural or indigenous links to the sea, fishing communities, communities dependent on coastal tourism and communities affected by land-based mining of minerals found in the deep sea. The scale of each potential effect of deep-sea mineral exploitation would be greatly influenced by forthcoming regulatory decisions, yet our analysis of official ISA Observers shows that such stakeholder groups are highly under-represented in decision-making processes relating to the stewardship of minerals in the international seabed area. In national jurisdictions, the picture is more varied.

If judicious decisions are to be made on mineral sourcing, based on a comparative analysis of the merits of each available course of action, it is vital that the views of all potentially affected stakeholder groups are fully heard. Otherwise, the scale of potential effects on them cannot be soundly gauged. Greater stakeholder participation, like further knowledge gathering, is an essential prerequisite for sound decision-making on the stewardship of deep-sea minerals.

Manufacturers, markets and other organizations in the mineral supply chain can take concrete steps to increase stakeholder participation in decision-making on the stewardship of deep-sea minerals by supporting civil-society groups that represent potentially affected stakeholder voices, and by actively engaging regulators, including ISA, in order to represent the views of their own stakeholders. These businesses can also contribute indirectly to pluralistic, consensus-based decision-making on deep-sea mineral stewardship by articulating the importance of scientific and economic knowledge they consider necessary for decision-making and supporting and facilitating public knowledge-sharing on the potential effects of deep-sea mineral exploitation.

To act as responsible corporate citizens and safeguard the planet's future, manufacturers and markets must prioritize the transition to a circular economy. In cases where new minerals still need to be used, manufacturers and markets should agree upon, and clearly articulate, the environmental, social and governance (ESG) principles they expect for the minerals they source. This is true of both terrestrial and deep-sea minerals, but, while a large amount of literature exists in the case of the former, very little has been written from manufacturers' and markets' perspective on the latter.

By formulating and stating ESG principles before any commercial exploitation of deep-sea minerals has been conducted, and perhaps before decisions have been taken on the passing of exploitation regulations, manufacturers and markets can take a stand for responsibility that is without precedent in mineral sourcing. Instead of reacting to a stakeholder backlash after avoidable damage has been experienced by people and the planet, manufacturers and markets can proactively set out to ensure that deep-sea mineral exploitation does not take place unless it meets their ESG expectations. By openly engaging with the wider responsible sourcing movement and potentially affected stakeholders, companies seeking to exploit deep-sea minerals can demonstrate a similar responsibility.

An early and prominent role for the responsible sourcing movement in the stewardship of deep-sea minerals can contribute to the pluralistic, evidence-based decision-making needed to ensure that decisions taken serve the best interests of the planet and humankind. In the face of unprecedented global challenges, including climate change, biodiversity loss, resource depletion and widespread poverty, the importance of such decisions cannot be overstated.

1 Introduction

Decision-making on deep-sea mineral stewardship is of generational importance, and the responsible sourcing movement can contribute positively.

This paper considers the roles of organizations in the minerals supply chain. In particular, manufacturers of finished goods, including vehicles and electronic devices, manufacturers of component parts such as batteries, and financial markets and metal exchanges (collectively "manufacturers and markets") need to ensure that the minerals driving the global economy, human development and clean energy transition are responsibly sourced. The paper focuses on the exploitation of minerals from the deep sea, a potential new industry for which regulations are currently being developed. The reason for this focus is the chance to build strong foundations from the industry's outset, if it is to go ahead, rather than any intrinsic assumption that deep-sea mineral exploitation would be overall better or worse, riskier or less risky, than the exploitation of available alternative sources of minerals. This paper takes no such position, nor any position on the relative credibility of claims made by any party involved in deep-sea mineral stewardship – private companies, civil-society groups or regulatory bodies. Rather, the paper seeks to find a balance between views, common ground, inclusivity and complementarity of efforts towards the common aim of sustainability.

Placing the aim of sustainability at the forefront, the paper views mineral stewardship as distinct from mineral exploitation. It views mineral stewardship as the product of responsible decision-making on when, how and *if* mineral resources should be exploited, taking into full and balanced consideration the interests of society, future generations and the natural environment, in a way that is accountable to society as a whole.

In any mineral industry, the environmental and social aspects of regulations for mineral extraction are increasingly complemented by responsible sourcing frameworks developed with the participation of manufacturers and markets. The rationale that creates such frameworks on land extends to the deep sea. Manufacturers, markets and their stakeholders have well-developed sustainability expectations, which they seek to formalize and apply to their supply chains. These expectations include thorough scientific knowledge of the environmental and social impacts of production and multistakeholder participation in decision-making on mineral stewardship.

This paper takes stock of efforts to build relevant knowledge and stakeholder participation in deep-sea mineral stewardship by regulators, potential producer companies, civil society and others. It recommends actions for organizations in the supply chain to drive additional progress, and to encourage cohesive, pluralistic decision-making on the potential sourcing of deep-sea minerals in a real-world context of imperfect information availability, sharply rising mineral demand and the need for urgent action to meet severe global challenges.

1.1 Global challenges and global goals

Humankind faces challenges that are unparalleled in its history, in their scale, complexity and interconnectivity. Among these challenges are climate change, biodiversity loss, poverty and the unsustainable consumption of the world's resources. "Climate action failure", "biodiversity loss", "livelihood crises" and "natural resource crises" each feature in the 10 global risks perceived as most severe for the next decade in the findings of the World Economic Forum *Global Risks Report 2022*.[2]

Metals and minerals will play an essential role in the transition to a less environmentally harmful society. Yet their production also has negative impacts. The greater the goals that society sets itself, the greater the potential gains and losses that must be weighed in decision-making, and world leaders have set highly ambitious goals that aim to curb future environmental damage. The Paris Agreement seeks to limit the rise in mean global temperature to below 2°C above pre-industrial levels, and preferably not more than 1.5°C.[3] The EU's European Green Deal aims to transform Europe to zero net emissions of greenhouse gases by 2050.[4] The UN's Sustainable Development Goals (SDGs) call for urgent and significant action to halt biodiversity loss.[5] The International Resource Panel of the UN Environment Programme has called for the "decoupling [of] natural resource use and environmental impacts from economic growth", so that growth can occur with a smaller impact on the natural world.[6]

Climate and natural resource-use goals must be achieved alongside the elimination of global poverty. The UN SDGs set a 2030 target to "end poverty in all its forms everywhere", alongside 16 related goals including inequality reduction between and within countries and industrialization.[7]

The world is not on track to meet these goals. Even if all of the pledges made at the COP26 Climate Change Conference in November 2021 are kept in full, global temperatures will still be on course for a rise of 1.8°–2.1°C by the end of the century. In July 2021, the UN Secretary-General António Guterres described the world as "tremendously off track" to achieve the SDGs by 2030.[8] Approximately a million species face extinction, many within decades.[9] A 2019 World Economic Forum white paper found that global resource consumption is "far beyond…

what the planet can sustain" and states that, without action, resource use will more than double from current levels by 2060.[10]

The imperative to rapidly decarbonize the global economy, halt biodiversity loss, alleviate global poverty and transition to circular resource use presents fundamental dilemmas and demands holistic, cohesive decision-making. New paradigms must be found if these four societal goals are all to be achieved in unison. Historically, poverty reduction has gone hand in hand with sharply increasing carbon emissions and resource use,[11] and changes will be required in government policies, corporate behaviour and consumption patterns by the public, to avoid the pitfalls of the past.[12]

Fundamental decision-making challenges are as present in mineral and metal industries as they are elsewhere. When metals are needed in large quantities – as they are projected to be in order to build the technology and infrastructure necessary for a more sustainable society – difficult choices must be made. Each course of action has positive and negative impacts, for people and planet, and metals must come from somewhere. The question is, from where?

1.2 Meeting goals sustainably in a new 'metals age'

“ An age of metals must reflect what we have learned from our past mistakes and strive towards equity, sustainability and balance with the natural environment.

Fossil fuels have been central to industrialized economies for decades, but times are changing. As the internal combustion engine gives way to electric propulsion, metals used in batteries, motors and other low-carbon technologies become more critical to the global economy, and demand for them is set to rise sharply.

The World Bank estimates that more than 3 billion tons of minerals and metals will be required to produce the clean energy technologies necessary to keep the global temperature rise below 2°C.[13] Even greater quantities may be needed to reach the Paris Agreement target of 1.5°C. The metals projected to be in greatest demand for the low-carbon transition (using current technologies) include cobalt, copper, lithium, manganese, nickel and rare earth elements. These metals can be obtained from terrestrial deposits, but large potential sources have also been identified on the deep seabed, often with several key minerals co-located.

To the fullest extent possible, future demand for minerals should be reduced through business model and technology innovation and behavioural changes, with the remaining demand met from advancements in the circular economy, which generally has lower environmental impacts than the mining of virgin ores. Conventional scrap recycling, urban mining, circular business models and other innovative solutions for circularity all have roles to play. However, new sources of mined minerals will still be needed in the decades ahead. There are not yet enough metals in circulation to build all of the low-carbon technologies that would be needed for decarbonization, as battery technologies currently stand. The International Energy Agency (IEA) projects that copper, lithium, nickel and cobalt from recycled sources could contribute just 10% of supply by 2040.[14] Where supply gaps from circular sources exist, they should be closed via the least environmentally and socially harmful routes available.

Protecting both ocean and land environments is fundamental to planetary health, the global economy and a sustainable future. The world's oceans have absorbed almost half of the CO_2 produced so far by human activity,[15] and more than 3 billion people are dependent on ocean biodiversity for their livelihoods. Considering market value alone, marine and coastal resources and industries account for approximately 5% of global GDP.[16] As for the deep sea, it is the biggest habitat on Earth, and its biodiversity is largely undiscovered.[17]

Mining today takes place almost exclusively on land, where environmental protection is just as crucial as at sea. A recent study[18] in the scientific journal *Nature Communications* shows that 8% of mining areas coincide with nationally designated Protected Areas, 7% with Key Biodiversity Areas,[19] and 16% with Remaining Wilderness.[20] The study found that mining areas overlapping Protected Areas and Remaining Wilderness that target materials needed for renewable energy production contain a greater density of mines than overlapping mining areas that target other materials. It concluded that biodiversity threats will rise as mineral production increases for renewable energy technologies and that "without strategic planning, these new threats to biodiversity may surpass those averted by climate-change mitigation".

Humankind has set itself laudable goals for a better future and must make hard choices if these goals are to be achieved. It is against this backdrop that the Age of Oil draws to a close, and a new "age of metals" is set to dawn. The critical commodities that power the future economy will not be fuels that are extracted and consumed. They will be the metals necessary to cleanly generate, transmit and store electrical energy on a vast scale, without which decarbonization would be wholly unachievable. Unlike fossil fuels, which are depleted through use, metals are readily recyclable. Transitioning from oil to metals is one step closer to a fully circular economy. In the Age of Oil, prosperity for some nations was achieved at the cost of global climate change. An age of metals must reflect what we have learned from our past mistakes and strive towards equity, sustainability and balance with the natural environment.

1.3 Deep-sea mineral stewardship: decisions of generational importance

The exploitation of mineral resources has underpinned the development of modern civilization. But civilization as we know it is not sustainable. As humankind enters a new chapter in its history and strives to achieve balance with the natural environment and equity among peoples, an opportunity for better stewardship of mineral resources exists. Options to meet mineral demand should be weighed on their global-level strengths and weaknesses, rather than on the interests of individual nations or narrower vested-interest groups, and international legal mechanisms and public-private collaboration should underpin such an endeavour.[21]

A principle for globalized mineral stewardship is already incorporated in the legal regime for the minerals of the international seabed area. The UN Convention on the Law of the Sea (UNCLOS) designates these minerals the "common heritage of [hu]mankind" and states that any exploitation must be carried out for the benefit of humankind as a whole. Under international law, the concept of the common heritage of humankind considers future generations as well as people living today. UNCLOS gives the International Seabed Authority (ISA) the responsibility to steward these minerals on humankind's behalf, including the regulation of all associated exploration and exploitation activities.[22] ISA's membership consists of the 167 countries that are parties to UNCLOS, including the European Union.

Decisions made on the stewardship of deep-sea minerals have many implications for humankind.

ISA is currently overseeing commercial exploration of many deep-sea mineral deposits. Exploration areas are widely distributed in the Pacific, Atlantic and Indian Oceans, with a concentration in the Clarion-Clipperton Zone – a vast region of the abyssal plains containing polymetallic nodules in the central Pacific.[23] Exploration contracts are sponsored by 21 countries, from some of the world's largest economies, including China and the UK, to small island states such as Nauru and the Cook Islands. All seabed exploration contractor companies must be sponsored by a supporting state. In some cases, a sponsoring state will apply for a licence to be held by its national agency and not a contractor company.

Since 2014, ISA has been developing exploitation regulations for the minerals of the international seabed area.[24] The ISA Council determined that regulations on the exploitation of mineral resources should be adopted as a matter of urgency,[25] and originally set a target year of 2020 for the regulations to be approved.[26] Discussions on the development of regulations were unable to proceed after the start of the COVID-19 pandemic in March 2020, though supporting work by the ISA Legal and Technical Commission and Secretariat continues.

Meanwhile, the Pacific island state of Nauru – a sponsoring country for a deep-sea mineral contractor company – initiated a legal process in June 2021, commonly known as the "two-year rule", which requests that the ISA Council completes the elaboration and adoption of regulations for exploitation within two years.[27] Failing that, the Council would have to consider and decide upon any applications for exploitation that are subsequently submitted, notwithstanding the absence of a finalized set of exploitation regulations.

Some countries are also developing extractive capabilities in their own national jurisdictions, where the governance of deep-sea mineral exploitation would reflect national-level interests, analogous to existing regimes for conventional land-based mining or oil and gas projects. Exploration activities overseen by national governments and ISA are summarized in Table 1.

TABLE 1 **An overview of current deep-sea mineral exploration worldwide**

Jurisdiction	Deep-sea mineral deposit type	Development status
International seabed area	Polymetallic nodules	19 exploration contracts issued in the CCZ, the Indian Ocean and the Western Pacific Ocean
	Seafloor massive sulphides	Seven exploration contracts issued in the Southwest Indian Ridge, Mid-Atlantic Ridge and the Central Indian Ocean
	Cobalt-rich crusts	Five exploration contracts issued in the Western Pacific Ocean, the Magellan Mountain in the Pacific Ocean and the Western Pacific Ocean.
Japanese national waters	Seafloor massive sulphides	Tested equipment for mineral exploitation in 2017[28]
	Cobalt-rich crusts	Tested equipment for mineral exploitation in 2020[29]
Cook Islands national waters	Polymetallic nodules	Exploration licensing process launched in October 2020[30]
Norwegian national waters	Seafloor massive sulphides	May issue exploitation licences from 2023–2024[31]

The establishment of regulations to guide the potential exploitation of deep-sea minerals, by appropriate national and international authorities, is a vital part of the overall decision-making ecosystem on deep-sea mineral stewardship. Another part – comparatively less well studied – will come from companies in the minerals supply chain through their responsible sourcing programmes. In any supply chain, manufacturers and markets increasingly influence how materials are produced and processed, with the aim of minimizing negative environmental and social impacts.

Decisions made on the stewardship of deep-sea minerals have many implications for humankind. If exploited on a large scale, globally significant supplies of key minerals would be obtained, while the marine areas most directly affected by exploitation would be disrupted. These new mineral supplies could affect the economics of decarbonization and the speed of transition to circularity, as well as the economics of conventional, land-based mining, with knock-on environmental and social consequences. The disruption caused to areas of the deep ocean could negatively affect ecosystems and could also have associated social effects, while the revenues from mineral exploitation could be channelled to social goods. Research is still underway to understand the scale and significance of these potential impacts.

When considering the possible commencement of a deep-sea mineral exploitation industry, companies throughout the supply chain state a common aim: to ensure that economically necessary minerals are produced with the smallest possible negative impact for people and planet. However, there is currently little consensus within the minerals supply chain over the relative significance of the potential impacts of deep-sea mineral exploitation, or whether they compare favourably or unfavourably with the impacts of land-based mineral exploitation. Greater consensus must be created if judicious decisions are to be taken on the stewardship and exploitation of the Earth's mineral resources as a whole, including minerals from both land and sea.

BOX 1 What are deep-sea minerals and where are they found?

Deep-sea minerals occur on the seabed, at depths below 200 metres.[32] There are three principal types, each of which can be found in the international seabed area, under the jurisdiction of ISA, and in several countries' national jurisdictions. An overview of key characteristics of these three deposit types is given in Table 2.

TABLE 2 Key characteristics of deep-sea mineral deposit types

	Deposit type			
	Cobalt-rich crusts	Polymetallic nodules	Seafloor massive sulphides (active vents)	Seafloor massive sulphides (inactive vents)
Physical deposit characteristics	A thin surface layer of up to 25 cm on the tops and sides of undersea mountains known as seamounts[33, 34]	Can range in size from a small pebble to a potato and lie unattached on the seabed on most of the abyssal plains of the deep ocean[35]	Mounds tens of metres thick, occurring when water rich in dissolved metals is ejected at the seabed through hydrothermal vents[36, 37]	
Mineral content profile	Cobalt, manganese and nickel, among other metals[38]	Can contain copper, cobalt, manganese, nickel and other metals[39]	Metals present can include copper, gold and zinc[40]	
Geographic distribution	Widely distributed throughout the world's oceans[41]	Important nodule fields include the Clarion-Clipperton Zone, within the international seabed area in the central Pacific, and those in the Cook Islands' national jurisdiction[42]	Vents (both active and inactive) are found in areas of geological activity in the international seabed area[43] and in the coastal waters of countries including Japan[44] and Norway[45]	
Marine life profile	Can be home to complex ecosystems that include corals and sponges	Species diversity and rarity in nodule fields is very high, but biota tend to be small[46]	Active vents are some of the most extreme environments on Earth and host many forms of life found nowhere else[47]	Inactive vents host invertebrate and microbial biota more typical of normal ocean conditions, compared to active vents[48]

Note: Data from open sources listed in the endnotes

An overview of the estimated mineral quantities obtainable from the deep sea was given by the World Economic Forum, based on earlier research by other organizations, in a November 2020 briefing paper, available here.

2

Manufacturers' and markets' involvement in mineral stewardship

Organizations in metal supply chains play an increasingly large role in ensuring mineral exploitation is environmentally and socially responsible.

Manufacturers and markets have a significant stake in mineral stewardship. All mineral exploitation has environmental and social impacts, and manufacturers and markets must decide what environmental and social impacts are acceptable within supply chains.

The manufacturers potentially most affected by deep-sea mineral exploitation would be producers of electronic goods, vehicles and machines generating renewable energy, and of components such as batteries and magnets and their parts. Relevant markets include metal exchanges, such as the London Metal Exchange, Shanghai Futures Exchange or Chicago Mercantile Exchange, and the financial markets that provide investment and loans for companies in the metals supply chain.

2.1 Rising stakeholder expectations

Manufacturers' and markets' stakeholders view these entities as responsible for more than the production of goods, commodity trading and project financing. Expectations are rising for businesses in the value chain to be responsible corporate citizens in a global community, accountable for the social and environmental impacts associated with mineral production. Companies in the 21st century are pressed by their stakeholders to find solutions to problems in their supply chains, to play a part in correcting environmental damage and social injustice and ultimately to bear responsibility, not abdicate from it.

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Analysis conducted by the World Economic Forum in November 2020 identified some of the risks that could arise for manufacturers if deep-sea minerals enter their supply chains without their exploitation being sufficiently socially accepted. Recent history shows the reputational fallout and legal consequences of sourcing policies that are not perceived as “responsible”. Examples include the use of child labour in cobalt mines in the Democratic Republic of the Congo[49] or deforestation associated with Indonesian palm oil production.[50]

Moreover, where there is potential for negative effects in one part of society from a course of action that is designed to have positive outcomes in another, companies are increasingly expected to find ways to provide compensation as part of their responsible sourcing strategies. The Dutch rights group SOMO reflected this principle in a 2021 publication that calls for the closure of coal mines, in part to slow climate change, while at the same time urging coal-purchasing energy companies to support a just economic and social transition for the coal miners who will be left without jobs.[51] Similar patterns of negative effects in tandem with intended positive outcomes have the potential to arise for deep-sea mineral exploitation, too, as is discussed in Section 3.1.3.

2.2 The responsible sourcing movement and deep-sea minerals

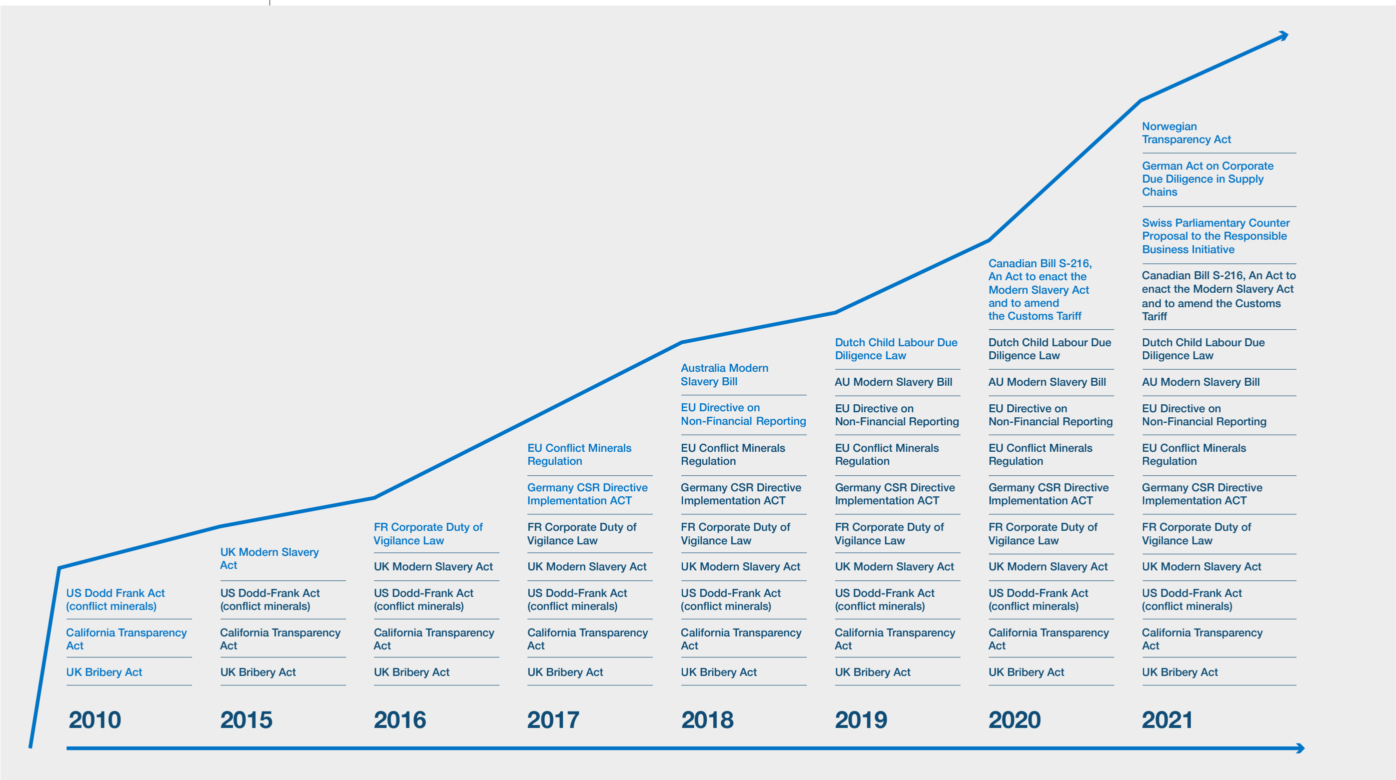
A cornerstone of manufacturers' responsible sourcing efforts is to conduct supply chain due diligence, to identify and mitigate negative social and environmental impacts associated with the production and processing of the input materials they buy. Mineral production in global supply chains today takes place solely within national jurisdictions, and the strength of national governance in producer countries is considered within manufacturers' due diligence processes. The same would be true for deep-sea minerals produced within national waters.

It is reasonable to ask what due diligence, if any, manufacturers should conduct for the minerals of the international seabed area. ISA is legitimately mandated to steward these resources by UN convention, and to protect and preserve the marine environment.[52] Decisions made at ISA are not from just one government – ISA's 167 member states and the EU will have an opportunity to vote on whether to approve or disapprove of rules governing seabed exploration.

However, the strength or legitimacy of a governance regime for material production does not negate the expectation for companies to perform supply-chain due diligence. The *OECD Guidelines for Multinational Enterprises*,[53] published in 1976, and the United Nations' *Guiding Principles on Business and Human Rights*,[54] published in 2011, state that companies should seek to prevent or mitigate adverse impacts to which they contribute or are linked by a business relationship and, to enable this, they should conduct due diligence. This recommendation is independent of the jurisdiction in which linked companies operate. On land, supply-chain due diligence is conducted even when minerals come from countries whose governance is perceived to be strong, such as the US or Australia.

In many jurisdictions, the general mandate to source responsibly that is established by the UN, the OECD and others is translated into specific bodies of legislation. In 2010, the Dodd-Frank Act was enacted in the US with requirements for mineral supply-chain due diligence. The UK Bribery Act and California Transparency in Supply Chains Act were enacted in the same year. Due diligence legislation worldwide has grown steadily year on year ever since, as shown in Figure 1.

FIGURE 1 **The steady growth in responsible sourcing and due diligence regulations worldwide**



Note: designed by TDi Sustainability'

In addition to national-level regulations, recent legal precedent has seen sustainability requirements placed on commercial companies based on overarching societal goals. In a landmark legal case in May 2021, a Dutch court ordered Shell to reduce its carbon emissions, and those of its suppliers, to align with the Paris Climate Accord.[55] Global-level, rather than local-level, sustainability expectations may be the future norm.

Organizations that set market access rules increasingly require responsible sourcing criteria to be met, too. In 2019 the London Metal Exchange (LME) launched a policy and requirements for responsible sourcing,[56] covering the risks of association with conflict and gross human rights abuses (though not environmental risks) and a "materials passport" to record materials' sustainability credentials. The LME is an important intermediary in the trade and financing of minerals to market. Its sourcing criteria cover cobalt, copper, lead, lithium, nickel, zinc and precious metals.

The great wave of stakeholder expectations, discussed in Section 2.1, and associated due diligence requirements discussed above, leads many manufacturers to adopt a highly proactive approach to supply-chain sustainability. It is reasonable to assume that concrete sustainability expectation from stakeholders, and associated legal and market access requirements, will emerge in the future for the minerals of the deep sea, too. To stay in front of the sustainability wave, manufacturing companies must approach any new sourcing decision with the management of supply-chain environmental and social impacts at front of mind.

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One way in which manufacturers and markets take charge of supply-chain sustainability, beyond due diligence, is to collaborate to develop formal sustainability standards for suppliers. Criteria for impact management and assurance within sustainability standards frequently exceed regulatory requirements in the jurisdictions in which their suppliers operate. Such standards are typically initiated by industry associations for individual metals. Examples include Responsible Steel, the Aluminium Stewardship Initiative and the Copper Mark.

Recently, some manufacturers of finished goods have gone beyond setting standards, intervening directly to work with material producers, regulators and others to improve operating conditions. An example is the involvement of manufacturers including Google and Tesla in the Fair Cobalt Alliance, a multistakeholder platform that includes mineral producers. Together, companies at different ends of the supply chain promote better working conditions for cobalt miners in the Democratic Republic of the Congo[57] through activities such as supplier dialogue, capacity building for relevant NGOs and infrastructure investment at extraction sites.[58] Another example is the Responsible Mica Initiative, which takes a holistic approach to improving working conditions in mica supply chains in India, including community empowerment projects and the encouragement of legal reforms. Membership of the Responsible Mica Initiative includes the major automotive manufacturers Porsche, BMW and Daimler.[59]

Potential deep-sea mineral suppliers should stand ready to engage with the vibrant responsible sourcing movement. They are likely to experience increasing calls to engage directly with manufacturers and markets on environmental and social matters in future.

2.3 The supply and sustainability crunch

A key challenge for manufacturing companies is to source materials that are accepted by their stakeholders, including customers, investors and civil society, as being responsibly produced, traded and transported to their factories and plants, while at the same time ensuring reliable, affordable long-term material supplies in a context of decreasing supply chain security[60] and in an increasingly complex geopolitical landscape.[61]

The World Bank predicts that the production of some minerals will need to increase by up to 500% by 2050 to meet global demand,[62] as they are critical to manufacturing the building blocks of the future economy, including rechargeable batteries and motors for electric vehicles, wind turbines, infrastructure for increasing urbanization, household appliances and mobile devices.

Craig Woodburn, Head of ESG at the battery manufacturing company Britishvolt, commented for this paper:

“ As demand for batteries increases so does the need for raw materials to produce them. If significant efforts aren’t made to bring new mineral supplies online in the next few years, a major supply crunch is a real possibility. This, in turn, could jeopardize the transition to a low-carbon, battery-dependent economy. We need to think hard now about how to secure those future mineral supplies in the most sustainable way possible.

Woodburn stressed the importance of a circular economy approach to these challenges, stating further:

“ The global approach should be to reuse and recover as much raw material as possible from existing end-of-life products to minimize the demand for virgin raw materials, hence why Britishvolt is embedding recycling into its supply, process and product design.

When demand cannot be met wholly by recycling, new minerals must be extracted. As the above figures from the World Bank show, supplies of some minerals will likely need to increase very significantly over the next 30 years.

Should manufacturers incorporate minerals from the deep sea into their supply chains in future, they may find that the bar for stakeholder acceptance has been raised to a high level. In any new industry, public unfamiliarity alone can cause apprehension over possible environmental and social impacts, irrespective of the research that may have been conducted to try to mitigate those impacts. Moreover, without a strong rationale for change, stakeholders are inclined to maintain the status quo – in this case, mineral exploitation from land-based deposits only.

Damien Giurco, an expert on sustainable resource use and Deputy Director of the Institute for Sustainable Futures at the University of Technology Sydney, commented for this paper:

“ People will place the burden of proof on the deep-sea mineral industry, before and during any operations, to evidence claims that it is better environmentally and socially than land-based mining. Deep-sea operations would need to be in the very highest bracket for sustainability performance if they were to be considered socially acceptable.

Several recognized finance industry experts consulted for this paper relayed that companies will have difficulty raising capital if they introduce deep-sea minerals into supply chains, under prevailing perceptions of their associated environmental and social risks. None of the experts consulted gave an opposing view. Lenders are increasingly hesitant to bring additional risk into their financing, and risk perception goes hand in hand with apprehension of the unknown in any industry. Lenders would need strong assurances from long-term studies to demonstrate that deep-sea extraction’s environmental and social impacts could be predicted and mitigated.

Stakeholder expectations may be especially high for potential mineral exploitation in the international seabed area, since UNCLOS sets the goal of any mineral exploitation here as nothing short of “the benefit of [hu]mankind as a whole”.[63] ISA is mandated to achieve this goal, and governments and civil society regularly assess the work of ISA with reference to it, in public discourse and in formal ISA consultation processes.[64, 65]

Reflecting the high standards placed by the public on potential deep-sea mineral exploitation, a moratorium movement has emerged in recent years. Many groups oppose current moves towards exploitation until further research on the potential environmental, social and economic impacts can be conducted, fuller conclusions on environmental safety can be drawn and regulator capacity can be strengthened. These groups frequently overlap but include several hundred ocean conservation organizations[66] and marine scientists,[67] as well as national governments and the European Parliament.[68] In a recent example of opposition, a motion calling for a moratorium on deep-sea mining was adopted by the International Union for Conservation of Nature World Conservation Congress in September 2021. Governments and government agencies voted for the moratorium by 82% for to 18% against with 28 abstentions. NGOs and civil-society organizations voted 95% for, 5% against with 35 abstentions.[69, 70]

How, in light of strong public expectations, can manufacturers and markets balance the need to secure vital mineral and metal supplies with the imperative to ensure their sourcing is socially acceptable?

How can deep-sea mineral contractor companies build social acceptance for the minerals they hope to extract?

2.4 Manufacturers' reactions to deep-sea minerals

> Manufacturers and markets have frameworks for the responsible sourcing of minerals on land, but these do not easily transfer to the deep sea.

Some manufacturers have already reacted to stakeholder apprehension over the potential extraction of deep-sea minerals. During 2021, the BMW Group, Samsung SDI, Google, Volvo Group, Philips, Volkswagen, Scania, Renault and Patagonia signed a statement supporting a civil society-led moratorium movement. They committed not to use metals produced from the deep sea until the environmental and social risks are "comprehensively investigated", all alternatives are explored and it can be demonstrated that activities can be managed in a way that ensures the effective protection of the marine environment.[71]

Research efforts are under way to understand and manage environmental and social risks, and to develop science-based regulations for deep-sea mineral exploitation – the need for which is recognized by ISA and relevant national authorities. Complementary efforts are required to build broad acceptance of decision-making on deep-sea mineral stewardships among manufacturers, markets and their stakeholders.

Manufacturers and markets have frameworks for the responsible sourcing of minerals on land, but these do not easily transfer to the deep sea. Analysis, conducted by the World Economic Forum in April 2021, showed that significant work would be needed before the frameworks used to build supply-chain standards that assess and assure environmental and social responsibility of mineral production on land could be applied.[72] These underlying frameworks include the biodiversity mitigation hierarchy, the World Heritage Site system and processes for establishing communities' free, prior and informed consent to extractive activities. The adaptation of such frameworks to the context of the deep sea could take many years.

This paper takes a broader view, looking at some of the underlying, thematic expectations of manufacturers and markets with regard to the decision-making systems that steward the world's minerals, and extrapolating the expectations that are likely to be applied to deep-sea minerals in the years ahead. These include knowledge-based decision-making and multistakeholder participation. Current efforts to fulfil these expectations as they relate to deep-sea minerals, by ISA and others, are discussed in Sections 3.4 and 4, and recommendations to supply-chain entities to support and augment these efforts are given in Section 6.

BOX 2

The World Economic Forum Deep-Sea Minerals Dialogue

The Deep-Sea Minerals Dialogue (DSM Dialogue) of the World Economic Forum creates an opportunity for businesses active in the downstream minerals value chain to learn about and discuss the implications of the potential emergence of minerals supplied from the deep seabed. The DSM Dialogue is working to inform manufacturers and markets about this important topic through balanced discussion and by providing salient information on the impacts associated with deep-seabed mineral extraction in an impartial manner. The Forum does not take a position on whether deep-seabed mining should operate at a commercial scale, but rather seeks to ensure that this important question is asked and that downstream businesses are able to contribute to addressing this question, in line with their sustainability objectives and based on the best information available.

2.5 The importance of knowing about the impacts

It is important to manufacturers and markets to know the environmental and social effects of mineral exploitation. Often, their due diligence commitments require them to map these effects and establish systems that prioritize the most serious or urgent negative impacts so they can undertake mitigation action.

Knowledge of impacts is increasingly mapped and shared in public forums that are supported by manufacturers and markets; for example, the Material Change report,[73] which analysed the ESG risks associated with 50 minerals, and its online successor, the Material Insights platform.[74] This platform provides a continually updated set of information and analysis on country, supply chain and ESG issues for terrestrial minerals and is used as a daily guide by many companies in the automotive and electronics industries. Similarly, the OECD publishes analysis on allegations and public reports on human rights abuses in mineral supply chains.[75] The Responsible Minerals Initiative publishes a metals smelter and refinery conformant list that shows the companies that have successfully completed an assessment against an eligible standard.[76] And the European Partnership for Responsible Minerals maintains a due diligence hub to enable the responsible sourcing of conflict minerals.[77]

2.6 The importance of multistakeholder participation

Manufacturers and markets value multistakeholder participation in the stewardship of mineral resources. The environmental and social standards schemes they adopt are generally governed by bodies comprising stakeholders from different parts of their supply chains, and from civil society as well as business. This lends rigour to their requirements and credibility through participation of voices representing affected communities.

ISEAL, a membership organization that promotes effective voluntary standards and market-based sustainability systems, requires its members to adhere to a set of credibility principles. These include principles to empower "stakeholders to participate in decisions and hold the system to account. It involves a balanced and diverse group of stakeholders in decisions that will affect them. It strives to understand the context and perspectives of stakeholders who have been under-engaged or under-represented, and it creates opportunities to ensure their participation in decision-making."[78]

The ISEAL member Initiative for Responsible Mining Assurance enacts these criteria through a board comprising representors from five "sectors": mining companies, companies that purchase mined materials, non-governmental organizations, affected communities and organized labour. Responsible Steel, the Copper Mark and the Aluminium Stewardship Initiative all have boards with representatives from non-industry institutions, and this diversity is augmented by advisory boards with an even broader scope of expertise and experience.

The next section examines the extent to which existing knowledge allows manufacturers, markets and their stakeholders to predict the potential social, environmental and economic effects of deep-sea mineral exploitation. This is followed by an examination of the status of multistakeholder participation in decision-making systems for the stewardship of deep-sea minerals. We then identify gaps that should be closed if manufacturers' and markets' anticipated expectations for deep-sea mineral stewardship are to be met.

3 Predictability of the effects of deep-sea mineral exploitation

To make sound decisions on deep-sea mineral stewardship, an understanding of the scale of potential effects of exploitation is vital.

To make sound responsible sourcing decisions, manufacturers need to assess the scale of environmental and social impacts associated with each actual and potential source of materials in their supply chain. A key question asked by manufacturers, therefore, when considering a possible new form of mineral sourcing, is the extent to which the scale of potential effects of exploitation can be predicted with current levels of knowledge. In other words, what is our capacity to know what will happen if exploitation takes place?

The knowledge required to predict the scale of effects of deep-sea mineral exploitation is broad, encompassing knowledge of the deep-sea environment, extractive technologies, environmental impact management and mitigation techniques, the economics of metal supply and demand, and governance systems for revenues.

This paper discusses the predictability of the scale of potential effects of deep-sea mineral exploitation. It does not aim to predict whether any particular effect will be large or small, significant or insignificant, were deep-sea mineral exploitation to commence. To do so would require specific knowledge of planned exploitation activities, as the scale of effects would vary widely depending on the type of deep-sea mineral deposit being exploited, the characteristics of the deposit area, the legal jurisdiction under which exploitation took place, the extractive techniques and impact mitigation measures applied by contractors, and the quantities of minerals extracted, among other factors. For example, the impacts on marine tourism could vary depending on how close an extraction site was to the coast, and the significance of revenues from exploitation will vary between jurisdictions according to the taxation and royalty regimes in place.

Figure 2 depicts the capacity of manufacturers, markets and their stakeholders to know the scale of effects of a given exploitation plan for deep-sea minerals were one to be proposed. It arranges the potential effects according to the predictability of their scale, graded as high, moderate or low. The potential effects are also subdivided into those that would result from a significant increase in metals available on the market, those that would result from disturbance to the marine environment, and those that would result from the generation and distribution of revenue from new sources, such as royalties and taxation on deep-sea mineral exploitation activities.

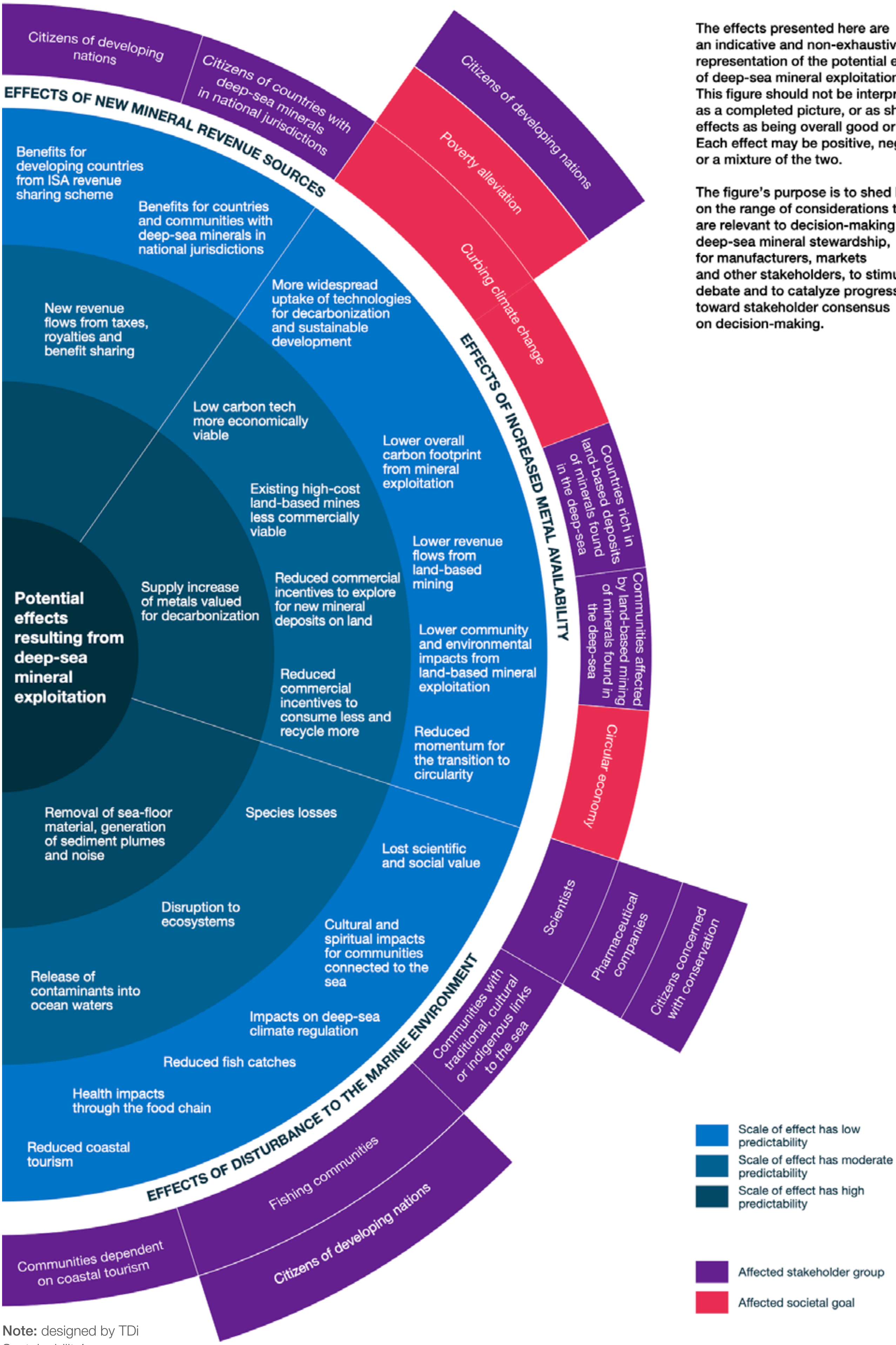
The effects shown in Figure 2 compare possible futures, rather than comparing the future with the present. For example, the effect labelled "existing high-cost land-based mines less commercially viable" anticipates reduced viability of such mines in a future where deep-sea minerals are exploited, compared with a future where they are not exploited. It does not mean that deep-sea exploitation would cause high-cost land-based mines to become less commercially viable than they are today, since this would depend on a range of other factors including overall future mineral demand.

The stakeholder groups shown around the rim of Figure 2 do not encompass every person and entity that could be affected by deep-sea mineral exploitation. Instead, the figure attempts to focus on those groups that could be most affected. For example, the curbing of climate change would affect everyone on Earth in some way, but "citizens of developing nations" are selected as the corresponding stakeholder group because they are more vulnerable than others to the negative effects of climate change.[79]

In order to sort the potential effects of deep-sea mineral exploitation into categories of high, moderate and low predictability of scale, insights were gained from a thorough review of the appropriate literature and from two expert panels convened by the World Economic Forum: an Ocean Science Expert Panel comprising scientists involved in the study of deep-sea biota and ecosystems, the potential ecosystem effects of deep-sea mineral exploitation, extractive technologies and proposed impact management and mitigation techniques; and an Economics Expert Panel, comprising supply-and-demand forecasters, metal-trading specialists, mining experts and circular economy experts.

To ensure the two panels represented a balanced range of views, recommendations for participating experts were sought from diverse organizations – international good governance bodies, international development agencies, civil-society groups, relevant regulatory bodies and deep-sea mineral contractor companies. Panellists' views were gathered using a mixture of structured surveys and semi-structured interviews, and the research approach was also validated through review by a range of organizations. Data generated from the two expert panels was augmented by an extensive literature review, the results of which are summarized in Annexe A, and ad hoc consultation with representatives from industry, governments and civil society.

FIGURE 2 | **Current predictability of the scale of effects that could result from deep-sea mineral exploitation**



The effects presented here are an indicative and non-exhaustive representation of the potential effects of deep-sea mineral exploitation. This figure should not be interpreted as a completed picture, or as showing effects as being overall good or bad. Each effect may be positive, negative or a mixture of the two.

The figure's purpose is to shed light on the range of considerations that are relevant to decision-making on deep-sea mineral stewardship, for manufacturers, markets and other stakeholders, to stimulate debate and to catalyze progress toward stakeholder consensus on decision-making.

Note: designed by TDi Sustainability'

The predictability of effects decreases as the rings in Figure 2 widen because each effect depends on the effects in the rings closer to the centre, and also on additional unknowns. Uncertainty is layered upon uncertainty. For example, if species losses were to occur, the value to society of the scientific knowledge lost would depend both on the scale of species loss and on the unknown scientific advances that could otherwise have been realized through studying each lost species, such as medical and pharmaceutical innovations gained from the analysis of their genetic material. Some species have genetic resources that are more valuable for society than others.

The range of effects presented in Figure 2 demonstrates the complexity of decision-making on the stewardship of deep-sea minerals. There are no easy answers as to what course of action is "best" for humankind. The risks associated with each course of action must be weighed against the anticipated benefits within a balanced debate. Many different stakeholder groups and societal goals could be affected, and the effects are interconnected.

The outermost ring shows the effects that would most directly affect stakeholder groups and societal goals. These are the effects that matter most for the social acceptance of decision-making on deep-sea minerals. Yet, their scale is also the least predictable, the most open to speculative claims by interested parties and the most dependent on extensive additional knowledge-gathering to truly understand and assess.

" These are the effects that matter most for the social acceptance of decision-making on deep-sea minerals. Yet, their scale is also the least predictable.

Sections 3.1–3.3 discuss society's current power to predict the scale of resulting effects, were deep-sea mineral exploitation to commence. These sections of the paper identify knowledge gaps that make effective and socially acceptable decision-making on the stewardship of deep-sea minerals difficult. "Key current knowledge gaps" are presented at the end of most subsections of Sections 3.1–3.3, as a view of the current picture.

Knowledge, and the power to predict, will undoubtedly increase over time, through efforts by ISA, national governments, contractor companies, scientists, economists, engineers and other experts to gather and share relevant knowledge, and the pace of this increase is discussed in Section 3.4. It should be noted, however, that predicting the scale of potential effects of deep-sea mineral exploitation does not depend on knowledge-gathering alone. Stakeholders have the potential to shape the future through their choices, such as by prioritizing courses of action that reduce overall metals demand, decreasing the need for new metals supplies in future and proactively engaging in discussions on benefit sharing. Instead of a fixed picture, we need to understand that the scale of potential effects of deep-sea mineral exploitation is fundamentally dynamic in nature, dependent on the future we create for ourselves as a species.

3.1 Predictability of the effects of increased availability of metals

High-predictability effects

Effect	Predictability of scale
Supply increase of metals valued for decarbonization	High

The scale of increase in the supply of metals valued for decarbonization would be relatively highly predictable for any given exploitation plan for deep-sea minerals. Accurately forecasting this increase depends on knowledge of mineral resources available in deposit areas and the projected importance of corresponding metals for decarbonization.

Research already conducted through surveys of deposit areas indicates that large quantities of many minerals can be found in the deep sea. These areas include the Clarion-Clipperton Zone (CCZ), which is thought to hold between 340% and 600% of existing land-based reserves of cobalt, 180–340% of land-based reserves of nickel, 23–30% of land-based reserves of copper,[80] more than 100% of land-based reserves of manganese, tellurium, thallium and significant quantities of yttrium and other rare earth elements.[81] Assessment of deep-sea mineral resources generally, and in particular in polymetallic nodule areas such as the CCZ, may be more straightforward than assessments on land. Whereas land resources are hidden underground, nodules are visibly identifiable on the seabed.

The International Energy Agency identifies cobalt, copper, manganese, nickel and rare earth elements as some of the most important metals for the future of clean energy technologies, including electric vehicle batteries, wind and solar power generation.[82]

Consultation with the Economics Expert Panel convened for this paper indicated that the International Energy Agency's projections are very well respected. However, they are inherently subject to modelling assumptions on future technology developments, changing business models and behavioural adaptations influencing mineral demand, among other factors. The future is fundamentally uncertain.

Members of the Economics Expert Panel declined to offer specific predictions on new technology developments or other demand-influencing factors, which would be speculative, but a consensus view of the panel was that technology developments will, in some way, significantly alter the mineral demand picture in coming decades. The panellist Sven Teske, Associate Professor at the University of Technology Sydney's Institute for Sustainable Futures, and an expert on industrial decarbonization, commented that "the battery market will change. We already have batteries with no cobalt, and there are so many innovations on the horizon that we don't really know what a battery will look like in 2050 and what minerals will be needed for it."

Key current knowledge gaps: the potential for new technologies, behavioural change and business-model innovation to alter metal demand for the low-carbon transition, and the associated timescales on which demand change could take place.

Moderate-predictability effects

Effect	Predictability of scale
Low-carbon technologies more economically viable	Moderate
Existing high-cost land-based mines less commercially viable	Moderate
Reduced commercial incentives to explore for new mineral deposits on land	Moderate
Reduced commercial incentives to consume less and recycle more	Moderate

Figure 2 shows four potential economic effects of increased metal availability, the scale of which is moderately predictable. If the metals that can be obtained from the deep sea become available in large quantities, this increased availability could affect the economics of low-carbon technology manufacture, the economics of mining and mineral exploration on land, and the commercial incentives to consume less metal and increase recycling.

A clear finding from the Economics Expert Panel was that the scale of these effects will depend on how quickly deep-sea minerals can be brought to market, and how exactly the future cost of production compares to land-based sources. Only if production costs are relatively low, and large quantities of deep-sea minerals are rapidly brought to market, will the economics of low-carbon technology manufacture, terrestrial mining and exploration, and metals consumption and recycling be significantly affected.

If deep-sea minerals' production costs are relatively high or if they are unable to be brought to market for many years in a way that is accepted by society, their economic impact is likely to be limited. The global market economy would find ways to do without them and would not be significantly disrupted by their eventual arrival. Table 3 demonstrates how such economic adaptations can occur.

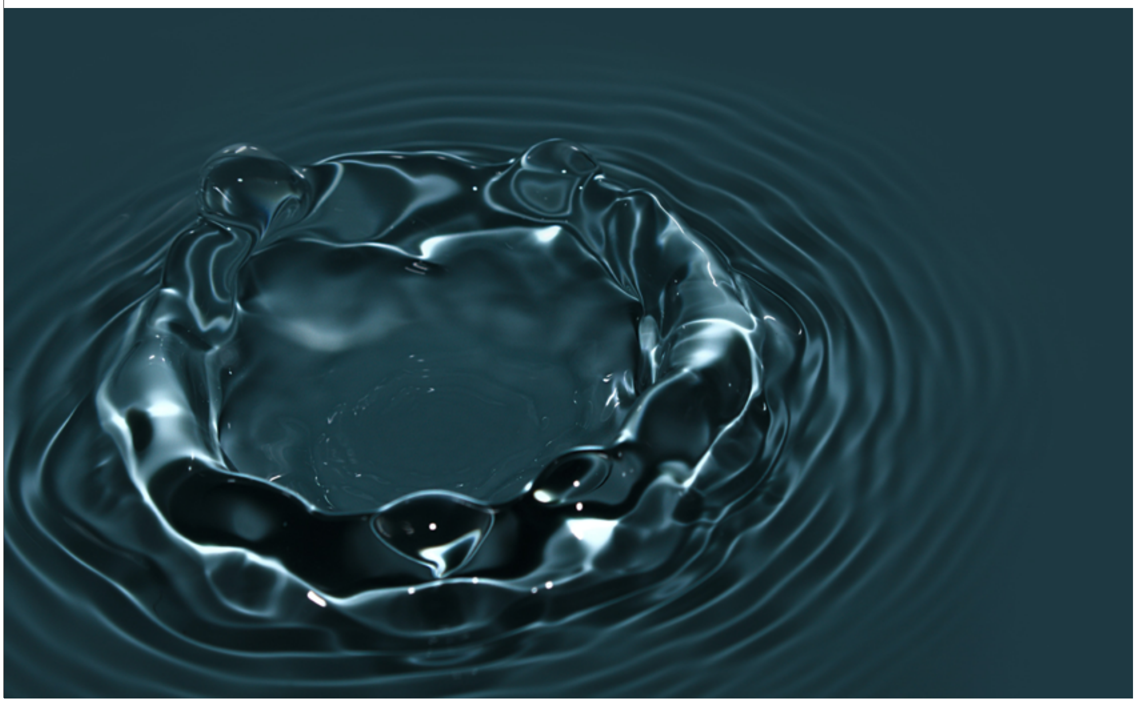


TABLE 3 | Two ways in which economic corrections can overcome mineral supply constraints

Route to overcome supply constraints	Explanation
Expansion of existing land-based mines and development of new land-based mines	With sufficient economic incentive, the production life of existing terrestrial mine sites can be extended, and new land-based mineral sources can be found.[83] While there is a risk that new mines would significantly affect the land-based environment, minerals can also come from mines with strong environmental and social attributes in well-regulated jurisdictions, such as those envisioned within the domestic supply component of the EU Raw Materials Initiative.[84, 85] The panellist Michael Tost, a sustainability researcher at Austria's university for mining, the University of Leoben, commented that "the EU is trying to expand domestic mining and to do so as sustainably as possible. The underground below the bedrock is basically still underexplored in the EU, so there are plenty of opportunities for new finds on land." The development of new land-based mines takes time, however – in the region of 10–15 years.[86] New mines also require social acceptance in the same way as deep-sea mineral exploitation would and could attract comparable levels of opposition from civil society.[87]
New technology development	When supply constraints affect minerals' affordability for manufacturers, or if social acceptance of minerals is lacking or for many other reasons, new technologies can be developed over time that reduce or eliminate the need for these minerals. One example is Tesla's search for alternatives to cobalt-containing electric vehicle batteries, including the use of batteries higher in nickel, due to cobalt's high monetary cost and the social and environmental issues associated with cobalt production.[88] While nickel production can also have significant negative impacts,[89] which must be managed, the impacts associated with cobalt are currently generally perceived as more severe. Another example of mineral substitution is China's BYD, the world's second-largest electric carmaker, which plans to completely remove cobalt and nickel from its batteries over safety concerns, favouring lithium-based alternatives.[90]

Knowledge of production costs, production quantities and timelines for deep-sea mineral exploitation are crucial to assess whether deep-sea minerals would significantly affect the global economy, or whether economic corrections would overcome supply shortages without them. The next section discusses the status of current knowledge in these three knowledge areas.

Production cost indicators for deep-sea mineral exploitation

As in any prospective new industry, there are many uncertainties regarding the financial viability of deep-sea mineral exploitation. The collapse of the Solwara 1 hydrothermal vent mineral exploitation project in Papua New Guinea in 2018 highlighted for many observers the financial challenges of bringing deep-sea minerals to market.[91]

Some experts are optimistic that production costs for future projects will be low, however. Analysis conducted by the Massachusetts Institute of Technology (MIT) for ISA projected that production costs for copper and nickel from polymetallic nodules would sit in the lower third of 2017 production costs from land-based sites.[92] The cost projection was based on information provided by contractors, literature review and comparison with other industries.

The MIT financial models have been challenged by several countries and civil-society organizations as insufficiently accounting for the environmental costs, the need to provide financial benefits to humankind, and compensation to land-mining nations for anticipated revenue losses.[93] These costs will be more clearly defined when ISA exploitation regulations are finalized, and greater accounting for these costs could cause production cost projections to rise.

Timeline indicators for deep-sea mineral exploitation

Several deep-sea mineral exploration companies are currently moving towards production. One, The Metals Company, has floated its shares publicly based on a target production year of 2024.[94] Another, GSR, plans to commence commercial exploitation in 2028, subject to the timely approval of regulations.[95] UK Seabed Resources, a subsidiary of Lockheed Martin, plans to commence operations in the "late 2020s or by 2030".[96]

These companies are industry leaders, and even assuming they meet these time targets (The Metals Company's target production year is seen by many observers as highly ambitious), other companies will not follow in their footsteps immediately.

Andrew Thaler, Editor-in-Chief of the DSM Observer, an online resource supported by the Pew Charitable Trusts, comments that "the real promise of the industry reaching fruition [will come] in the 2030s and into the 2040s".[97]

This timeline would put potential large-scale deep-sea mineral production roughly on par with the typical 10 to 15-year time frame for production from new land-based sources, though rigorous studies have not yet been conducted to establish this timeline concretely.

Quantity indicators for deep-sea mineral exploitation

The quantities of minerals that could be produced from the deep sea depend, both directly and indirectly, on the regulatory regimes that may be put in place for their exploitation.

Directly, production quantities hinge on the number of exploitation licences issued to companies by regulators. Indirectly, production quantities also rest on the taxation, royalty and environmental remediation requirements set by regulators, which are key factors in the commercial viability of extractive projects.

A study conducted by ISA in 2020[98] estimates that up to 12 companies could be producing metals from polymetallic nodules in the international seabed area by 2035. Scenarios of six and two producing companies were also considered. The study projects the quantities of metals that could be produced in each scenario. The quantities projected for the maximal 12-company scenario are compared in the table below to annual production on land:

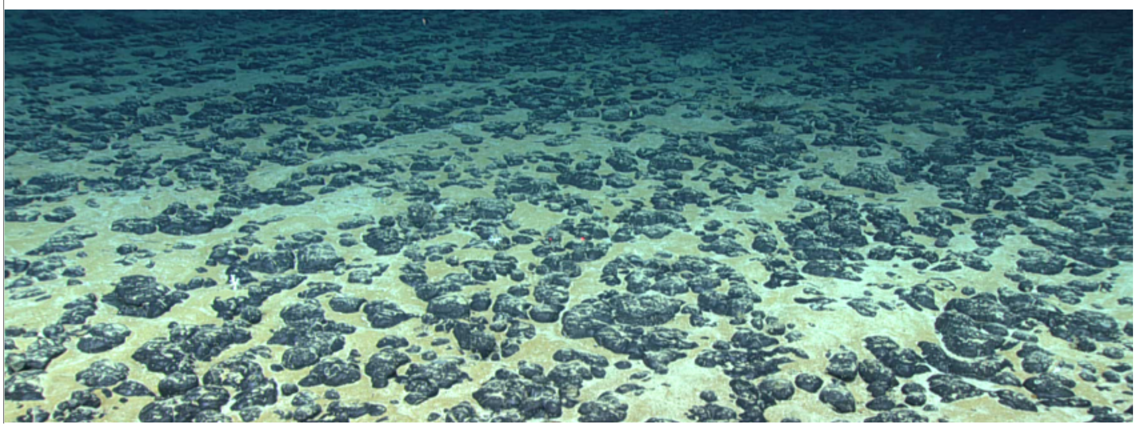
TABLE 4 **Projected production of metals from polymetallic nodules in the international seabed area by 2035**

Metal	Annual quantity produced from polymetallic nodules under the ISA "12 companies" scenario (metric tons)	Amount produced globally in 2020 (metric tons)*	Production in ISA "12 companies" scenario as a percentage of 2020 production
Cobalt	61,200	140,000	43.7%
Copper	356,400	20,000,000	1.8%
Manganese	9,201,600	18,500,000	49.7%
Nickel	444,600	2,500,000	17.8%

* Source: United States Geological Survey

The ISA study considers a range of scenarios for future metal demand growth, as well as for deep-sea mineral production. It shows significant variation in the effects on market price for these minerals, under different supply and demand growth scenarios, and draws no firm conclusions on how mineral prices will be affected by envisioned deep-sea mineral exploitation.

Key current knowledge gaps: production costs for planned deep-sea mineral exploitation projects; the production cost implications of future exploitation regulations, including those associated with taxation, royalties, and environmental remediation; the future pace of licence issuance within potential exploitation programmes.



Low-predictability effects

Effect	Predictability of scale
More widespread uptake of technologies for decarbonization and sustainable development	Low
Lower overall carbon footprint from mineral exploitation	Low
Lower revenue flows from land-based mining	Low
Lower community and environmental impacts from land-based mineral exploitation	Low
Reduced momentum for the transition to circularity	Low

“ If low-carbon technologies were to become more economically viable, it could lead to greater uptake of these technologies, which could aid decarbonization and help to ensure the sustainability of economic development.

If large quantities of minerals from the deep sea were rapidly brought to market, with low production costs, additional knowledge would still be required to predict the scale of the resulting effects on decarbonization, land-based mining industries and the transition to circularity.

If low-carbon technologies were to become more economically viable, it could lead to greater uptake of these technologies, which could aid decarbonization and help to ensure the sustainability of economic development. This in turn could contribute to climate change reduction and poverty alleviation. The potential effect of deep-sea minerals exploitation on decarbonization is viewed by some countries,[99, 100] and some contractor companies,[101] as highly significant. While economic viability is crucial for technology uptake, it is also dependent on other unknown factors, especially an enabling future policy environment. For example, affordable electric vehicles would not be widely purchased simply because they were affordable. Governments would also need to ensure robust charging infrastructure was in place to make them attractive. Because of the many unknowns identified in the research conducted for this paper, the predictability of the scale of this effect was rated low.

If a supply of deep-sea minerals meant that the commercial incentive to mine and explore for minerals on land was reduced, this could lead to lower levels of land-based mining in future. This in turn could result in an overall relatively lower carbon footprint for global extractive industries. One study projects that the cradle-to-gate CO_2 emissions associated with polymetallic nodule exploitation would be 80% lower for nickel and 76% lower for copper compared to obtaining the same quantities of metals from land-based extraction, with smaller differences for other metals.[102] Another study finds a 38% reduction in overall cradle-to-gate CO_2 emissions to produce the metals found in polymetallic nodules, compared to production from land-based sources.[103] The available evidence therefore indicates that polymetallic nodule exploitation offers a significant carbon reduction, though there is disparity between studies on the exact size of the reduction. Similar studies have not yet been conducted for other deep-sea mineral types. Further research would be needed, under a range of modelling assumptions, to establish a broad-based consensus on the differences in carbon footprints between land-based and deep-sea mineral exploitation.

Relatively reduced land-based mineral exploitation could also lead to a range of impacts for land-mining nations. Mining on land provides revenues for national budgets, employment for local people and other benefits such as skills transference and funding for community projects. The African Group of countries at ISA has already expressed concerns over a potential fall in manganese prices and the associated economic impacts, were deep-sea mineral exploitation to go ahead.[104] A fall in the price of cobalt, meanwhile, could negatively affect the million or more residents of the Democratic Republic of the Congo who are economically dependent on small-scale cobalt mining.[105] A 2020 study commissioned by ISA found that deep-sea mineral exploitation “may result in serious adverse effects on export earnings or economy of [Developing Land-Based Producer States]”, under some production scenarios.[106] ISA plans to establish a fund to provide compensation for economic losses to affected land-mining developing nations,[107, 108] as required by UNCLOS (Art. 151(10)). Compensation claims would be settled on a case-by-case basis by an Economic Planning Commission within ISA. The Commission has not yet been established and the basis on which it would evaluate claims is not yet publicly known.[109, 110]

Alongside the positive economic and community impacts, land-based mining can also cause negative environmental impacts, such as air, water and soil pollution, deforestation, and biodiversity losses, and can in some cases be associated with social conflict and human rights abuses. These negative impacts could also be lessened if deep-sea mineral exploitation led to lower mineral prices, comparative to a scenario where deep-sea minerals were not exploited, and in turn led to a relative reduction in land-based mining. However, such a cause-and-effect link is far from certain.

It is important to note that there is no direct “choice” to be made between land-based and deep-sea mineral exploitation projects. No global authority exists to make such a choice and, while exploiting minerals from the deep sea may curb

> The potential effect of deep-sea mineral exploitation on the transition to a circular economy is also unpredictable.

financial incentives for land-based mining, it will not necessarily lead to mine closures or to planned new mines being abandoned. Nor would it selectively eliminate land-mining operations with the lowest environmental or social performance since pressure on land-based mines would correlate to their production costs rather than their sustainability attributes. There is no existing body of work to reliably indicate which land-based mines would be most threatened by deep-sea mineral exploitation – whether it would be the best or worst environmental and social performers. Metal cost curves are a widely used methodology to indicate which mines are close to becoming economically unviable, but there is no public knowledge resource mapping this data to mines' sustainability performance. Such a resource would be necessary to predict the effects of deep-sea mineral exploitation on the terrestrial mining industry, its sustainability profile and associated stakeholders and societal goals.

The potential effect of deep-sea mineral exploitation on the transition to a circular economy is also unpredictable. Several members of the Economics Expert Panel suggested a link between the two. The panellist Eléonore Lèbre, an expert in the circular economy and mineral exploitation at the University of Queensland, commented that "introducing significant flows of new resources such as deep-sea minerals would economically disincentivize the shift towards more sustainable resource consumption". Economic incentives are an important factor in the transition to circularity, though other factors such as future government policies will also play important roles, and these future policies cannot be known at the current time.

Key current knowledge gaps: fuller CO_2 emissions modelling, especially for sea-floor massive sulphide and cobalt-rich crust exploitation; comparable, disaggregated reference data on land-based mines' environmental and social performance correlated to production costs; economic modelling of the potential effects of mineral price reductions on low-carbon technology uptake and the transition to circularity; knowledge of future government policies on the low-carbon transition and circular economy.

3.2 Predictability of the effects of disturbance to the marine environment

> Extractive equipment can be tested, and impacts can be modelled, in computer simulations, under controlled conditions on land and at trial sites on the seabed. ... The scale of potential physical effects is relatively predictable based on current extractive technologies.

3.2.1 High-predictability effects

Effect	Predictability of scale
Removal of sea-floor mineralized material, generation of sediment plumes and noise	High

If deep-sea minerals are commercially extracted, it will inevitably involve the removal of sea-floor material, and the generation of sediment plumes and noise. Data from the Ocean Science Expert Panel and literature review (summarized in Annexe A) indicates that these physical effects will vary between deposit types (see Box 1: *What are deep-sea minerals and where are they found?*) and will depend on the extractive technology and techniques and mitigation strategies employed, but they will have relatively high predictability. Extractive equipment can be tested, and impacts can be modelled, in computer simulations, under controlled conditions on land and at trial sites on the seabed. Even delocalized physical effects, such as the spread of sediment plumes, can often be modelled with a fair degree of accuracy.

According to members of the Ocean Science Expert Panel, for example, it is achievable to have reliable, well-founded physical modelling of sediment plumes within two years of seabed collector technology trials, informed by in-situ ocean measurements of turbulence, sediment properties, ocean currents and mineral source conditions.[111]

The scale of potential physical effects is relatively predictable based on current extractive technologies. It is possible that the effects could change in future as new extraction technologies are introduced, however. For example, one commercial company is developing a possible new method of nodule collection in which the nodules are lifted individually from the seabed by autonomous robots that propel themselves through the water. By eliminating tracked seabed vehicles, in-situ nodule crushing and the pumping of mineral slurry to the surface, the company hopes that the negative impacts, including those arising from the generation of sediment plumes and noise, could be significantly reduced.[112] It should be noted that it is far from certain whether this technology, or any other major technical innovation, will be successfully commercialized in the future. Several industry experts consulted for this paper are sceptical. A scenario considered more likely is that existing technologies will be gradually refined over time.

3.2.2 Moderate-predictability effects

Effect	Predictability of scale
Species losses	Moderate
Disruption to ecosystems	Moderate
Release of contaminants into ocean waters	Moderate

The removal of sea-floor material, and the generation of sediment plumes and noise, have the potential to affect marine biota, the ecosystems of which they are part and ocean waters.

Any deep-sea mineral extraction that takes place where marine life is found would involve the loss of habitats and the biota they support. In the case of polymetallic nodule exploitation, organisms that rely on nodules to sustain life (known as "nodule obligates"[113]), would not be able to recover from their removal. Organisms from wider ecosystems would also be affected.

A visual example of a nodule obligate is seen in Figure 3. It should be noted, though, that the little evidence available suggests that bacteria, rather than larger organisms, play the dominant role in abyssal ecosystems, which are where nodules are found.[114]

Other types of deep-sea mineral deposits – cobalt-rich crusts and sea-floor massive sulphides – also serve as marine habitats that would be lost through mineral exploitation (see Box 1: *What are deep-sea minerals and where are they found?*).

FIGURE 3 | *Abyssoprimnoa gemina*

Note: *Abyssoprimnoa gemina*, a deep-sea coral known to exist only in the Clarion-Clipperton Zone, was discovered less than 10 years ago and was formally described in 2015. It attaches to nodules as an anchor

“ Suspended sediments made from mineralized seabed materials could release dissolved metals into ocean waters. Noise from extractive machinery could place physiological stress on biota, disrupt their behaviour and lead to effects such as geographic migration and changes in community composition. Marine biota, like all life on Earth, play roles within wider ecosystems, which could be affected by extraction.

Sediment plumes and exogenous noise have the potential to affect the marine environment. Sediments from mineral extraction and processing could clog and harm organisms' respiratory, olfactory and feeding organs and tissues, and affect their behaviour, reproduction and survival. Suspended sediments made from mineralized seabed materials could release dissolved metals into ocean waters. Noise from extractive machinery could place physiological stress on biota, disrupt their behaviour and lead to effects such as geographic migration and changes in community composition.[115] Marine biota, like all life on Earth, play roles within wider ecosystems, which could be affected by extraction.

Consultation with the Ocean Science Expert Panel and an extensive literature review (summarized in Annexe A) revealed the breadth of factors that would determine the scale of species losses, ecosystem disruption and contaminant release into ocean waters, in the event of deep-sea mineral exploitation. Relevant factors for species losses and ecosystem disruption include species' abundance, richness and endemicity, interactions between species and between ocean ecosystems, organisms' sensitivity thresholds for suspended sediments and exogenous noise, systems of benthic and pelagic biological recovery and associated timescales. Relevant factors for predicting contaminant release into ocean waters include the physical and chemical environmental conditions to which metal-bearing materials are exposed.[116]

Crucial to predicting the scale of all of these marine effects is, first, the establishment of a comprehensive environmental baseline for the various habitats in which extraction might occur, followed by the development – and an understanding of the efficacy of – management and mitigation techniques that could be employed in exploitation operations to minimize the negative impacts. The aim of deep-sea mineral exploration companies is to identify and adopt approaches that not only minimize the immediate impacts but also, more importantly, encourage long-term ecosystem health. This can involve efforts to avoid impacting particular species that are endemic, rare or crucial to overall ecosystem functioning. It can also include the designation of set-aside areas within and between exploitation areas to act as refuges for marine fauna.[117]

The panel consultation and literature review revealed gaps in scientific knowledge in relevant areas. For example, a 2020 study commissioned by the non-governmental High Level Panel for a Sustainable Ocean Economy found that "extreme knowledge gaps remain, particularly in understanding how deep-ocean ecosystems will respond to industrial-scale mining disturbance".[118] A joint statement by more than 500 marine science and policy experts states that, without additional rigorous scientific information, "the potential risks of deep-sea mining to deep-ocean biodiversity, ecosystems and functioning, as well as human well-being, cannot be fully understood".[119]

ISA,[120, 121] national authorities, deep-sea mineral contractors and the researchers they support are working to fill relevant knowledge gaps, and to define meaningful thresholds and criteria for contractors' environmental performance,[122, 123] which could be enforced through regulations that are under development. Meanwhile, scientists and supporting experts are defining with progressive clarity where future research efforts should be directed.[124]

A peer-reviewed paper, encompassing a literature review and stakeholder consultation, led by Diva Amon, a deep-sea biologist, published in the journal *Marine Policy* finds that "despite an increase in deep-sea research, there are few categories of publicly available scientific knowledge comprehensive enough to enable evidence-based decision-making regarding environmental management, including whether to proceed with mining in regions where exploration contracts have been granted by the International Seabed Authority".[125] The paper proposes a roadmap for closing knowledge gaps on the marine environmental effects of potential deep-sea mineral exploitation, including an increase in the collection of environmental baseline data and data related to the impacts and management of exploitation activities.

“Even if broad consensus were reached on the scale of species losses anticipated from deep-sea mineral exploitation, the value that those species could have had for scientific and pharmaceutical applications would likely still be indeterminable. The potential to find out would be lost, along with the species themselves.

Many other literature review papers, listed in Annexe A, point to specific knowledge gaps for particular regions, organism types and exploitation techniques.

The concept of geographic scale is crucial to understanding the overall effects of potential deep-sea mineral exploitation on the marine environment. Individual exploitation projects would occupy small areas in large seas, and some experts consulted for this paper argue that the negative environmental impacts (or at least their knock-on effects for humankind) would be correspondingly limited. Looking at the size of the exploration area allocated to ISA contracts in the CCZ illustrates this point. Each contract is allocated 75,000 km^2, which is just 1.7% of the Clarion-Clipperton Zone's overall size,[126] and the zone is only a small part of the wider Pacific Ocean. Moreover, contractors estimate that only 30–40% of an exploration area would typically be economically viable for nodule extraction.[127]

Some scientists caution that examining local effects may address only part of the risks of mineral exploitation, due to ecosystem interconnectivity and the potential for non-localized or cumulative effects, on which little research has been done. Cindy Van Dover of Duke University, an expert in the ecology of the deep sea, comments that:

“The management and mitigation techniques people are developing are generally for local-level impacts. It will be very important to also consider cumulative effects that could occur over, or across, entire oceans. In the US dustbowl in the 1930s, for example, the effects of ill-suited agricultural practices were indiscernible on a farm-by-farm basis, but cumulatively they created a disaster. One can also look at acid rain, or the ozone hole, to see how damaging cumulative non-localized effects can be. None of these effects were predicted, or even understood, until many years after they had happened. Nor would they ever have been understood, without environmental monitoring programmes that measured the right things at the right scales. Much more work is required before analogous risks can be ruled out for deep-sea mineral exploitation.”

Key current knowledge gaps: environmental baseline data at proposed exploitation sites, at regional and contractor scale; data related to the environmental impacts of, and regulation and management of, exploitation activities, and associated habitat recovery times; the potential for non-localized and cumulative negative effects of exploitation to occur.

3.2.3 Low-predictability effects

Effect	Predictability of scale
Lost scientific and social value	Low
Cultural and spiritual impacts for communities connected to the sea	Low
Impacts on deep-sea climate regulation	Low
Reduced fish catches	Low
Health impacts through the food chain	Low
Reduced coastal tourism	Low

More complete scientific knowledge could lead to greater predictability of the scale of effects of mineral exploitation, including potential species losses, disruption to ecosystems and release of contaminants into ocean waters.

However, additional knowledge would be needed to understand the knock-on effects for broader ocean ecosystem services and for humankind, making the scale of these effects relatively less predictable.

For example, even if broad consensus were reached on the scale of species losses anticipated from deep-sea mineral exploitation, the value that those species could have had for scientific and pharmaceutical applications would likely still be indeterminable. The potential to find out would be lost, along with the species themselves.

Evidence from communities connected to the sea suggests that cultural and spiritual impacts could arise from deep-sea mineral exploitation, in particular in national jurisdictions, where communities would be geographically closer to exploitation sites than

❝ Evidence from communities connected to the sea suggests that cultural and spiritual impacts could arise from deep-sea mineral exploitation.

would be the case for the international seabed area. For example, in 2019 a clan chief in Papua New Guinea commented about a now-abandoned exploitation project in national waters that "when they start mining the seabed, they'll start mining part of me".[128] Principles for assessing the cultural and spiritual impacts of resource exploitation in general are well established, but extensive social scientific research on community links to the sea would be required to assess the true scale of the cultural and spiritual effects of deep-sea mineral exploitation, were it to commence.

Some commentators have identified reductions in fish catches, toxic metal release into the human food chain and impacts on ecosystems services, including climate regulation, as risks associated with deep-sea mineral exploitation.[129, 130] Many factors would influence the scale of these effects, including the types of deposits exploited and the environmental impact mitigation measures employed. One study finds that commercially caught fish species would not be directly affected by plumes from nodule exploitation in the CCZ, for example, provided that post-processing sediments were discharged at sufficient depth.[131] And, while benthic and pelagic ecosystems are closely linked, and impacts at the seabed can have effects higher in the water column, the scale of potential exploitation activities suggests these knock-on effects from plume discharge could be limited. A computer simulation study of plume spread finds that a model commercial nodule exploitation operation could raise sediment levels above twice the background level (an assumed safety threshold) in 500 km^2 of ocean at a given time.[132] This is 0.01% of the 4.5 million km^2 area spanned by the CCZ.

Models of specific planned exploitation activities are, by necessity, limited in the breadth of possibilities they consider, and many scientists argue that further research is needed under a range of scenarios to assess the possible impacts. Nélia Mestre, from the Centre for Marine and Environmental Research at the University of Algarve, Portugal, commented for the Ocean Science Expert Panel that:

❝ The effects of deep-sea mineral exploitation that are felt near the surface will depend on a lot of factors, including deposit type, geographic location, duration of the activity and the equipment and techniques employed. Deep-sea mineral exploitation has the potential to release metals into the water column that could eventually build to toxic levels in organisms, accumulate through the food chain and ultimately affect top predators, fisheries and human health. However, we don't yet have models of metal discharge and bioabsorption, or interactions between benthic and pelagic ecosystems, that could predict the scale of these effects under a range of exploitation conditions."

Some studies have indicated that future deep-sea mineral exploitation could act as a disincentive for coastal tourism. For example, a 2018 paper that surveyed divers and snorkellers who had visited Fiji found that respondents "would significantly reduce their future visits" if the country were to commence exploitation activities, due to their perceptions that exploitation would degrade the country's coral reefs. This travel reduction, according to the paper, "could severely impact Fiji's tourism economy".[133] There was no suggestion in the paper that participants had any special knowledge of the actual impacts that could be anticipated for coral reefs, but their perceptions appeared sufficient to affect their decision-making. Generalized conclusions cannot be drawn from individual studies, and additional research would be required to assess the scale of tourism impacts and associated economic effects that could arise from deep-sea mineral exploitation in a wider range of circumstances and geographies.

Key current knowledge gaps: scientific, social and economic value of species threatened by deep-sea mineral exploitation; social-scientific understanding of community perceptions of potential deep-sea mineral exploitation; interactions between benthic and pelagic ecosystems, under a range of exploitation conditions; models of metal discharge and bioabsorption; socioeconomic understanding of tourists' perception of deep-sea mineral exploitation and their associated potential behavioural changes.

3.3 Predictability of the effects of new sources of revenue from mineral exploitation

❝ It will be up to regulators to decide where potential revenues flow, and in what quantities.

Unlike the potential effects of deep-sea mineral exploitation associated with the increased availability of metals, and those associated with disturbance to the marine environment, the effects of new sources of revenue from mineral exploitation would largely be determined administratively. It will be up to regulators to decide where potential revenues flow, and in what quantities.

Because of this difference from other potential effects, no Expert Panel was convened to assess the predictability of the effects of new sources of revenue from mineral exploitation. In the absence of final regulations for revenue distribution, from ISA or in national jurisdictions, the value of an Expert Panel is limited. Instead, a literature review was conducted, and commentary was received from relevant regulatory bodies.

The absence of final regulations for revenue distribution is also the reason why no "high-predictability effects" have been identified in this section, or in Figure 2.

3.3.1 Moderate-predictability effects

Effect	Predictability of scale
New revenue flows from taxes, royalties, and benefit sharing	Moderate

All mining projects generate revenues for host countries and communities, which can come in the form of taxes, royalties and benefit-sharing schemes. Plans for deep-sea mineral exploitation incorporate these same features. ISA is mandated by UNCLOS to develop a revenue-distribution scheme for mineral exploitation in the international seabed area that benefits humankind as a whole and accounts for "the special interests and needs of developing countries, whether coastal or land-locked".[134] The Finance Committee of ISA has developed recommendations for ISA on benefit sharing that would direct the flow of revenues to state parties to UNCLOS (as opposed to all states worldwide), and which would favour lower-income state parties for revenue distribution.[135, 136] Options for revenue-distribution systems and formulas have been drawn up, though no final decision has yet been taken on which to adopt.[137]

A study on the economics of deep-sea mining that assesses potential revenue-collection models was conducted for ISA by MIT in 2018.[138] The African Group of countries at the ISA Assembly criticized the MIT report in a series of analyses, stating that the payment regime appeared to be "designed around the overarching goal of ensuring post-tax profits are sufficient to motivate commercial mining",[139] and that the royalty rates proposed would result in revenue flows of "approximately $97.8 thousand per year" per nodule exploitation contract, to each ISA member country. A sum that the group "does not consider … fair compensation to mankind" for the loss of resources to common ownership.[140] It is not yet known whether finalized revenue-collection schemes from ISA will address these concerns.

Like ISA, countries that exploit deep-sea minerals within their national jurisdictions will adopt revenue-collection and distribution schemes. Few figures are available so far on the scale of revenues from deep-sea mineral exploitation that countries could expect. One African Union strategy document estimates the total value of the continent's seabed minerals at $6 billion,[141] though it does not explain how this figure was reached. The sum of $6 billion is a small but not insignificant figure compared to continental gross domestic product of $2.7 trillion.[142] Revenues for small islands states could be comparatively much greater. According to media reporting, the Cook Islands, for example, estimates that its deep-sea minerals could be worth tens of billions of dollars and could increase its gross domestic product a hundredfold.[143]

While it seems likely that the majority of public revenues from deep-sea mineral extraction would flow directly to national budgets, as is already the case for other forms of mineral exploitation, special provisions for community benefits or compensation may also be adopted. The Norwegian Seabed Minerals Act, for example, has no special provisions for how government revenues from deep-sea mineral exploitation should be spent, though it specifies that fishermen should be compensated by the government for losses incurred due to mineral exploitation activities. It does not give details of a compensation mechanism,[144] and distribution structures for deep-sea mineral revenues are currently under discussion by the Norwegian Finance Department.[145] The Cook Islands Seabed Minerals Act has no special provisions for how government revenues from deep-sea mineral exploitation should be spent. A draft version required that title holders obtain the "free, prior, and informed consent, including by way of compensation" from "marine or coastal users likely to be adversely affected by … seabed mineral activities", but the final version of the Act had this provision removed.[146, 147]

Key current knowledge gaps: total revenue amounts collectible from deep-sea mineral exploitation in each jurisdiction; details of revenue-sharing schemes that would be implemented by ISA and deep-sea mineral-exploiting countries.

3.3.2 Low-predictability effects

Effect	Predictability of scale
Benefits for developing countries from ISA revenue-sharing schemes	Low
Benefits for countries and communities with deep-sea minerals in national jurisdictions	Low

Greater certainty over revenue-distribution schemes, both for the minerals of the international seabed area and in national jurisdictions, would allow financial flows to countries and communities to be better predicted for any given mineral exploitation plan.

However, the benefits that revenues would bring to those countries and communities would be less certain. As is the case for any revenue-generating industry, including land-based mining, the potential benefits for countries and communities that could arise from deep-sea mineral extraction would depend on the strength of governance in jurisdictions where the revenues are distributed. In many jurisdictions where governance is weak, significant potential benefits from mineral revenues are lost through corruption and mismanagement.

ISA has not publicly indicated that it intends to adopt any oversight mechanism for how revenues distributed to countries are spent, nor is it required to exercise such oversight under UNCLOS. Revenue flows from the exploitation of deep-sea minerals in national jurisdictions, of course, would be overseen solely by the relevant authorities in producer countries.

Given these revenue-distribution uncertainties, the scale of potential benefits for developing countries from ISA revenue-sharing schemes and the scale of potential benefits for countries and communities with deep-sea minerals in national jurisdictions were both rated low in our analysis.

3.4 Is knowledge of the potential effects sufficient for decision-making?

“ There are not commonly agreed benchmarks on when risk appreciation could be considered comprehensive, when research could be considered thorough, what environmental protections could be considered effective or precautionary or how the requirements for each might vary between phases of operations.

3.4.1 The challenge of benchmarking ‘sufficiency’

While it is a truism that more complete knowledge can lead to better decision-making, real-world decisions often take place in situations where knowledge is lacking or disputed, and where the outcomes of decisions are difficult to predict. This “uncertainty factor” underpins much public debate on potential deep-sea mineral exploitation. On first impression, the current debate landscape on deep-sea mineral exploitation can appear highly polarized. On the one hand are the companies drawing up exploitation plans and the regulators developing exploitation regulations with urgency. On the other hand are the groups of conservationists, scientists, manufacturing companies and others, urging for a moratorium on deep-sea mineral exploitation.

However, the dialogue is not as polarized as it may at first seem. When talking about the stewardship of deep-sea minerals, organizations from across the spectrum of opinions use similar language.

The civil-society body Deep Sea Conservation Coalition calls for a moratorium on deep-sea mineral exploitation until the “environmental, social and economic risks are comprehensively understood”, among other criteria.[148] A group of major manufacturers and other businesses also back a moratorium until these risks are “comprehensively investigated” and “effective protection of the marine environment” can be assured.[149] Microsoft supports a moratorium “until the proper research and scientific studies have been completed”.[150] The Pew Charitable Trusts calls for a “precautionary approach” to deep-sea mineral exploitation.[151]

Meanwhile, the deep-sea mineral contractor GSR has pledged not to produce minerals from the deep sea before the environmental risks are “comprehensively understood”, echoing the language of pro-moratorium organizations.[152] The Metals Company states that if “research shows that producing critical battery metals from seafloor nodules will do more planetary harm than good, we will not seek to apply for an exploitation contract”.[153] ISA states that it is developing regulatory frameworks “based on best environmental practices, for the protection of the marine environment from harmful effects”.[154] Exploration regulations published to date specifically require a “precautionary approach”.[155]

While the language used by these diverse organizations is often similar, there is not yet concrete consensus on its meaning. There are not commonly agreed benchmarks on when risk appreciation could be considered comprehensive, when research could be considered thorough, what environmental protections could be considered effective or precautionary or how the requirements for each might vary between phases of operations.

Achieving a broader-based consensus in these areas and others would give much-needed clarity to questions of knowledge sufficiency for decision-making on deep-sea mineral exploitation.

3.4.2 'Sufficiency' is not 'completeness'

Decisions taken on mineral sourcing – to support overarching societal goals of limiting global temperature rises, halting biodiversity loss, reducing resource consumption and alleviating poverty (as described in Section 1.1) – are time-sensitive. Decisions cannot wait for complete knowledge, and arguments exist for moving towards deep-sea mineral exploitation, notwithstanding the associated uncertainties.

Greater consensus on knowledge of the potential effects of deep-sea mineral exploitation is required if a common concept of knowledge sufficiency for decision-making is to emerge.

One such argument was made by the government of the Pacific island state of Nauru when it invoked what is commonly known as the "two-year rule" in June 2021, allowing for a commercial exploitation plan of work to be "considered and provisionally approved" by ISA after a two-year period even if full exploitation regulations have not been finalized by that point. In an explanation of this move, Nauru cited the urgency of climate change, to which it is especially vulnerable, and the potential for polymetallic nodules to support the global transition away from fossil fuels.[156]

A second argument could be made if it were shown that the existing knowledge already ascertained that deep-sea mineral exploitation was preferable to other exploitation types. In this vein, The Metals Company, the parent company of a deep-sea mineral contractor for the state of Nauru, states that polymetallic nodule exploitation can already be seen to have significantly reduced the impacts on "climate change, non-living resources, biodiversity and biomass, and measures of social and economic well-being", compared with terrestrial mining.[157]

Not everyone in the metals supply chain agrees with such arguments. For example, Claudia Becker, a sustainability expert at BMW, stated to the BBC in April 2021 that "with [terrestrial] mines we do understand the consequences and we do have solutions but in the deep ocean we don't even have the tools to assess them".[158]

Greater consensus on knowledge of the potential effects of deep-sea mineral exploitation is required if a common concept of knowledge sufficiency for decision-making is to emerge.

3.4.3 How does knowledge compare to other industries?

Current levels of uncertainty about the potential effects of deep-sea mineral exploitation can be compared to the levels of uncertainty present in other industrial contexts, prior to projects' commencement.

Several members of the Ocean Science Expert Panel familiar with the launch of projects in other industries were asked to compare environmental knowledge levels between those contexts and deep-sea mineral exploitation. Panellists spoke about knowledge of potentially affected ecosystems, knowledge of the potential effects on ecosystems, and knowledge of management and mitigation techniques for ecosystem impacts (depending on their expertise). Five panellists responded that "much less is known" about relevant environmental considerations in the deep-sea mineral exploitation context than in the other context with which they are familiar. One panellist responded that "less is known" and three panellists responded that "approximately the same is known". No members of the Ocean Science Expert Panel responded that "more" or "much more" was known in the deep-sea context than in other contexts with which they are familiar, prior to the commencement of project activities.

Speaking of the relative paucity of knowledge of the effects of deep-sea mineral exploitation, the panellist Tanja Stratmann, a researcher on deep-sea ecology at Utrecht University, gave the following example:

> **"In an experimental study about land-based iron-ore mine tailing disposal on a soft sediment community from 200 metre water depth in a Norwegian fjord, we detected significant changes in the capacity of the organisms to remineralize fresh organic material when the sediment was covered with 1 mm of mine tailings. Similar data is lacking completely for the Clarion-Clipperton Fracture Zone. We do not know the threshold of sediment deposition depth at which the sediment community will be affected and therefore it should be avoided to not cause serious environmental harm."**

Another panellist, a marine environmental consultant with professional experience of seabed mining, stated that:

> **"No other industrial sector had all the answers before activities commenced, and the Clarion-Clipperton Zone has been reasonably well studied, compared to most deep-water oil and gas sites pre-exploitation. Deep-sea mineral exploitation in the Clarion-Clipperton Zone is in some ways at quite a reasonable stage of preparation. Standards and guidelines are close to being in place, and the precautionary approach is fully acknowledged, as is the need for adaptive management and extensive monitoring of operational effects.**

Like the views of organizations with opposing views on a moratorium (discussed in Section 3.4.1), the perspectives of these two panellists are not as divergent as they may at first appear. Knowledge gaps are widely recognized, principles and processes exist to fill knowledge gaps, and knowledge will increase further before decisions on the commencement of deep-sea mineral exploitation are taken.

One area where organizations' opinions frequently diverge is on knowledge acquisition and knowledge sufficiency – how, and by how much, knowledge should increase before exploitation decisions can be taken.

3.4.4 How will knowledge increase?

Regulators including ISA are incorporating an understanding of the potential effects of deep-sea mineral exploitation into draft regulations as relevant scientific knowledge becomes available. Regulators would also require scientific knowledge-gathering in potential exploitation areas before contracts could be granted. This would include the conduct and establishment of environmental baseline studies, environmental impact statements and environmental management and monitoring plans. ISA has published, and will periodically update, guidance for such studies, including specifications for data gathering on physical and chemical oceanography, geological properties, biological communities, sediment disturbances, linkages between pelagic and benthic habitats, oxygen consumption and food web structures.[159]

"Contractors point out that, without industry funding, which is stimulated by the prospect of future exploitation licences, the current pace of research and knowledge acquisition would drop markedly.

Contractors point out that, without industry funding, which is stimulated by the prospect of future exploitation licences, the current pace of research and knowledge acquisition would drop markedly. Kris Van Nijen, Managing Director at Global Sea Mineral Resources, commented for this paper that:

"Contractors are an important contributor to deep-sea science and research, and ultimately knowledge. For example, to complete the required environmental baseline studies and environmental impact assessment for a deep-seabed mining licence application, between €75 million [$80 million] and €85 million [$93 million] is anticipated to be spent per contractor. This is in addition to the funds allocated to technology research and development.

Michael Clarke, Environmental Manager at the Metals Company, expressed similar views:

"Approximately two-thirds of the research campaigns mobilized to the CCZ since 2013 have been wholly or partially funded by industry. The current pace of research cannot be sustained with civil-society support alone, so a moratorium would limit the rate of accumulation of the information we need to determine if seabed mineral extraction is a viable partial solution to the time-sensitive climate crisis.

3.4.5 Building consensus on 'sufficiency' of knowledge

Industry-backed research is a crucial engine of knowledge acquisition. However, a wider range of organizations must have their say if consensus is to be built on what knowledge must be gathered, and on when the knowledge gathered is sufficient for decision-making. Deep-sea mineral contractors' knowledge gathering is primarily shaped by the requirements of regulators. Regulatory requirements, including those of ISA, are still under development. It is not known whether they will satisfy the expectations of the bulk of civil-society stakeholders and the expectations of manufacturers and markets when finalized.

Civil-society organizations and other parties have criticized the perceived weaknesses in ISA's current structures for knowledge gathering on the potential environmental effects of deep-sea mineral exploitation.[160] The Pew Charitable Trusts has stated that past environmental impact assessments undertaken for ISA regarding test extraction have had "significant gaps that, unfortunately, made it impossible to assess whether [they] or future commercial-scale operations would harm the environment".[161]

Pradeep Singh, a researcher at the University of Bremen in Germany and an expert on deep-sea mineral regulations, commented for this paper that:

"Under the existing ISA exploration regulations and the current version of the draft exploitation regulations, there are no strict requirements for contractors to conduct any form of in-situ testing of their mining equipment or systems. It's not compulsory – it's optional at the behest of the contractor – and at the exploration phase it's primarily geared towards assessing technical feasibility, as opposed to truly understanding the potential environmental consequences. In other words, it is entirely possible that an application for exploitation can be considered and approved without any form of prior physical in-situ testing and demonstration of the contractor's ability to manage environmental harm."

“ The current lack of consensus also highlights the importance of broad-based multistakeholder participation in decision-making processes on whether to exploit minerals – and if so, how.

ISA’s requirements for environmental knowledge gathering are not yet finalized, and may evolve to satisfy civil-society concerns. This cannot be guaranteed, however, and deep-sea mineral contractors should look beyond the regulatory requirements for knowledge gathering to build a broader consensus on knowledge requirements for decision-making, and try to achieve social acceptance of their planned exploitation of deep-sea minerals. Common ground on knowledge requirements and knowledge sufficiency could be found by building better public understanding of the potential effects of deep-sea mineral exploitation through enhanced knowledge-sharing and discussion in open forums. Felix Janssen, an expert on the potential ecological effects of deep-sea mining at the Helmholtz Centre for Polar and Marine Research, comments for this paper that:

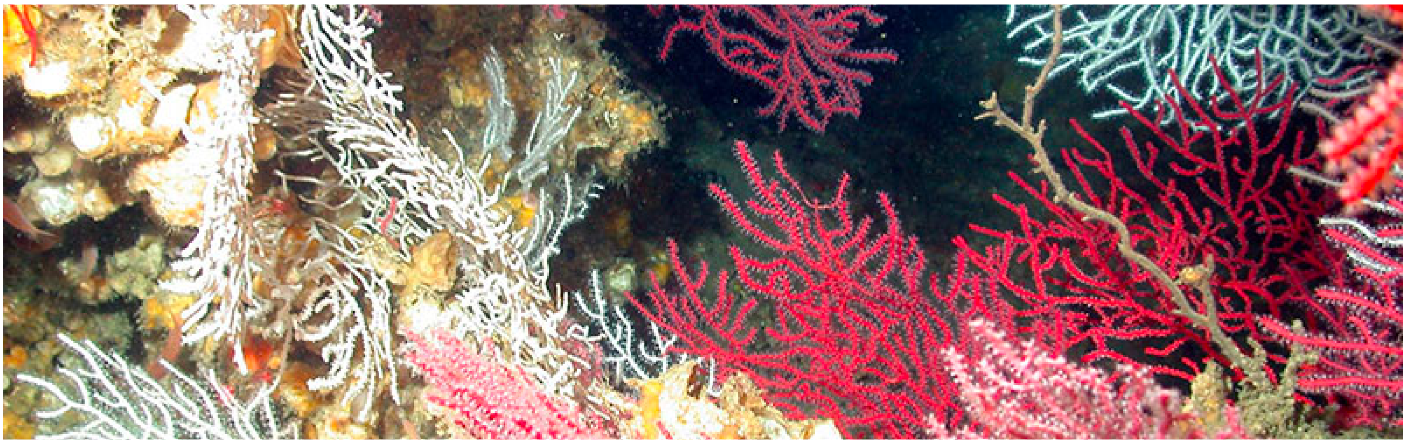
“ Much more cooperation is necessary across the scientific community and ISA exploration contract holders. Some contractors recognize the benefit of sharing data and knowledge, but so far this is largely restricted to bilateral cooperation between one contractor and one scientific consortium. Progress towards a comprehensive ecosystem understanding could be so much faster with better data sharing and integration, and important regional aspects can only be addressed through open access to all relevant data, and integrated study approaches.”

An open-access forum for knowledge related to the potential environmental effects of deep-sea mineral extraction could build on existing open-access platforms, including the DeepData ISA database,[162] which hosts raw data from contractors’ environmental studies.

Open-access knowledge forums could help to achieve consensus on other vital questions for the stewardship of deep-sea minerals, such as their likely future demand, and their criticality in the low-carbon transition. Economics panellist Damien Giurco of the Institute for Sustainable Futures at the University of Technology Sydney, says:

“ In the case of fossil fuels, information is available such as the annual *BP Statistical Review of World Energy*, and from the International Energy Agency, which assesses and forecasts supply and demand. The split of forecast supply into component parts, for example, from currently producing sources, discovered but not yet developed sources and sources ‘needing to be discovered’ to meet demand, builds up a picture layer by layer in a way that can be publicly understood and engaged with. There is no public, freely available, regularly updated analogue for minerals. As a result, we tend to have simplistic generalized conversations, of ‘we’re running out of this mineral’, and then the situation evolves and ‘we’re not running out any more’, ignoring regional supply-and-demand contexts, geopolitics, social licences to extract and other factors.

The current lack of consensus also highlights the importance of broad-based multistakeholder participation in decision-making processes on whether to exploit minerals – and if so, how. Through participation, greater consensus can be achieved on knowledge sufficiency and on the characteristics of a knowledge-based decision-making system for the responsible stewardship of mineral resources. A substantial body of social science research demonstrates that participatory decision-making can increase the quality of decisions that are made, [163] promote public trust in decision-making processes,[164] enhance perceptions of their legitimacy[165] and acceptance of their effects.[166] Moreover, social acceptance of decision-making is a vital aspect of manufacturers’ and markets’ emerging expectations for deep-sea mineral stewardship.



BOX 3 The pace of environmental knowledge acquisition in the Clarion-Clipperton Zone

The potential environmental effects of deep-sea mineral exploitation are some of the most important considerations within a decision-making system for mineral stewardship. They are also the focus of a significant amount of current research. To assess the pace at which humankind's knowledge of the environmental aspects of deep-sea mineral exploitation will grow, the Ocean Science Expert Panel was consulted on the time required for scientific consensus to be reached in key knowledge areas.

As a case study, data is presented in Figure 4 from panellists' responses as they pertain to the polymetallic nodule fields of the Clarion-Clipperton Zone (CCZ). The CCZ was chosen because a sufficient number of panellists are focused on the area to give a range and balance of views, and because of the attention currently given to it as a potential exploitation area. Each panellist was asked to provide estimates only within their individual areas of expertise, so respondent numbers vary. In some cases, panellists gave a range estimate, from which an average was taken. For example, "three to five years" was converted to "four years".

The time estimates shown in Figure 4 do not represent a generally held view among the scientific community. Nor do they show a fixed picture. Respondents were asked to estimate, in years, the period until broad scientific consensus can be achieved *at the current pace of research,* and it is possible that these time estimates could shorten significantly were the pace of research to increase.

Average figures are given for the years until consensus in four aggregated areas of knowledge. Such an averaging approach is intrinsically a simplification – progress towards knowledge consensus on one aspect of deep-sea mineral exploitation does not imply progress in other areas, and "averaged" knowledge across different areas is not what would be required, in reality, for effective decision-making. This would require a sound base of knowledge in each of the areas featured in Figure 4, and others, too.

Figure 4 provides an early impression of the timescales on which knowledge consensus could be reached, in knowledge areas relevant to the environmental effects of potential deep-sea nodule extraction. It is by no means a complete or definitive picture and should best be interpreted as an indicative presentation of where future research efforts could be directed.

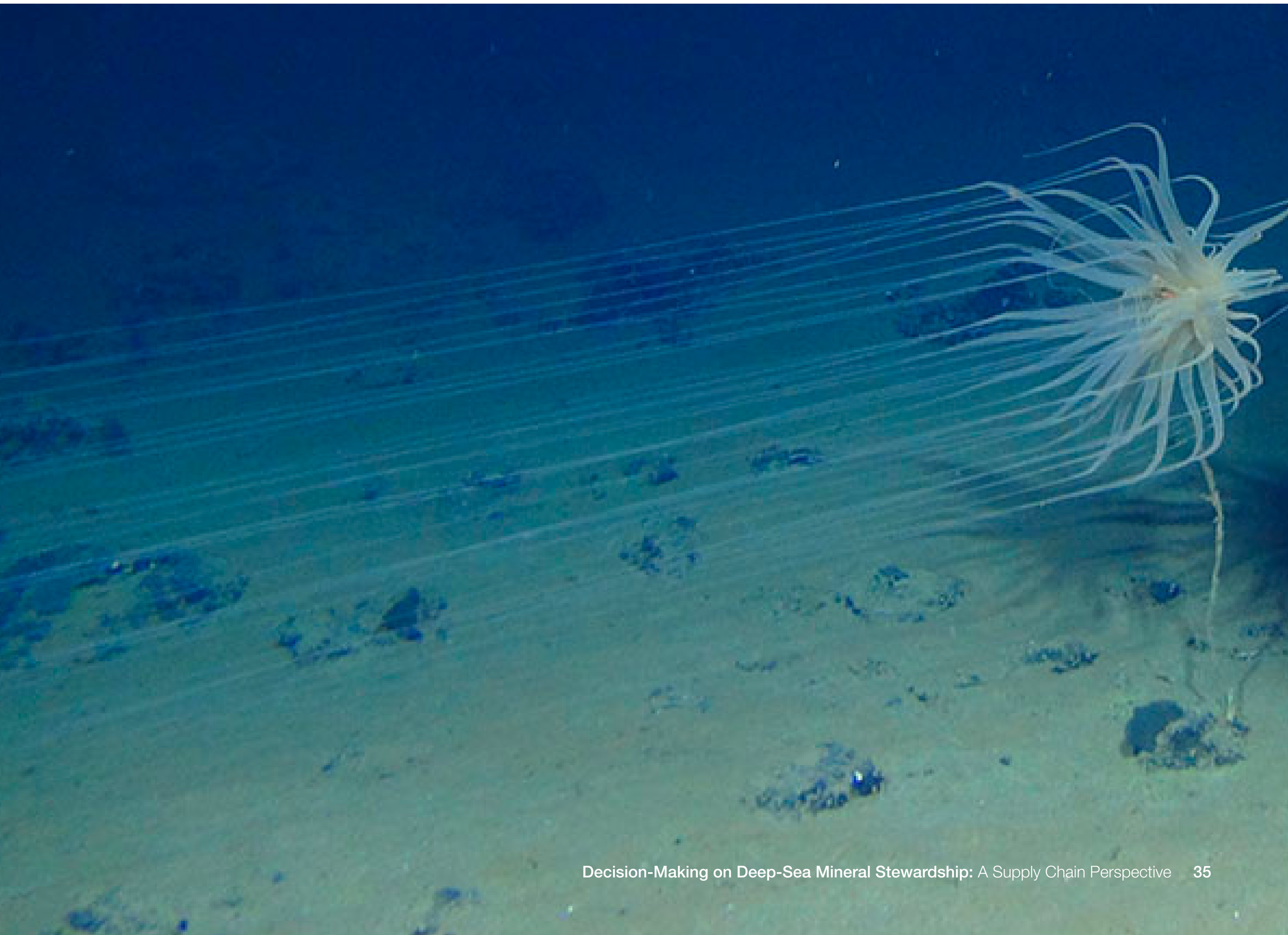
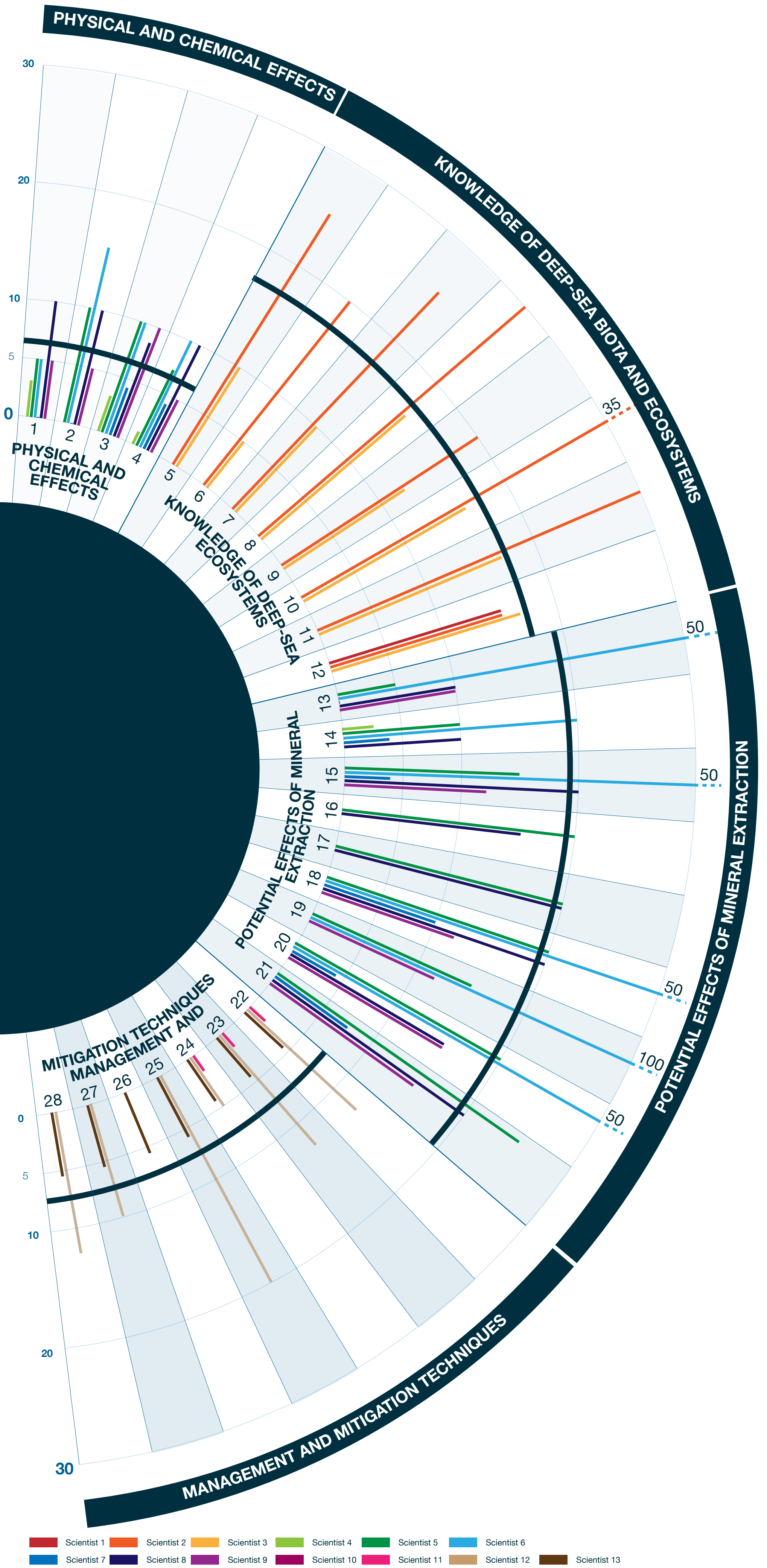


FIGURE 4 **Estimated years to achieve broad consensus on the effects of nodule exploitation in the CCZ**



1. Physical changes that will occur at deep-sea extraction sites
2. Chemical changes that will occur at deep-sea extraction sites
3. Dynamics and scale of plume spread (both for site-level plume generation and for plumes from ship-based mineral processing)
4. Input data necessary to model plume spread
5. The richness of benthic species
6. The abundance of benthic species
7. The endemicity of benthic species
8. The richness of species in associated pelagic zones
9. The abundance of species in associated pelagic zones
10. The endemicity of species in associated pelagic zones
11. The system of interactions between benthic and pelagic organisms and ecosystems
12. The seabed and water column's role in the global carbon cycle and carbon sequestration (both the mechanics and the significance of its role)
13. Localised effects that physical and chemical changes will have on biota at deep-sea extraction sites
14. Scale of potential contaminant release into the water (e.g. heavy metals) resulting from extraction
15. Scale of potential negative ecosystem effects from contaminant release, resulting from extraction
16. The quantities of seafloor CO2 that could be released by deep-sea extraction
17. The scale of potential disruption to marine carbon sequestration from for deep-sea extraction
18. The overall scale of potential impacts of deep-sea extraction on the benthic ecosystem
19. Systems of benthic biological recovery and associated timescales, after extractive activity
20. Significance of plumes' potential effects on the marine ecosystem (both for site-level plume generation and for plumes from ship-based mineral processing)
21. Significance of potential effects of exogenous noise and light from deep-sea extraction and processing on the marine ecosystem
22. Efficacy of protected areas approaches, for the avoidance of biodiversity loss and negative ecosystem impacts from deep-sea extraction
23. Required parameters of protected areas (for example, necessary size and location)
24. Design of extraction and processing equipment and techniques to minimize biodiversity and ecosystem losses
25. Efficacy of potential restoration schemes for benthic zone biodiversity
26. Viability of in-kind offset schemes to achieve the aim of no net loss of biodiversity from deep-sea extraction
27. Viability of out-of-kind offset schemes to achieve the aim of no net loss of biodiversity from deep-sea extraction
28. Overall knowledge of the extent to which ecosystem health can be preserved, through the application of the available range of management and mitigation techniques

Note: Illustration of the estimated years until broad scientific consensus can be achieved in key knowledge areas for understanding the potential environmental effects of nodule exploitation in the Clarion-Clipperton Zone (CCZ) **;** Designed by TDi Sustainability'

Figure 4 indicates that scientific consensus on the potential physical and chemical effects of deep-sea exploitation is expected to be reached relatively quickly as these effects are more tangible and open to modelling than others. The average time estimate given by participating scientists for consensus to be reached in the examined areas is 6.5 years at the current pace of research. Consensus of knowledge on deep-sea biota and ecosystems may take longer to achieve, averaging 18.5 years. Knowledge of the potential effects of mineral exploitation shows a slightly greater average figure, with the number of years required until consensus can be reached being 19.5.

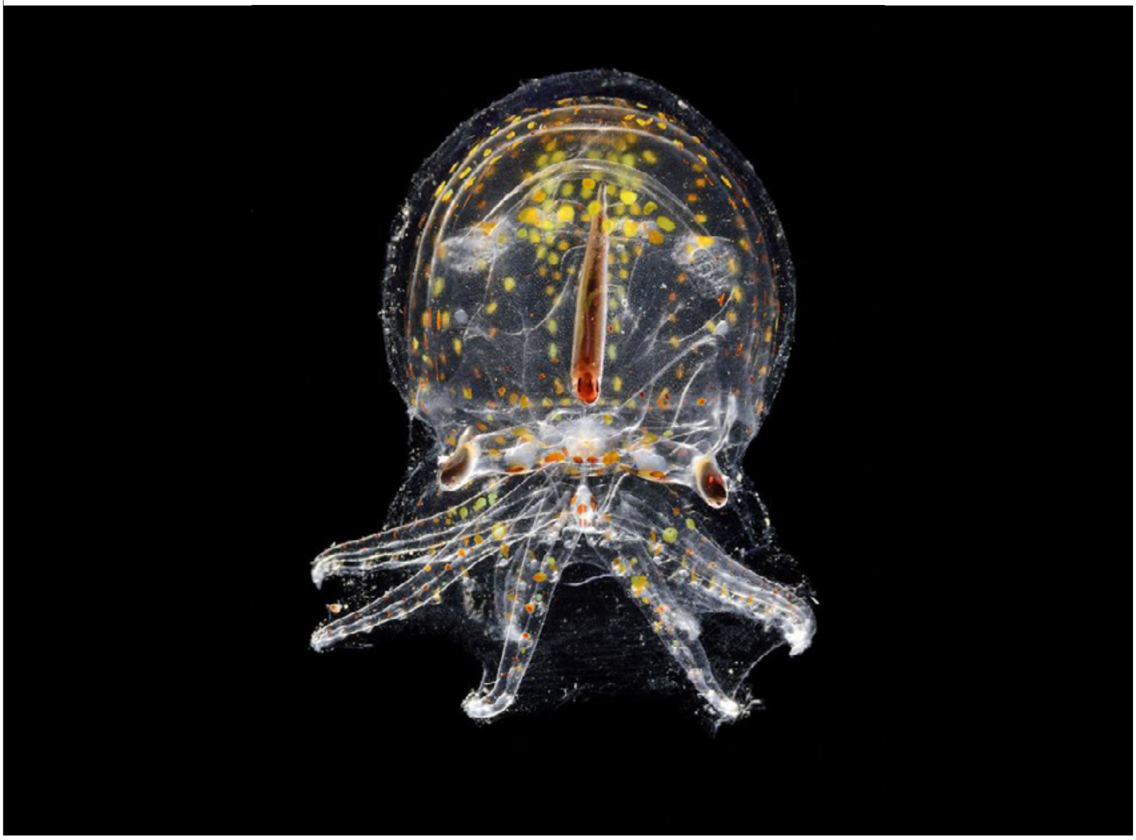
Perhaps surprisingly, the estimated range of years until scientific consensus can be achieved on management and mitigation techniques is lower than for knowledge of deep-sea biota and ecosystems and the potential effects of mineral exploitation. According to our expert panel, the average time until consensus is reached on management and mitigation techniques is seven years. Understanding all aspects of deep-sea biota and ecosystems, and understanding all of the potential ecosystems and water column effects of exploitation, is not a prerequisite for management and mitigation techniques to be understood. As summarized by a contractor company interviewed for this paper: “We don’t need to know every detail about what’s down there, in order to manage impacts” This sentiment may explain the relatively short anticipated timescales for consensus on management and mitigation techniques that were given by respondents.

The prospect of rapid consensus on knowledge of management and mitigation techniques is a noteworthy finding. However, conclusions should not be drawn too freely. As shown in the text of questions 22 to 28, panellists were asked about knowledge *regarding* the viability and efficacy of techniques. Achieving this knowledge does not mean that the proposed techniques *would be* viable or effective, nor does it imply that the continuous environmental m onitoring that would be required for the effective application of management and mitigation techniques would necessarily be in place.

Even the relatively short time frame for consensus on management and mitigation techniques that is indicated in Figure 4 would significantly overrun the June 2023 deadline for ISA to begin considering applications for exploitation licences, which was legally invoked by the pro-exploitation island nation of Nauru in June 2021. ISA is not obliged to accept any applications made at that point,[167] but if exploitation licences were granted in the Clarion-Clipperton Zone prior to the achievement of broad scientific consensus on appropriate environmental impact management and mitigation techniques, it is unlikely that the minerals produced would be socially accepted.

4 The state of stakeholder participation in decision-making on deep-sea mineral stewardship

Decisions on deep-sea mineral stewardship could affect many stakeholder groups, and all should have a say.



The need for strong stakeholder participation in decision-making on deep-sea mineral stewardship is widely recognized.

The decision-making arena for the stewardship of deep-sea minerals can be split into two parts: one for minerals that lie in the international seabed area; the other for minerals within countries' national jurisdictions. Sections 4.1 and 4.2 examine the current levels of stakeholder participation in decision-making for the international seabed area and national jurisdictions respectively.

The need for strong stakeholder participation in decision-making on deep-sea mineral stewardship is widely recognized. In addition to being a general expectation of manufacturers and markets, as discussed in Section 2.6, participation is called for by prominent international civil-society bodies. The High-Level Panel for a Sustainable Ocean Economy, an initiative of 14 world leaders, recommended in a 2020 report enhancing "societal awareness of the choices associated with deep-seabed mining", conducting broad outreach and facilitating the inclusion of diverse views within decision-making processes, in order to enhance decision-making quality, and ensure public trust and consent to decisions. In its 2018 policy recommendations to ISA, the Institute for Advanced Sustainability Studies stated: "Broad public participation, transparency and consideration of the social and cultural impacts of activities are necessary to ensure that due regard is given to the interests of civil society, in particular in developing countries, and of future generations."[168]

4.1 Participation in decision-making on mineral stewardship in the international seabed area

Stewardship of minerals in the international seabed area, which are considered the common heritage of humankind, is the responsibility of the International Seabed Authority (ISA). ISA's membership comprises the 167 countries that are parties to the United Nations Convention on the Law of the Sea (UNCLOS), and the European Union. These entities make up the ISA Assembly, which is responsible for setting general policy,[169] and which elects a Council of 36 members that serves as the executive organ of ISA. The Council's mandate includes setting rules, regulations and procedures, and approving contracts.[170]

The ISA Strategic Plan 2019–2023 recognizes the importance of broad-based participation, involving "open, meaningful and constructive dialogue, including on stakeholder expectations".[171] ISA grants observer status at the Assembly and Council to specified classes of entities and, as of November 2020, these observers comprised 30 non-member states, 32 UN agencies and intergovernmental organizations and 30 non-governmental organizations. Observers and members of the public are invited to provide comments on draft versions of ISA regulations during their development and ISA publishes the commentary it receives. ISA regularly conducts public workshops and webinars on topics relevant to the stewardship of deep-sea minerals.[172] Past sessions of the ISA Council and Assembly have been live-streamed, although recordings and transcripts are not made available after the events.

ISA has released a draft Communications and Stakeholder Engagement Strategy, which, among other provisions, describes the currently established rules on observer status of non-governmental organizations and associated eligibility criteria.[173] ISA invited public commentary on the strategy from December 2020 to January 2021.[174] The draft document attracted criticism from some organizations for the perceived weakness of its provisions for stakeholder engagement. The Pew Charitable Trusts, for example, says that: "The draft Strategy's definition of stakeholders focuses only on those entities who are [already] 'interacting with the ISA'. This is a limited pool – many States do not engage at the ISA and it is rare for the Assembly to achieve its 51% quorum (84 States). Similarly, observer organization participation is limited and does not represent a wide membership or demographic."[175]

The Deep-Sea Conservation Coalition also commented on the draft, stating its opinion that it "all but ignores access to information and access to review procedures and in many respects restricts rather than provides for public participation".[176]

The Pew Charitable Trusts also perceives weaknesses in the stakeholder participation provisions of ISA's draft exploitation regulations. The organization gave its opinion for this paper, commenting:

Critical elements of stakeholder participation are missing from the draft exploitation regulations, including elements covering access to information, opportunities to participate in decision-making processes and access to justice. The ISA must not only solicit stakeholder input, but also actively respond to stakeholders and explain how their views are being taken into account, which may require additional capacity. Mineral exploitation should not go forward until these gaps, among others, are addressed.

Contractor companies do not currently have a way to formally participate in decision-making processes at ISA, though in practice some routes for direct representation in ISA deliberations appear to exist with the facilitation of sponsoring states. In February 2019, two contractor companies were invited by sponsoring states to directly address the Council and present their visions for deep-sea mineral exploitation.[177] Bloomberg described the event as an "extraordinary display" of private-sector influence in breach of UN protocol.[178]

A view expressed by some contractor companies[179] is that the structure of ISA already incorporates strong stakeholder representation in decision-making, in part because its Assembly includes 167 member states and the EU. This contrasts with decision-making on resource stewardship at the national level, which is always conducted by a single government. While state representatives at the Assembly do have a legitimate mandate from UNCLOS to make decisions on the stewardship of deep-sea minerals, contractors may find that additional non-state inclusivity is needed in order to ensure the minerals they extract are accepted by society. The importance of broad-based, empowered participation for the social acceptance of decision-making is well established in social science literature,[180, 181] and its importance specifically for manufacturers and markets is discussed in detail in Section 2.6. Moreover, state representation at ISA has significant gaps. Of the 13 developing states identified in an ISA study as having the potential to suffer adverse economic impacts due to increased metal supply from polymetallic nodule exploitation, 12 are currently ineligible to vote at ISA due to membership fee arrears or because they are not member states. Only three attended any ISA sessions between 2018 and 2020.[182]

4.1.1 Characteristics of current non-governmental observers at ISA

An assessment of the 32 non-governmental organizations with observer status at ISA,[183] shown in Table 4, demonstrates that participation by stakeholder representative groups is limited, and participation by the Global South is low. The great majority of observer organizations participate either from a policy advisory or conservation perspective (63% and 34% respectively), and 81% are headquartered in OECD countries.

In Table 5, organizations are categorized as participating from a "policy advisory" perspective in cases where policy advisory is a stated aim of the organization, or when the organization's role involves specific technical expertise relevant to ISA policy-making. Organizations categorized as participating from a "conservation" perspective may also have policy-advisory aims, but these are present alongside clear advocacy positions for environmental conservation.

"Conservation" organizations can be viewed as representing subgroups of the citizens worldwide for whom conservation is a key concern. This affected stakeholder group is identified in Figure 2 (Section 3: *Predictability of the effects of deep-sea mineral* exploitation).

A "stakeholder representation" category was also applied to the list of non-governmental observers at ISA. This category was assigned to any organization that could be viewed as representing the voices of other potentially affected stakeholder groups, beyond citizens concerned with conservation. The typology of affected stakeholder groups in Figure 2 was used for this purpose.

Only one "stakeholder representation" observer organization was identified – the Thyssen-Bornemisza Art Contemporary, a Vienna-based group that explores the spiritual aspects of the ocean through art, and which could be viewed as partially representing the stakeholder grouping in Figure 2 of "communities with traditional, cultural or indigenous links to the sea". No ISA observer organizations appear to directly represent stakeholder voices in any of the other nine stakeholder groups identified in Figure 2. Broader-based participation at ISA could bring important stakeholder perspectives into decision-making processes on a wider range of the potential effects of deep-sea mineral exploitation than are currently covered by non-governmental observers.

Also absent from the list of non-governmental observers at ISA is any organization representing manufacturers and markets. ISA does not publish a definition of what it considers a "non-governmental organization", but the inclusion of the International Association of Drilling Contractors as an observer suggests that the definition is broad and industry associations may participate. An industry body representing manufacturers and markets could add important perspectives to deliberations.

TABLE 5 **Characteristics of current non-governmental observers at ISA**

Organization name	Participation perspective	Headquarters location
Advisory Committee on the Protection of the Sea	Conservation	OECD country
African Minerals Development Centre	Policy advisory	Non-OECD country
Center for Oceans Law and Policy, University of Virginia School of Law	Policy advisory	OECD country
Center for Polar and Deep Ocean Development, Shanghai Jiao Tong University	Policy advisory	Non-OECD country
Committee for Mineral Reserves International Reporting Standards	Policy advisory	OECD country*
Conservation International	Conservation	OECD country
Deep Ocean Stewardship Initiative	Policy advisory	N/A**
Deep Sea Conservation Coalition	Conservation	OECD country
IBRU Centre for Borders Research, Durham University	Policy advisory	OECD country
Earthworks	Conservation	OECD country
Fish Reef Project	Conservation	OECD country
Greenpeace International	Conservation	OECD country
Institute for Advanced Sustainability Studies	Policy advisory	OECD country
International Association of Drilling Contractors	Policy advisory	OECD country
International Cable Protection Committee	Policy advisory	OECD country
International Dialogue on Underwater Munitions	Policy advisory	OECD country
International Marine Minerals Society	Policy advisory	OECD country
International Ocean Institute	Conservation	Non-OECD country
InterRidge	Policy advisory	N/A**
Japan Agency for Marine-Earth Science and Technology	Policy advisory	OECD country
Law of the Sea Institute	Policy advisory	OECD country
Mining Standards International	Policy advisory	OECD country
MIT Policy Lab at the Center for International Studies	Policy advisory	OECD country
OceanCare	Conservation	OECD country
Ocean Society of India	Policy advisory	Non-OECD country
Resolve Conservation	Conservation	OECD country
Sargasso Sea Commission	Conservation	OECD country
Sasakawa Peace Foundation	Policy advisory	OECD country
The Pew Charitable Trusts	Policy advisory	OECD country
Thyssen-Bornemisza Art Contemporary	Stakeholder representation	OECD country
World Ocean Council	Policy advisory	OECD country
World Wildlife Fund	Conservation	OECD country

*Based on HQ location of the parent organization, the ICMM

**Organizations have no geographic headquarters and are composed of participating organizations in both OECD and non-OECD countries

4.2 Participation in decision-making on mineral stewardship in countries' national jurisdictions

Deep-sea minerals that lie within countries' jurisdictions are considered a national resource endowment, in the same way as subsoil resources on land. Consequently, stakeholder consultation on the stewardship of these resources occurs at the national level.

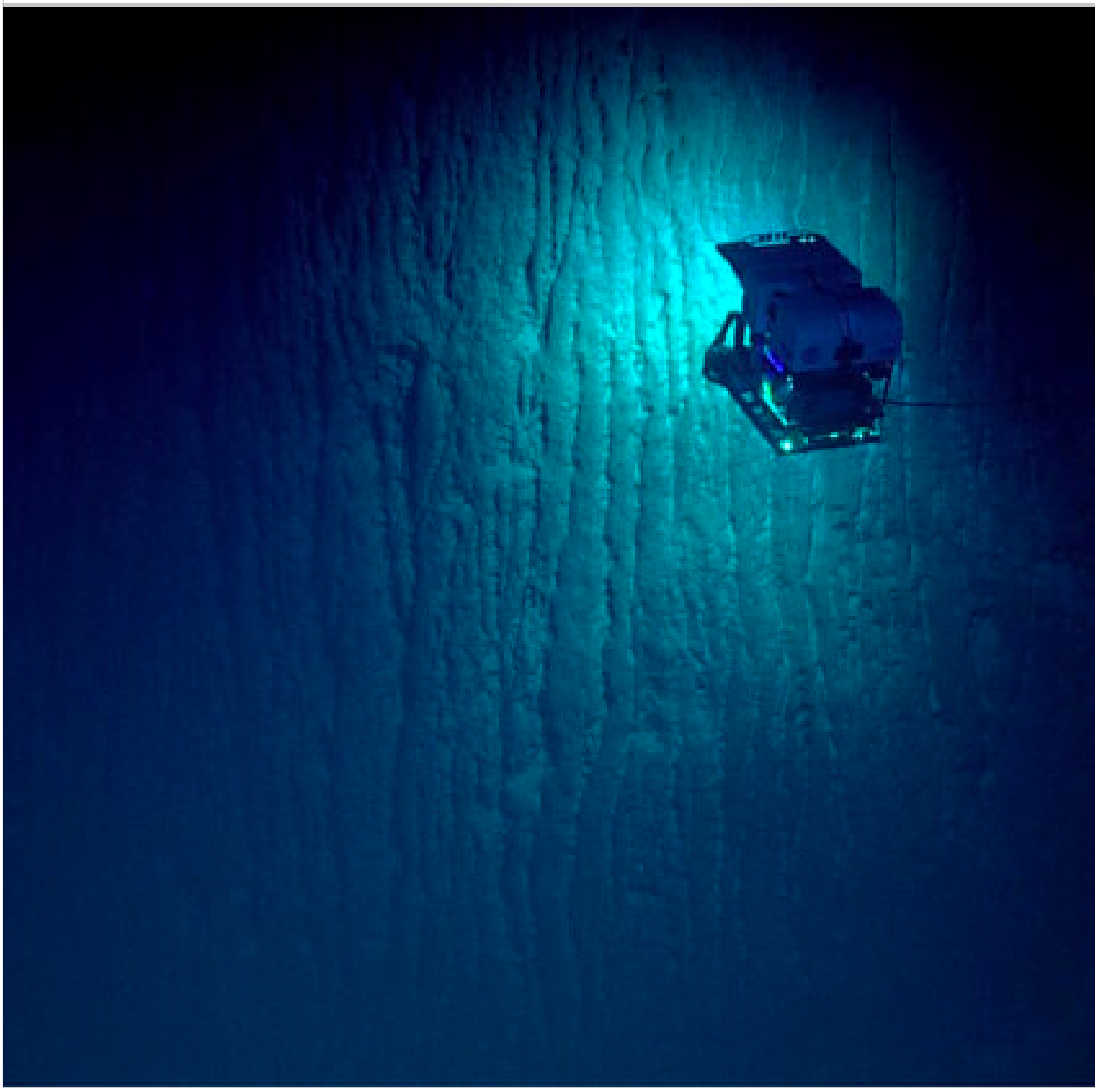
Some countries that are considering the exploitation of deep-sea minerals have structures in place for broad-based local stakeholder consultation. The Cook Islands' Seabed Minerals Act established the Seabed Minerals Authority's duty to hold public consultation in relation to licence applications. The public have the right to comment, and their comments must legally be considered, but the public do not have substantive rights to approve or reject a proposed project.[184, 185] The Cook Islands' Seabed Minerals Authority has an advisory committee of community leaders representing "religious, aronga mana [traditional tribal councils], environmental, private sector, sporting, youth and academic perspectives".[186]

The Norwegian government is preparing to conduct an environmental impact study to assess the potential impacts of deep-sea mineral exploitation. Public consultations will be held in 2022, prior to further consideration of deep-sea mineral exploitation by parliament, but no details are currently available about the nature and subjects of the consultations.[187]

New Zealand has scrutinized potential deep-sea mineral exploitation for many years, and this process has included extensive formal community consultation. Consultation requirements are laid out in the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012, with consultation taking place with a legally established Māori Advisory Committee, fishing industry groups, environmentalists, independent scientists and others.[188, 189] The government's deliberative process for proposed deep-sea mineral exploitation projects has so far rejected the three applications for exploitation licences that have been made since 2013. The most recent rejection came from a Supreme Court decision in October 2021, which ruled that the original regulatory decision to approve the application did not favour "caution and environmental protection". The ruling established the principal that any future applications must demonstrate that "material harm" can be avoided, mitigated or remediated.[190]

5 Conclusion

Significant knowledge, participation and consensus gaps impede sound decision-making for deep-sea mineral stewardship – their closure should be accelerated.



Unless the closure of knowledge and participation gaps is accelerated, manufacturers and markets will struggle to make judicious decisions on what role, if any, deep-sea minerals should play in their supply chains, in line with current timelines for deep-sea mineral production.

This paper has analysed the predictability of the scale of potential effects of deep-sea mineral exploitation, given the current levels of relevant knowledge. Important knowledge gaps were identified, and it was found that the potential effects that are currently the least predictable are the ones that most directly affect people and planet.

Real-world decision-making often takes place with imperfect knowledge. Uncertainty about the outcome of decisions underlines the importance of strong multistakeholder participation in decision-making processes. Groups that could be affected by decisions should have a say. The analysis conducted for this paper found that stakeholder participation in decision-making on deep-sea mineral stewardship also has significant gaps.

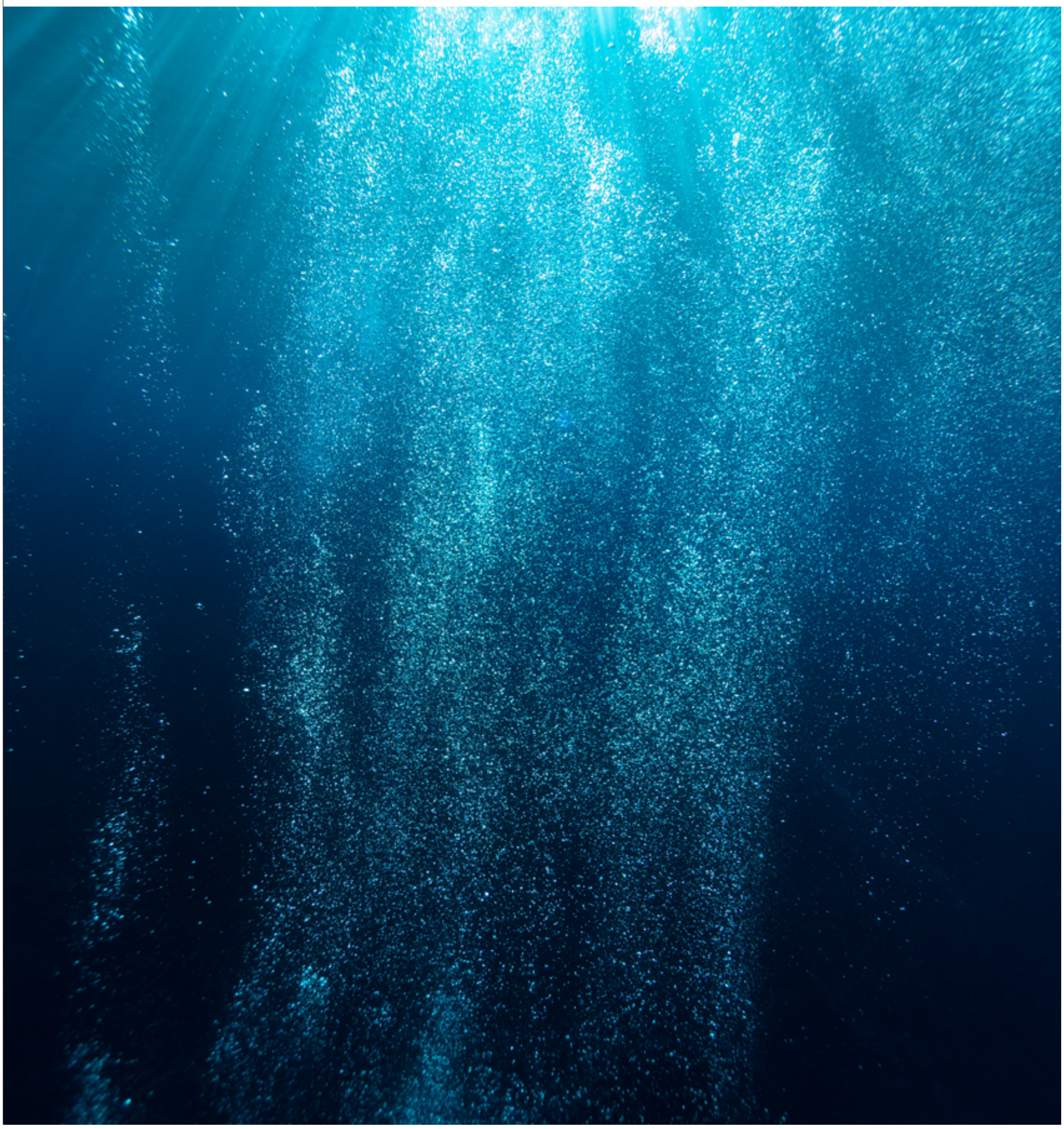
These gaps in knowledge and participation are significant for manufacturers and markets. Manufacturers are rightly expected to meet high and rising standards for responsible sourcing. At the same time, they need to secure supplies of critical raw materials for production. Unless the closure of knowledge and participation gaps is accelerated, manufacturers and markets will struggle to make judicious decisions on what role, if any, deep-sea minerals should play in their supply chains, in line with current timelines for deep-sea mineral production.

Manufacturers, markets and other organizations in the minerals supply chain can take concrete steps to help close the knowledge and participation gaps now, when it matters most: prior to regulatory decisions taking place on deep-sea mineral exploitation. Applying responsible sourcing principles to deep-sea minerals can ultimately support the pluralistic, evidence-based and consensus-based decision-making that is needed to ensure that the best interests of humankind and the planet are served.

6

Recommendations

Organizations throughout the metals supply chain should play a greater role in the stewardship of deep-sea minerals.



The recommendations of this paper are made exclusively to private-sector organizations in the metal value chain today and those in the potential deep-sea mineral supply chain.

Regulatory bodies in deep-sea mineral-containing jurisdictions, member states and Observers at ISA, civil-society groups and others have vital roles to play in the stewardship of deep-sea minerals. While insights could be drawn for each such organization from the findings of this paper, these organizations' existing stewardship roles, activities and processes have not been exhaustively analysed here. Without such analysis, any recommendations given could not be critically assessed for their potential to support pragmatic, positive change.

It is hoped that the findings of this paper will aid the ongoing efforts of other research bodies whose expertise allows them to build effective recommendations for the diverse organizations they study, scrutinize and support. The recommendations given below to these private-sector organizations should be viewed as one part of this overall whole.

6.1 Recommendations for manufacturers, markets and companies in the potential deep-sea minerals supply chain

In order to promote broadly participatory, consensus-based decision-making on deep-sea mineral stewardship that supports beneficial outcomes for people and planet, these companies should:

1. Collaborate to support public knowledge-sharing on the potential effects of deep-sea mineral exploitation. Facilitate broad collaboration among relevant experts, catalyze progress towards consensus on the scale of potential effects of deep-sea mineral exploitation, in particular their potential effects on stakeholder groups and societal goals, support closure of the related "key knowledge gaps" identified in Section 3, improve public understanding of the subject matter and support the formation of consensus viewpoints on knowledge sufficiency for decision-making. Practical implementation of this recommendation could include the commissioning of an online knowledge platform.

2. Collaborate to support organizations and groups whose participation can enhance decision-making on the stewardship of deep-sea minerals. These should include:

    a. Environmental science groups, mineral economists and other subject-matter experts, working to increase knowledge of the scale of potential effects of deep-sea mineral exploitation, in particular those related to the 18 key knowledge gaps identified in Section 3.

    b. Civil-society organizations that represent community stakeholders potentially affected by deep-sea mineral exploitation, including communities with traditional, cultural or indigenous links to the sea, fishing communities, communities dependent on coastal tourism and communities affected by land-based mining.

    c. Civil-society organizations that address global challenges, including conservation.

6.2 Additional recommendations for manufacturers and markets

To demonstrate leadership and take comprehensive responsibility for the environmental and social outcomes associated with their metal usage choices, including their effects on societal goals for decarbonization, the preservation of biodiversity, the transition to circularity and poverty reduction, manufacturers and markets should, in addition to the recommendations in Section 6.1:

1. Progressively strengthen corporate knowledge surrounding deep-sea minerals, including:

   a. The scales of the anticipated effects of exploitation and how these potential effects relate to manufacturers' and markets' environmental and social values and priorities.

   b. The roles, functions and mandates of relevant regulatory bodies and the evolving regulatory regimes in place for deep-sea mineral stewardship.

   c. The stakeholder landscape for deep-sea mineral stewardship and the expectations of key stakeholders.

2. Prioritize investment in accelerating the transition to circular business models, including transitioning from product consumption to service usage, prolonging product lifespan, reducing the dependence on non-renewable resources, transitioning product design and supply chains to reduce raw material dependence, and supporting circular economy initiatives.

3. Recognize the current unique and time-sensitive opportunity to engage constructively with the potential deep-sea mineral exploitation industry, before regulations have been set and commercial activities have commenced. Through timely engagement, manufacturers and markets can help to build consensus on responsible deep-sea mineral stewardship early on, setting a new precedent for responsibility in a manufacturing industry that has historically been largely reactive, engaging with supply chains only once avoidable damage to planet and people has already occurred.

4. Collectively, and with broad participation from potentially affected stakeholder groups, including those identified in Section 3, develop a set of environmental and social principles to be applied to the stewardship of deep-sea minerals that reflect the expectations, values and priorities of manufacturers and markets. These principles should cover, but not be limited to: requirements for scientific knowledge on the environmental effects of extraction; the importance of considering the cumulative environmental impacts of multiple exploitation projects; the rights of communities affected by exploitation; and the necessity of multistakeholder participation in decision-making. In addition, the principles should cover the contributions of potential exploitation projects to overarching societal goals, in line with the need for holistic decision-making on global mineral stewardship and the UNCLOS principle that exploitation activities in the international seabed area should serve the common benefit of humankind.

5. Through existing industry associations or a new purpose-made association, engage in dialogue on the development of regulations and guidance documents with national governments and the International Seabed Authority (ISA) to ensure they reflect the expectations, values and priorities of manufacturers and markets and their stakeholders, as articulated in the principles called for in Recommendation 4. Address stakeholder concerns with ISA and other regulators where they exist, including concerns about the robustness of regulations for environmental monitoring and protection, and regulatory provisions for public accountability and public participation in decision-making.

6. Communicate extensively with deep-sea mineral contractor companies to ensure they are familiar with manufacturers' and markets' expectations, values and priorities for decision-making on mineral stewardship, both in general for all forms of mineral supply and specifically for the potential supply of deep-sea minerals, as articulated in the set of principles called for in Recommendation 4.

7. When developing a due-diligence framework for the evaluation of supply-chain risks associated with deep-sea minerals:

   a. Do so collectively, and in collaboration with organizations that provide authoritative guidance on the conduct of supply-chain due diligence.

   b. Do so with broad participation from subject-matter experts, companies in deep-sea mineral supply chains, and civil-society organizations that represent potentially affected stakeholder groups, including those identified in Section 3 of this paper.

   c. Ensure the framework reflects the principles developed in Recommendation 4 and include: provisions for identifying deep-sea minerals in potential future supply chains and for mapping associated environmental and social risks; guidance on response measures when deep-sea minerals and associated risks are identified; a template for the public disclosure of steps undertaken.

6.3 Additional recommendations for deep-sea mineral contractor companies

To demonstrate leadership, as they aspire to develop a new industry that betters the environmental and social performance of past and present industries, contractors should, in addition to the recommendations in Section 6.1:

1. Openly and transparently share gathered environmental baseline and monitoring data analysis conducted on potential environmental impacts and the efficacy of mitigation measures and data on production costs and timelines, to contribute to the public knowledge resources described in Section 6.1.

2. Recognize the importance of manufacturers and markets as stakeholders in the responsible stewardship of deep-sea minerals and ensure these stakeholders' expectations are incorporated into planned exploitation activities. In particular, this includes expectations regarding knowledge-based decision-making and multistakeholder participation.

3. Engage with manufacturers and markets on the development of due-diligence frameworks for deep-sea minerals to ensure they match the realities of the deep-sea mining industry, and to ensure the environmental and social impact data gathered by companies (e.g. through environmental impact assessments) will align with the requirements of future standards.

4. Recognize the importance of regulatory frameworks and the necessary stakeholder process to develop them and commit not to apply for exploitation licences in the deep seabed until there are finalized regulatory frameworks in place.

5. Consult on the environmental and social aspects of planned mineral exploitation activities with a wide range of potentially affected global stakeholders, beyond the extent required by regulators. Conduct thorough, structured assessments of potential stakeholder impacts and prioritize consultation with those stakeholders likely to be most significantly affected. Commit to full responsiveness to stakeholder inputs through iterative dialogue and progressive improvement processes.

6. Commit to use their standing at ISA and with other governance bodies to advance broad multistakeholder participation in decision-making.

Glossary

Circular economy
The circular economy is a systems solution framework that tackles global challenges such as climate change, biodiversity loss, waste and pollution. The circular economy is based on the principles of eliminating waste, and circulating products and materials at their highest value, and for products and materials to be of a regenerative nature.[191]

Clarion-Clipperton Zone
The Clarion-Clipperton Zone, or CCZ, is an area of the ocean outside of national jurisdictions that spans 4.5 million square kilometres (1.7 million square miles) between Hawaii and Mexico. Its seabed is rich in polymetallic nodules.

Common heritage of humankind
The common heritage of humankind is a core concept in UNCLOS. In international law, it represents the notion that certain global commons or elements regarded as beneficial to humanity as a whole should not be unilaterally exploited by individual states or their nationals, nor by corporations or other entities, but rather should be exploited under some sort of international arrangement or regime for the benefit of humankind as a whole, including future generations.[192]

Contractors
In the context of this paper, contractors are private companies or national agencies sponsored by one or more states that apply to ISA for contracts to explore for deep-sea minerals.

International seabed area or 'the Area'
The international seabed area (also known as "the Area") is defined by the 1982 United Nations Convention on the Law of the Sea (UNCLOS) as the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction.

International Seabed Authority
The International Seabed Authority, or ISA, is an intergovernmental organization made up of 167 member states and the European Union. It is mandated by UNCLOS to organize, conduct and control all mineral-related activities in the Area.

Legal and Technical Commission of ISA
The Legal and Technical Commission (LTC) is entrusted with various functions relating to activities in the Area, including the review of applications for plans of work, supervision of exploration or mining activities (including review of annual reports submitted by contractors), development of environmental management plans, assessment of the environmental implications of activities in the Area, formulation and review of the rules, regulations and procedures for activities in the Area, and making recommendations to the Council on all matters relating to the exploration and exploitation of non-living marine resources (such as polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts).

Manufacturers and markets
In this paper, the phrase "manufacturers and markets" refers to manufacturers of finished goods, such as vehicles and electronic devices, manufacturers of component parts such as batteries and magnets, financial markets and metal exchanges.

Mineral stewardship
For the purposes of this paper, mineral stewardship is defined as the sound management of mineral resources for the greatest overall benefit to people and planet. Mineral stewardship can entail decisions to exploit mineral resources responsibly for the benefit of societies, while minimizing the negative environmental and social impacts. It can also entail decisions not to exploit mineral resources, leaving these resources intact for future generations while managing current mineral demand through alternative routes.

Paris Agreement
The Paris Agreement is a legally binding international treaty on climate change adopted in December 2015, which officially came into force in November 2016. Its goal is to limit global warming to "well below" 2°C.

Responsible sourcing
Responsible sourcing is the incorporation of ethical and sustainability principles into supply-chain management practices.

Sponsoring state
A sponsoring state is a country that sponsors contractors to apply for exploration contracts for deep-sea minerals at ISA (and exploitation contracts in future, upon finalization of the relevant regulations). A sponsoring state must be a "state party" to UNCLOS, as defined in the text of the convention, and is responsible for the contractor's activities. It has an obligation to ensure that the contractor conforms to ISA's rules and regulations.

Supply-chain due diligence
Supply-chain due diligence is an ongoing, proactive and reactive process through which companies can identify, assess and mitigate negative social and environmental impacts in their supply chains.[193]

UNCLOS
The United Nations Convention on the Law of the Sea (UNCLOS) is an international treaty that was adopted and signed in 1982. It establishes a legal framework for all marine and maritime activities.

Voluntary sustainability standard
Voluntary sustainability standards are standards that require supply-chain companies to fulfil specific social and environmental sustainability criteria. They are often assured through third-party assessment processes and are typically adopted by companies to manage reputational risks and maintain market share, by demonstrating corporate responsibility.

Annexe A:

A review of literature relevant to understanding the potential effects of deep-sea mineral exploitation

Author Author	Title	Journal/book	Year	Link/DOI
Agarwal et al.	Feasibility Study on Manganese Nodules Recovery in the Clarion-Clipperton Zone	The LRET Collegium 2012 Series: Seabed Exploitation	2012	https://eprints.soton.ac.uk/349889/
Aguon and Hunter	Second Wave Due Diligence: The Case for Incorporating Free, Prior, and Informed Consent into the Deep-Sea Mining Regulatory Regime	Stanford Environmental Law Journal 38	2018	https://law.stanford.edu/publications/sec-ond-wave-due-diligence-the-case-for-incor-porating-free-prior-and-informed-consent-in-to-the-deep-sea-mining-regulatory-regime/?fbclid=I-wAR1jp2wyt2Bkyxopluqv79gB1Ed5EFuKkeY1u8 7ZQEcWj94I5cYkwj0Y750
Aleynik et al.	Impact of Remotely Generated Eddies on Plume Dispersion at Abyssal Mining Sites in the Pacific	Scientific Reports 7	2017	https://www.nature.com/articles/s41598-017-16912-2
Alves Dias and Blagoeva	Cobalt: Demand-Supply Balances in the Transition to Electric Mobility	EC Joint Research Centre	2018	https://publications.jrc.ec.europa.eu/repository/bit-stream/JRC112285/jrc112285_cobalt.pdf
Amon et al.	Insights into the Abundance and Diversity of Abyssal Megafauna in a Polymetallic-Nodule Region in the Eastern Clarion-Clipperton Zone	Scientific Reports 6	2016	https://doi.org/10.1038/srep30492
Amon et al.	Megafauna of the UKSRL Exploration Contract Area and Eastern Clarion-Clipperton Zone in the Pacific Ocean: Annelida, Arthropoda, Bryozoa, Chordata, Ctenophora, Mollusca	Biodiversity Data Journal 5	2017	https://doi.org/10.3897/BDJ.5.e14598
Andrews et al.	The Economic Viability of a Four-Metal Pioneer Deep Ocean Mining Venture	NOAA Repository	1983	https://repository.library.noaa.gov/view/noaa/12287
Ardyna et al.	Hydrothermal Vents Trigger Massive Phytoplankton Blooms in the Southern Ocean	Nature Communications 10	2019	https://doi.org/10.1038/s41467-019-09973-6
Batker and Schmidt	Environmental and Social Benchmarking Analysis of the Nautilus Minerals Inc. Solwara 1 Project	Earth Economics	2015	https://mining.com/wp-content/uploads/2015/06/Earth-Economics-Environmental-Social-Benchmarking-Sol-wara-1-2015.pdf
Boetius and Haeckel	Mind the Seafloor	Science 359	2018	https://science.sciencemag.org/con-tent/359/6371/34.full
Bonifácio et al.	Alpha and Beta Diversity Patterns of Polychaete Assemblages Across the Nodule Province of the Eastern Clarion-Clipperton Fracture Zone (Equatorial Pacific)	Biogeosciences 17	2020	https://doi.org/10.5194/bg-17-865-2020
Boschen-Rose et al.	Assessing the Ecological Risk to Deep-Sea Megafaunal Assemblages from Seafloor Massive Sulfide Mining Using a Functional Traits Sensitivity Approach	Ocean and Coastal Management 210	2021	https://doi.org/10.101 6/j.ocecoaman.2021. 105656

Author Author	Title	Journal/book	Year	Link/DOI
Brown	Mining at 2,500 Fathoms Under the Sea: Thoughts on an Emerging Regulatory Framework	Ocean Science Journal 53	2018	https://doi.org/10.1007 /s12601-018-0033-z.
Buydens	The importance of Polymetallic Nodules for the Mega- and Meiofauna Benthos of the Clarion–Clipperton Fracture Zone	n/a	2019	n/a
Cameron et al.	The Economic Feasibility of Deep-Sea Mining	Engineering Costs and Production Economics 5	1981	https://ideas.repec.org/a/eee/ecpeco/v5y1981i3-4p279-287.html
Christodoulou et al.	Dark Ophiuroid Biodiversity in a Prospective Abyssal Mine Field	Current Biology 29	2019	https://www.sciencedirect.com/science/article/pii/S0960982219311728
Church and Crawford	Green Conflict Minerals: The Fuels of Conflict in the Transition to a Low-Carbon Economy	n/a	2018	https://sun-connect.org/green-conflict-minerals-the-fuels-of-conflict-in-the-transition-to-a-low-carbon-economy/
Clark and Neutra	Mining Manganese Nodules: Potential Economic and Environmental Effects	Resources Policy 9	1983	https://econpapers.repec.org/article/eeejrpoli/v_3a9_3ay_3a1983_3ai_3a2_3ap_3a99-109.htm
Clark et al.	The Impacts of Deep-Sea Fisheries on Benthic Communities: A Review	ICES Journal of Marine Science 73	2015	https://doi.org/10.1093/icesjms/fsv123
Collins et al.	A Primer for the Environmental Impact Assessment of Mining at Seafloor Massive Sulfide Deposits	Marine Policy 42	2013	https://doi.org/10.1016/j.marpol.2013.01.020
Conrad et al.	Formation of Fe-Mn Crusts Within a Continental Margin Environment	Ore Geology Reviews 87	2016	https://www.sciencedirect.com/science/article/abs/pii/S0169136816301834
Copley et al.	Ecology and Biogeography of Megafauna and Macrofauna at the First Known Deep-Sea Hydrothermal Vents on the Ultraslow-Spreading Southwest Indian Ridge	Scientific Reports 6	2016	https://www.nature.com/articles/srep39158
Cuvelier et al.	Are Seamounts Refuge Areas for Fauna from Polymetallic Nodule Fields?	Biogeosciences 17	2020	https://bg.copernicus.org/articles/17/2657/2020/
De Groot et al.	Global Estimates of the Value of Ecosystems and Their Services in Monetary Units	Ecosystem Services 1	2012	https://doi.org/10.1016/j.ecoser.2012.07.005
De Smet et al.	The Community Structure of Deep-Sea Macrofauna Associated with Polymetallic Nodules in the Eastern Part of the Clarion-Clipperton Fracture Zone	Frontiers in Marine Science 4	2017	https://doi.org/10.3389/fmars.2017.00103
Dick	Tiefseebergbau Versus Landbergbau: Metallproduktion aus Manganknollen und Nickellateriterzen im Wirtschaftlichkeitsvergleich	Kiel Institute of World Economics	1981	http://hdl.handle.net/10419/46834
Dominish et al.	Responsible Minerals Sourcing for Renewable Energy	n/a	2019	https://www.earthworks.org/cms/assets/uploads/2019/04/MCEC_UTS_Report_lowres-1.pdf
Drazen et al.	Report of the Workshop Evaluating the Nature of Midwater Mining Plumes and Their Potential Effects on Midwater Ecosystems	Research Ideas and Outcomes 5	2019	https://nsuworks.nova.edu/cgi/view content.cgi?article=2070&context=occ_facarticles

Author Author	Title	Journal/book	Year	Link/DOI
Drazen et al.	Opinion: Midwater Ecosystems Must Be Considered When Evaluating Environmental Risks of Deep-Sea Mining	PNAS 117	2020	https://doi.org/10.1073/pnas.2011914117
Dreschler	Exploitation of the Sea: A Preliminary Cost-Benefit Analysis of Nodule Mining and Processing	Maritime Studies and Management 1	1973	https://doi.org/10.1080/03088837300000007
Du Preez and Fisher	Long-term Stability of Back-Arc Basin Hydrothermal Vents	Frontiers in Marine Science	2018	https://doi.org/10.3389/fmars.2018.00054
Dunn et al.	A Strategy for the Conservation of Biodiversity on Mid-Ocean Ridges from Deep-Sea Mining	Science Advances 4	2018	https://advances.sciencemag.org/content/4/7/eaar4313?utm_source=sciencemagazine&utm_medium=twitter&utm_campaign=6397toc-20278
Durden et al.	A Procedural Framework for Robust Environmental Management of Deep-Sea Mining Projects Using a Conceptual Model	Marine Policy 84	2017	https://doi.org/10.1016/j.marpol.2017.07.002
Durden et al.	Environmental Impact Assessment Process For Deep-Sea Mining in "the Area"	Marine Policy 87	2018	https://www.sciencedirect.com/science/article/pii/S0308597X17305316
Ecorys	Study to Investigate State of Knowledge of Deep-Sea Mining	European Commission – DG Maritime Affairs and Fisheries	2014	https://webgate.ec.europa.eu/maritimeforum/sites/default/files/FGP96656%20DSM%20Interim%20report%20280314.pdf
Gausepohl et al.	Scars in the Abyss: Reconstructing Sequence, Location and Temporal Change of the 78 Plough Tracks of the 1989 DISCOL Deep-Sea Disturbance Experiment in the Peru Basin	Biogeosciences 17	2020	https://bg.copernicus.org/articles/17/1463/2020/bg-17-1463-2020-discussion.html
Gillard et al.	Physical and Hydrodynamic Properties of Deep-Sea Mining-Generated, Abyssal Sediment Plumes in the Clarion Clipperton Fracture Zone (Eastern-Central Pacific)	Elementa: Science of the Anthropocene 7	2019	https://online.ucpress.edu/elementa/article/doi/10.1525/elementa.343/112485/Physical-and-hydrodynamic-properties-of-deep-sea
Gollner et al.	Resilience of Benthic Deep-Sea Fauna to Mining Activities	Marine Environmental Research 129	2017	https://doi.org/10.1016/j.marenvres.2017.04.010
Gooday et al.	Abyssal Foraminifera Attached to Polymetallic Nodules from the Eastern Clarion Clipperton Fracture Zone: A Preliminary Description and Comparison with North Atlantic Dropstone Assemblages	Marine Biodiversity 45	2015	https://link.springer.com/article/10.1007/s12526-014-0301-9
Gooday et al.	Giant Protists (Xenophyophores, Foraminifera) Are Exceptionally Diverse in Parts of the Abyssal Eastern Pacific Licensed for Polymetallic Nodule Exploration	Biological Conservation 207	2017	https://doi.org/10.1016/j.biocon.2017.01.006
Gooday et al.	The Biodiversity and Distribution of Abyssal Benthic Foraminifera and Their Possible Ecological Roles: A Synthesis Across the Clarion-Clipperton Zone	Frontiers in Marine Science	2021	https://www.proquest.com/openview/3c403c316bd72e987a2149043e105531/1?pq-origsite=gscholar&cbl=2049538
Haffert et al.	Assessing the Temporal Scale of Deep-Sea Mining Impacts on Sediment Biogeochemistry	Biogeosciences 17	2020	https://bg.copernicus.org/articles/17/2767/2020/

Author Author	Title	Journal/book	Year	Link/DOI
Haugan and Levin	What Role for Ocean-Based Renewable Energy and Deep-Seabed Minerals in a Sustainable Future?	n/a	2020	https://oceanpanel.org/sites/default/files/2020-10/Ocean%20Energy%20and%20Deep-Sea%20Minerals%20Full%20Paper.pdf
Hauton et al.	Identifying Toxic Impacts of Metals Potentially Released During Deep-Sea Mining – a Synthesis of the Challenges to Quantifying Risk	Frontiers in Marine Science	2017	https://www.frontiersin.org/articles/10.3389/fmars.2017.00368/full
Hein and Koschinsky	Deep-Ocean Ferromanganese Crustsand Nodules.	Treatise on Geochemistry 13	2014	https://doi.org/10.1016/B978-0-08-095975-7.01111-6
Hein et al.	Deep-Ocean Mineral Deposits as a Source of Critical Metals for High- and Green-Technology Applications: Comparison with Land-Based Resources	Ore Geology Reviews 51	2013	https://www.sciencedirect.com/science/article/abs/pii/S016913681200234X
Heinrich et al.	Quantifying the Fuel Consumption, Greenhouse Gas Emissions and Air Pollution of a Potential Commercial Manganese Nodule Mining Operation	Marine Policy 114	2019	10.1016/j.marpol.2019.103678
Herrouin et al.	A Manganese Nodule Industrial Venture Would Be Profitable: Summary of Four-Year Study in France	Offshore Technology Conference	1989	https://doi.org/10.4043/5997-MS
Hillman (US Department of the Interior, Bureau of Mines)	Manganese Nodule Resources of Three Areas in the Northeast Pacific Ocean, with Proposed Mining-Beneficiation Systems and Costs: A Minerals Availability System Appraisal	n/a	1983	https://archive.org/details/manganesenoduler00hill
ISA Legal and Technical Commission	Report on the International Seabed Authority's Workshop on Polymetallic Nodule Mining Technology: Current Status and Challenges Ahead	n/a	2008	https://isa.org.jm/files/files/documents/isba-14ltc-3_1.pdf
ISA 2020: Deep CCZ Biodiversity Synthesis Workshop, Friday Harbor, Washington, USA	Workshop Report	n/a	2019	https://www.isa.org.jm/files/files/documents/Deep%20CCZ%20Biodiversity%20Synthesis%20Workshop%20Report%20-%20Final-for%20posting-clean-1.pdf
Jaeckel	Deep Seabed Mining and Adaptive Management: The Procedural Challenges for the International Seabed Authority	Marine Policy 70	2016	https://www.sciencedirect.com/science/article/abs/pii/S0308597X16300756
Jones et al.	Biological Responses to Disturbance from Simulated Deep-Sea Polymetallic Nodule Mining	PLOS ONE	2017	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0171750
Jones et al.	Mining Deep-Ocean Mineral Deposits: What Are the Ecological Risks?	Elements 14	2018	https://pubs.geoscienceworld.org/msa/elements/article-abstract/14/5/325/559104/Mining-Deep-Ocean-Mineral-Deposits-What-are-the
Jones et al.	Environment, Ecology and Potential Effectiveness of an Area Protected from Deep-Sea Mining (Clarion Clipperton Zone, Abyssal Pacific)	Progress in Oceanography 197	2021	https://doi.org/10.1016/j.pocean.2021.102653

Author Author	Title	Journal/book	Year	Link/DOI
Kaikkonen et al.	Assessing the Impacts of Seabed Mineral Extraction in the Deep Sea And Coastal Marine Environments: Current Methods and Recommendations for Environmental Risk Assessment	Marine Pollution Bulletin 135	2018	https://doi.org/10.1016/j.marpolbul.2018.08.055
Kaiser et al.	Editorial: Biodiversity of the Clarion Clipperton Fracture Zone	Marine Biodiversity 47	2017	https://link.springer.com/article/10.1007/s12526-017-0733-0
Kirchain and Roth	MIT Presentation: Decision Analysis Framework and Review of Cash Flow Approach	n/a	2019	https://isa.org.jm/files/files/documents/dec-analysis_0.pdf
Kuhn and Rühlemann	Exploration of Polymetallic Nodules and Resource Assessment: A Case Study from the German Contract Area in the Clarion-Clipperton Zone of the Tropical Northeast Pacific	Minerals 11	2021	https://www.mdpi.com/2075-163X/11/6/618
Kuhn et al.	Tiefseeförderung von Manganknollen	Offshore and Merestechnik	2011	https://www.nrwinvest.com/fileadmin/mapdata/gaib/Images/expic/5592b2653a0bc0c68c0d2af6a4d-26cd4_54379702_schiffhafen_meeresbergbau.pdf
Kung et al.	Governing Deep-sea Mining in the Face of Uncertainty	Journal of Environmental Management 279	2021	https://doi.org/10.1016/j.jenvman.2020.111593
Krutilla et al. (The World Bank)	Implementing Precaution in Benefit-Cost Analysis: The Case of Deep Seabed Mining	n/a	2020	https://openknowledge.worldbank.org/handle/10986/34022
Laffoley et al.	Eight Urgent Fundamental and Simultaneous Steps Needed to Restore Ocean Health, and the Consequences for Humanity and the Planet of Inaction or Delay	International Programme of the State of the Ocean	2019	http://www.stateoftheocean.org/wp-content/uploads/2019/07/IPSO-2019-Report-Final_web-PDF.pdf
Le et al.	Incorporating Ecosystem Services into Environmental Management of Deep-Seabed Mining	Advances in Deep-Sea Biology: Biodiversity, Ecosystem Functioning and Conservation 137	2017	https://doi.org/10.1016/j.dsr2.2016.08.007
Lèbre et al.	The Social and Environmental Complexities of Extracting Energy Transition Metals	Nature Communications 11	2020	https://www.nature.com/articles/s41467-020-18661-9
Levin et al.	Defining "Serious Harm" to the Marine Environment in the Context of Deep-Seabed Mining	Marine Policy 74	2016	https://www.sciencedirect.com/science/article/pii/S0308597X1630495X
Levin et al.	Climate Change Considerations Are Fundamental to Management of Deep-Sea Resource Extraction	Global Change Biology	2020	https://doi.org/10.1111/gcb.15223
Lily and Roady	Regulating the Common Heritage of Mankind: Challenges in Developing a Mining Code for the Area	Global Challenges and the Law of the Sea	2020	https://link.springer.com/chapter/10.1007/978-3-030-42671-2_18
Lin et al.	Using Soundscapes to Assess Deep-Sea Benthic Ecosystems	Trends in Ecology and Evolution 34	2019	https://doi.org/10.1016/j.tree.2019.09.006
Lodge and Verlaan	Deep-Sea Mining: International Regulatory Challenges and Responses	Elements 14	2018	https://doi.org/10.2138/gselements.14.5.331.
Macheriotou et al.	Phylogenetic Clustering and Rarity Imply Risk of Local Species Extinction in Prospective Deep-Sea Mining Areas of the Clarion–Clipperton Fracture Zone	Proceedings of the Royal Society B	2020	https://royalsocietypublishing.org/doi/10.1098/rspb.2019.2666

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Marques and Araújo	Survey and Assessment of Seabed Resources from the Brazilian Continental Shelf by the Law of the Sea: From National to International Jurisdictions	Ocean and Coastal Management 178	2019	https://www.sciencedirect.com/science/article/abs/pii/S0964569119300250
Martino and Parson	A Comparison between Manganese Nodules and Cobalt Crust Economics in a Scenario of Mutual Exclusivity	Marine Policy 36	2012	https://doi.org/10.1016/j.marpol.2011.11.008
McQuaid et al.	Using Habitat Classification to Assess Representativity of a Protected Area Network in a Large, Data-Poor Area Targeted for Deep-Sea Mining	Frontiers in Marine Science	2020	https://internal-journal.frontiersin.org/articles/10.3389/fmars.2020.558860/full
Meiser and Muller	Manganese Nodules: A Further Resource to Meet Mineral Requirements?	n/a	1973	https://www.govinfo.gov/content/pkg/CZIC-tn291-5-u48-1974/html/CZIC-tn291-5-u48-1974.htm
Mengerink et al.	A Call for Deep-Ocean Stewardship	Science 344	2014	https://science.sciencemag.org/content/344/6185/696.summary
Menini et al.	An Atlas of Protected Hydrothermal Vents	Marine Policy 108	2019	https://www.sciencedirect.com/science/article/pii/S0308597X18309394
Mero	Geochemistry and Descriptions of Manganese Nodules and Crusts Retrieved from the Open Ocean	Pangaea	1965	https://doi.org/10.1594/PANGAEA.864089
MIDAS	Managing Impacts of Deep Sea Resource Exploitation: Research Highlights	n/a	2016	http://www.eu-midas.net/sites/default/files/downloads/MIDAS_research_highlights_low_res.pdf
Miljutin et al.	Deep-Sea Nematode Assemblage Has Not Recovered 26 Years After Experimental Mining of Polymetallic Nodules (Clarion-Clipperton Fracture Zone, Tropical Eastern Pacific)	Deep Sea Research Part I: Oceanographic Research Papers 58	2011	https://www.sciencedirect.com/science/article/pii/S0967063711001063
Miller et al.	An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts and Knowledge Gaps	Frontiers in Marine Science	2018	https://doi.org/10.3389/fmars.2017.00418
Morgan et al.	Benthic Megafaunal Community Structure of Cobalt-Rich Manganese Crusts on Necker Ridge	Deep Sea Research Part I: Oceanographic Research Papers 104	2015	https://doi.org/10.1016/j.dsr.2015.07.003
Mudd	The Limits to Growth and “Finite” Mineral Resources: Re-visiting the Assumptions and Drinking from that Half-Capacity Glass	International Journal of Sustainable Development 16	2013	doi:10.1504/IJSD.2013.056562
Mudd	Sustainable/Responsible Mining and Ethical Issues Related to the Sustainable Development Goals	Geological Society	2020	https://doi.org/10.1144/SP508-2020-113
Mudd et al.	Quantifying the Recoverable Resources of By-Product Metals: The Case of Cobalt	Ore Geology Reviews 55	2013	http://dx.doi.org/10.1016/j.oregeorev.2013.04.010
Mudd et al.	Mining in Papua New Guinea: A Complex Story of Trends, Impacts and Governance	Science of the Total Environment 741	2020	https://doi.org/10.1016/j.scitotenv.2020.140375
Mudd and Jowitt	A Detailed Assessment of Global Nickel Resource Trends and Endowments	Economic Geology 109	2014	https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/109/7/1813/128637/A-Detailed-Assessment-of-Global-Nickel-Resource

Author Author	Title	Journal/book	Year	Link/DOI
Mudd and Jowitt	Growing Global Copper Resources, Reserves and Production: Discovery Is Not the Only Control on Supply	Economic Geology 113	2018	https://pubs.geoscienceworld.org/segweb/economicgeology/article-pdf/113/6/1235/4530335/1235-1267.pdf
Mudd and Jowitt	Global Resource Assessments of Primary Metals: An Optimistic Reality Check	Natural Resources Research 27	2018	https://link.springer.com/article/10.1007/s11053-017-9349-0
Mudd et al.	The World's By-Product and Critical Metal Resources Part I: Uncertainties, Current Reporting Practices, Implications and Grounds for Optimism	Ore Geology Reviews 86	2016	https://doi.org/10.1016/j.oregeorev.2016.05.001
Mudd et al.	The world's Lead-Zinc Mineral Resources: Scarcity, Data, Issues and Opportunities	Ore Geology Reviews 80	2016	http://dx.doi.org/10.1016/j.oregeorev.2016.08.010
Mullins	The Fiscal Regime for Deep Sea Mining in the Pacific Region	Marine Policy 95	2016	https://www.sciencedirect.com/science/article/abs/pii/S0308597X16304808
Munoz Royo	Impact Extent of Deep-Sea Nodule Mining Midwater Plumes Is Influenced by Sediment Loading, Ocean Turbulence and Environmental Thresholds	n/a	to appear	n/a
Niner et al.	Deep-Sea Mining with No Net Loss of Biodiversity – an Impossible Aim	Frontiers in Marine Science	2018	https://www.frontiersin.org/articles/10.3389/fmars.2018.00053/full
Nyhart and Triantafillou	A Pioneer Deep Ocean Mining Venture	n/a	1984	https://trid.trb.org/view/420837
Nyhart et al.	A Cost Model of Deep Ocean Mining and Associated Regulatory Issues	n/a	1978	https://nsgl.gso.uri.edu/mit/mitt78001.pdf
Ouillon et al.	Dynamics of Continuously Released Gravity Currents from a Moving Source	n/a	2020	https://ui.adsabs.harvard.edu/abs/2020APS..DFD-DU05003O/abstract
Ouillon et al.	Gravity Currents from Moving Sources	n/a	to appear	n/a
Pape et al.	Limited Spatial and Temporal Variability in Meiofauna and Nematode Communities at Distant but Environmentally Similar Sites in an Area of Interest for Deep-Sea Mining	Frontiers in Marine Science	2015	https://doi.org/10.3389/fmars.2017.00205
Pasotti et al.	A Local Scale Analysis of Manganese Nodules Influence on the Clarion-Clipperton Fracture Zone Macrobenthos	Deep Sea Research Part I: Oceanographic Research Papers 168	2021	https://doi.org/10.1016/j.dsr.2020.103449
Paul et al.	Biogeochemical Regeneration of A Nodule Mining Disturbance Site: Trace Metals, Doc and Amino Acids in Deep-Sea Sediments and Pore Waters	Frontiers in Marine Science	2018	https://doi.org/10.3389/fmars.2018.00117
Paulikas et al.	Where Should Metals for the Green Transition Come From? Comparing Environmental, Social, and Economic Impacts of Supplying Base Metals from Land Ores and Seafloor Polymetallic Nodules	n/a	2020	http://www.fullertreacymoney.com/system/data/files/PDFs/2020/May/22nd/LCA-White-Paper_Where-Should-Metals-for-the-Green-Transition-Come-From.pdf f
Peacock and Ouillon	Deep-Sea Mining	n/a	to appear	n/a

Author Author	Title	Journal/book	Year	Link/DOI
Perks and Mudd	Soft Rocks, Hard Rocks: The World's Resources and Reserves of Ti and Zr and Associated Critical Minerals	International Geology Review	2021	https://doi.org/10.1080/00206814.2021.1904294
Petersen et al.	News from the Seabed – Geological Characteristics and Resource Potential of Deep-Sea Mineral Resources	Marine Policy	2016	https://www.sciencedirect.com/science/article/abs/pii/S0308597X16300732
Petterson and Tawake	The Cook Islands (South Pacific) Experience in Governance of Seabed Manganese Nodule Mining	Ocean and Coastal Management 167	2018	https://www.sprep.org/attachments/VirLib/Cook-Islands/experience-governance-seabed-manga-nese-nodule-mining.pdf
Popova et al.	Ecological Connectivity between the Areas Beyond National Jurisdiction and Coastal Waters: Safeguarding Interests of Coastal Communities in Developing Countries	Marine Policy 104	2019	https://www.sciencedirect.com/science/article/pii/S0308597X19300764
Ramboll	Analyse des Volkswirtschaftlichen Nutzens der Entwicklung Eines Kommerziellen Tiefseebergbaus in den Gebieten, in Denen Deutschland Explorationslizenzen der Internationalen Meeresbodenbehörde Besitzt, Sowie Auflistung und Bewertung von Umsetzungsoptionen mit Schwerpunkt Durchführung Eines Pilot-Mining-Tests	n/a	2016	https://www.bmwi.de/Redaktion/DE/Publika-tionen/Studien/analyse-des-volkswirtschaftli-chen-nutzens-der-entwicklung-eines-kommerziel-len-tiefseebergbaus.pdf?__blob=publicationFile&v=6
Rothstein and Kaufman	The Approaching Maturity of Deep Ocean-Mining. The Pace Quickens	n/a	1973	https://eurekamag.com/re-search/020/224/020224770.php
Sharma	Deep-Sea Mining: Economic, Technical, Technological, and Environmental Considerations for Sustainable Development	Marine Technology Society Journal 45	2011	https://doi.org/10.4031/MTSJ.45.5.2
Sharma	Environmental Issues of Deep-Sea Mining	Procedia Earth and Planetary Science 11	2015	https://www.sciencedirect.com/science/article/pii/S1878522015000776
Simon-Lledó et al.	Biological Effects 26 Years After Simulated Deep-Sea Mining	Scientific Reports 9	2019	https://www.nature.com/articles/s41598-019-44492-w
Simon-Lledó et al.	Megafaunal Variation in the Abyssal Landscape of the Clarion Clipperton Zone	Progress in Oceanography	2019	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6325340/
Singh	The Two-Year Deadline to Complete the International Seabed Authority's Mining Code: Key Outstanding Matters that Still Need to be Resolved	Marine Policy 134	2021	https://www.sciencedirect.com/science/article/abs/pii/S0308597X21004152
Singh and Pouponneau	Comments to the Draft Regulations on Exploitation of Mineral Resources in the Area: Transboundary Harm and the Rights of Coastal States Adjacent to the Area	n/a	2018	https://www.isa.org.jm/files/documents/EN/Regs/2018/Comments/PS-AP.pdf
Sommerfeld et al.	"Zero-Waste": A Sustainable Approach on Pyrometallurgical Processing of Manganese Nodule Slags	Minerals 8	2018	https://doi.org/10.3390/min8120544

Author Author	Title	Journal/book	Year	Link/DOI
Søreide et al.	Deep Ocean Mining Reconsidered – a Study of Manganese Nodule Deposits in Cook Islands	n/a	2003	https://www.researchgate.net/publication/286988541_Deep_Ocean_Mining_Reconsidered_a_Study_of_the_Manganese_Nodule_Deposits_in_Cook_Island
SPC (Secretariat of the Pacific Community)	Deep-Sea Minerals: Deep-Sea Minerals and the Green Economy	n/a	2013	https://dsm.gsd.spc.int/public/files/meetings/TrainingWorkshop4/UNEP_vol2.pdf
SPC (Secretariat of the Pacific Community) and Cardno	An Assessment of the Costs and Benefits of Mining Deep-Sea Minerals in the Pacific Island Region	n/a	2016	https://www.sprep.org/attachments/VirLib/Regional/deep-sea-mining-cba-PICs-2016.pdf
Sweetman et al.	Key Role of Bacteria in the Short-Term Cycling of Carbon at the Abyssal Seafloor in a Low Particulate Organic Carbon Flux Region of the Eastern Pacific Ocean	Limnology and Oceanography 64	2019	https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lno.11069
Taboada et al.	Implications of Population Connectivity Studies for the Design of Marine Protected Areas in the Deep Sea: An Example of a Demosponge from the Clarion-Clipperton Zone	Molecular Ecology 27	2018	https://doi.org/10.1111/mec.14888
Thompson et al.	Seabed Mining and Approaches to Governance of the Deep Seabed	Frontiers in Marine Science	2018	https://www.frontiersin.org/articles/10.3389/fmars.2018.00480/full
Tilot et al.	Traditional Dimensions of Seabed Resource Management in the Context of Deep Sea Mining in the Pacific: Learning from the Socio-Ecological Interconnectivity between Island Communities and the Ocean Realm	Frontiers in Marine Science	2021	https://doi.org/10.3389/fmars.2021.637938
Torres et al.	A Looming Tragedy of the Sand Commons	Science 357	2017	https://www.science.org/doi/10.1126/science.aao0503
Trottman (UN: Office for Ocean Affairs and Law of the Sea)	Selection of Sites for Seabed Manganese Nodule Processing Plants	n/a	1989	https://digitallibrary.un.org/record/488271?ln=fr
Tunnicliffe et al.	Strategic Environmental Goals and Objectives: Setting the Basis for Environmental Regulation of Deep Seabed Mining	Marine Policy 114	2018	https://doi.org/10.1016/j.marpol.2018.11.010
Uhlenkot et al.	Predicting Meiofauna Abundance to Define Preservation and Impact Zones in a Deep-Sea Mining Context Using Random Forest Modelling	Journal of Applied Ecology 57	2020	https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.13621
Van der Voet et al.	Environmental Implications of Future Demand Scenarios for Metals: Methodology and Application to the Case of Seven Major Metals	Journal of Industrial Ecology 23	2019	https://onlinelibrary.wiley.com/doi/10.1111/jiec.12722
Van Dover	Impacts of Anthropogenic Disturbances at Deep-Sea Hydrothermal Vent Ecosystems: A Review	Marine Environmental Research 102	2014	https://www.sciencedirect.com/science/article/pii/S0141113614000506

Author Author	Title	Journal/book	Year	Link/DOI
Van Dover	Inactive Sulfide Ecosystems in the Deep Sea: A Review	Frontiers in Marine Science	2019	https://www.frontiersin.org/articles/10.3389/fmars.2019.00461/full
Van Dover	Research Is Needed to Inform Environmental Management of Hydrothermally Inactive and Extinct Polymetallic Sulfide (PMS) Deposits	Marine Policy 121	2020	https://www.sciencedirect.com/science/article/pii/S0308597X20302943
Van Dover et al.	Ecological Restoration in the Deep Sea: Desiderata	Marine Policy 44	2014	https://www.sciencedirect.com/science/article/pii/S0308597X13001486
Van Dover et al.	Scientific Rationale and International Obligations for Protection of Active Hydrothermal Vent Ecosystems from Deep-Sea Mining	Marine Policy	2017	https://www.sciencedirect.com/science/article/pii/S0308597X17306061 .
Van Dover et al.	Biodiversity Loss from Deep-Sea Mining	Nature Geoscience 10	2018	https://www.nature.com/articles/ngeo2983.
Van Nijen et al.	A Stochastic Techno-Economic Assessment of Seabed Mining of Polymetallic Nodules in the Clarion Clipperton Fracture Zone	Marine Policy 95	2018	https://www.sciencedirect.com/science/article/pii/S0308597X1730903X
Vanreusel et al.	Threatened by Mining, Polymetallic Nodules Are Required to Preserve Abyssal Epifauna	Scientific Reports 6	2016	https://www.nature.com/articles/srep26808/
Vare et al.	Scientific Considerations for the Assessment and Management of Mine Tailings Disposal in the Deep Sea	Frontiers in Marine Science	2018	https://www.frontiersin.org/articles/10.3389/fmars.2018.00017/full
Volkmann et al.	A Comprehensive Approach for a Techno-Economic Assessment of Nodule Mining in the Deep Sea	Mineral Economics 31	2018	https://link.springer.com/article/10.1007/s13563-018-0143-1
Volz et al.	Natural Spatial Variability of Depositional Conditions, Biogeochemical Processes and Element Fluxes in Sediments of the Eastern Clarion-Clipperton Zone, Pacific Ocean	Deep-Sea Research I	2018	https://doi.org/10.1016/j.dsr.2018.08.006
Volz et al.	Impact of Small-Scale Disturbances on Geochemical Conditions, Biogeochemical Processes and Element Fluxes in Surface Sediments of the Eastern Clarion–Clipperton Zone, Pacific Ocean	Biosciences 17	2020	https://bg.copernicus.org/articles/17/1113/2020/
Vonnahme et al.	Effects of a Deep-Sea Mining Experiment on Seafloor Microbial Communities and Functions After 26 Years	Science Advances 6	2020	https://www.science.org/doi/10.1126/sciadv.aaz5922
Wakefield and Myers	Social Cost Benefit Analysis for Deep-Sea Minerals Mining	Marine Policy 95	2018	https://doi.org/10.1016/j.marpol.2016.06.018.
Washburn et al.	Ecological Risk Assessment for Deep-Sea Mining	Ocean and Coastal Management 176	2019	https://www.sciencedirect.com/science/article/pii/S096456911830838X
Washburn et al.	Environmental Heterogeneity Throughout the Clarion-Clipperton Zone and the Potential Representativity of the Apei Network	Frontiers in Marine Science	2021	https://www.frontiersin.org/articles/10.3389/fmars.2021.661685/full

Author Author	Title	Journal/book	Year	Link/DOI
Wear et al.	Bacterial and Archaeal Communities in Polymetallic Nodules, Sediments, and Bottom Waters of the Abyssal Clarion-Clipperton Zone: Emerging Patterns and Future Monitoring Considerations	Frontiers in Marine Science	2021	https://www.frontiersin.org/articles/10.3389/fmars.2021.634803/full?utm_source=S-TWT&utm_medium=SNET&utm_campaign=ECO_FMARS_XXXXXXXX_auto-dlvrit
Wedding et al.	From Principles to Practice: A Spatial Approach to Systematic Conservation Planning in the Deep Sea	Proceedings of the Royal Society B: Biological Sciences	2013	https://doi.org/10.1098/rspb.2013.1684.
Weng et al.	A Detailed Assessment of Global Rare Earth Element Resources: Opportunities and Challenges	Society of Economic Geologists	2015	https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/110/8/1925/128792/A-Detailed-Assessment-of-Global-Rare-Earth-Element
Willaert	Public Participation in the Context of Deep-Sea Mining: Luxury or Legal Obligation?	Ocean and Coastal Management 198	2020	https://www.sciencedirect.com/science/article/abs/pii/S0964569120302763
Wright and Lloyd	Ocean Mining: An Economic Evaluation	n/a	1976	n/a
Zeppilli	Seafloor Heterogeneity Influences the Biodiversity–Ecosystem Functioning Relationships in the Deep Sea	Scientific Reports 6	2016	https://www.nature.com/articles/srep26352

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Endnotes

1. London Metal Exchange, *Responsible Sourcing*: https://www.lme.com/en/Company/Responsibility/Responsible-sourcing.
2. World Economic Forum, *The Global Risks Report 2022*: https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf.
3. United Nations, *Paris Agreement*, 2015: https://unfccc.int/sites/default/files/english_paris_agreement.pdf.
4. European Commission, *A European Green Deal*: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.
5. United Nations Department of Economic and Social Affairs, *UN SDG 15*: https://sdgs.un.org/goals/goal15.
6. United Nations Environment Programme, *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*, 2011: https://wedocs.unep.org/handle/20.500.11822/9816.
7. United Nations Department of Economic and Social Affairs, *The 17 Goals*: https://sdgs.un.org/goals.
8. UN News, "'Tremendously Off Track' to Meet 2030 SDGs: UN Chief", 12 July 2021: https://news.un.org/en/story/2021/07/1095722.
9. IPBES, *Global Assessment Report on Biodiversity and Ecosystem Services*: https://ipbes.net/global-assessment.
10. World Economic Forum, IRC and PACE, *The Next Frontier: Natural Resource Targets – Shaping a Competitive Circular Economy within Planetary Boundaries*: http://www3.weforum.org/docs/WEF_The_Next_Frontier_Natural_Resource_Targets_Report.pdf.
11. European Environment Agency, *Growth Without Economic Growth,* 2021: https://www.eea.europa.eu/publications/growth-without-economic-growth/growth-without-economic-growth.
12. UNEP, *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth,* 2011: https://www.resourcepanel.org/reports/decoupling-natural-resource-use-and-environmental-impacts-economic-growth.
13. World Bank, *Climate Smart Mining: Minerals for Climate Action*: https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action.
14. IEA, *The Role of Critical Minerals in Clean Energy Transitions*, 2021: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary.
15. Sabine et al., "The Oceanic Sink for Anthropogenic CO2", Science 305 (5682), 2004, pp. 367–371: https://core.ac.uk/reader/36064968?utm_source=linkout.
16. United Nations, *UN SDG 14*: https://www.un.org/sustainabledevelopment/oceans/.
17. Paulus, Eva, "Shedding Light on Deep-Sea Biodiversity – A Highly Vulnerable Habitat in the Face of Anthropogenic Change", Frontiers in Marine Science, 6 April 2021: https://www.frontiersin.org/articles/10.3389/fmars.2021.667048/full.
18. Sonter et al., "Renewable Energy Production Will Exacerbate Mining Threats to Biodiversity", Nature Communications 11 (4174), 1 September 2020: https://www.nature.com/articles/s41467-020-17928-5.
19. IUCN, *A Global Standard for the Identification of Key Biodiversity Areas*, 23 March 2016: https://portals.iucn.org/library/sites/library/files/documents/2016-048.pdf.
20. Allan et al., "Temporally Inter-Comparable Maps of Terrestrial Wilderness and the Last of the Wild", Scientific Data 4 (170187), 12 December 2017: https://www.nature.com/articles/sdata2017187.
21. Giurco et al., "Mineral Supply for Sustainable Development Requires Resource Governance", Nature 543, pp. 367–372: https://eprints.ncl.ac.uk/file_store/production/233255/2BE4DD39-98D8-4A03-87F5-688571321ABC.pdf.
22. United Nations, *Convention on the Law of the Sea,* 1982: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.
23. International Seabed Authority, *Exploration Areas*: https://www.isa.org.jm/minerals/exploration-areas.
24. International Seabed Authority, *Draft Exploitation Regulations*: https://www.isa.org.jm/mining-code/ongoing-development-regulations-exploitation-mineral-resources-area.
25. International Seabed Authority Council, "Statement by the President of the Council on the Work of the Council During the Second Part of the Twenty-Fourth Session", Twenty Fourth Session, 25 July 2018: https://isa.org.jm/files/files/documents/isba24c-8add1-en_0.pdf.
26. International Seabed Authority Council, *Report of the Chair of the Legal and Technical Commission at Its Session in 2017*, 23rd Session, 9 August 2017: https://isa.org.jm/files/files/documents/isba-23c-13_5.pdf.
27. International Seabed Authority, "Nauru Requests the President of the ISA Council to Complete the Adoption of Rules, Regulations and Procedures Necessary to Facilitate the Approval of Plans of Work for Exploitation in the Area" [Press release], 9 June 2021: https://www.isa.org.jm/news/nauru-requests-president-isa-council-complete-adoption-rules-regulations-and-procedures.

28. The Japan Times, "Japan Successfully Undertakes Large-Scale Deep-Sea Mineral Extraction", 26 September 2017: https://www.japantimes.co.jp/news/2017/09/26/national/japan-successfully-undertakes-large-scale-deep-sea-mineral-extraction/#.XuiYffkzY2w.
29. JOGMEC, "JOGMEC Conducts World's First Successful Excavation of Cobalt-Rich Seabed in the Deep Ocean;
Excavation Test Seeks to Identify Best Practices to Access Essential Green Technology Ingredients While Minimizing Environmental Impact" [Press release], 21 August 2020: http://www.jogmec.go.jp/english/news/release/news_01_000033.html.
30. Seabed Minerals Authority, "Licensing Process for Seabed Exploration", 20 October 2020: https://www.sbma.gov.ck/news-3/article42.
31. Adomaitis, Nerijus, "Norway Eyes Sea Change in Deep Dive for Metals Instead of Oil", Reuters, 12 January 2021: https://www.reuters.com/article/us-norway-deepseamining-insight-idUSKBN29H1YT.
32. IUCN, *Deep-Sea Mining*: https://www.iucn.org/resources/issues-briefs/deep-sea-mining.
33. MIDAS, *Managing Impacts of Deep-Sea Resource Exploitation*: https://www.oceanfdn.org/sites/default/files/MIDAS_brief_Introduction.compressed.pdf.
34. Hein and Koschinsky, "Deep Ocean Ferromanganese Crusts and Nodules", Researchgate, January 2014: https://www.researchgate.net/publication/303108085_Deep-ocean_ferromanganese_crusts_and_nodules.
35. Ibid.
36. Lillie, Andrew, *Seafloor Massive Sulfides Mining*, NR&E, Fall 2019: https://www.hoganlovells.com/~/media/hogan-lovells/pdf/2019/11_11_19_seafloormassivesulfides.pdf.
37. MIDAS, *Managing Impacts of Deep-Sea Resource Exploitation*: https://www.oceanfdn.org/sites/default/files/MIDAS_brief_Introduction.compressed.pdf.
38. World Economic Forum, *Deep-Sea Minerals: What Manufacturers and Markets Need to Know*, November 2020: https://www3.weforum.org/docs/WEF_BP_Deep-Sea_Minerals_2020.pdf.
39. Ibid.
40. Ibid.
41. International Seabed Authority, *Exploration Areas*: https://www.isa.org.jm/minerals/exploration-areas.
42. Kingan, Stuart, *Manganese Nodules of the Cook Islands*, South Pacific Applies Geoscience Commission, September 1998: https://www.sprep.org/att/IRC/eCOPIES/countries/cook_islands/7.pdf.
43. International Seabed Authority, *Exploration Areas*: https://www.isa.org.jm/minerals/exploration-areas.
44. Henriques, Martha, "Japan's Grand Plans to Mine Deep-Sea Vents", BBC, 7 January 2019: https://www.bbc.com/future/article/20181221-japans-grand-plans-to-mine-deap-sea-vents.
45. Frimanslund, Erik, "Feasibility of Deep-Sea Mining Operation Within Norwegian Jurisdiction", NTNU, 2016: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2410761.
46. MIDAS, *Managing Impacts of Deep Sea Resource Exploitation*: https://www.oceanfdn.org/sites/default/files/MIDAS_brief_Introduction.compressed.pdf.
47. Schreier and Lutz, "Hydrothermal Vent Biota", Encyclopedia of Ocean Sciences (Third Edition), vol. 4, 2019, pp. 308–319: https://www.sciencedirect.com/science/article/pii/B9780124095489113910.
48. Van Dover, Cindy, "Inactive Sulfide Ecosystems in the Deep Sea: A Review", Frontiers in Marine Science, 23 July 2019: https://www.frontiersin.org/articles/10.3389/fmars.2019.00461/full.
49. "Top Tech Firms Sued Over DR Congo Cobalt Mining Deaths", BBC, 16 December 2019: https://www.bbc.com/news/world-africa-50812616.
50. World Economic Forum, *Deep-Sea Minerals: What Manufacturers and Markets Need to Know*, November 2019: http://www3.weforum.org/docs/WEF_BP_Deep-Sea_Minerals_2020.pdf.
51. Wilde-Ramsing, Joseph, *Responsible Disengagement from Coal as Part of a Just Transition*, SOMO, 12 July 2021: https://www.somo.nl/responsible-disengagement-from-coal-as-part-of-a-just-transition/.
52. *United Nations Convention on the Law of the Sea*, 1994: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.
53. Organisation for Economic Co-operation and Development, Guidelines for Multinational Enterprises, 1976: https://www.oecd.org/corporate/mne/.
54. United Nations, Guiding Principles on Business and Human Rights, 2011: https://www.ohchr.org/Documents/Publications/GuidingPrinciplesBusinessHR_EN.pdf 1.
55. Harrabin, Roger, "Shell: Netherlands Court Orders Oil Giant to Cut Emissions", BBC, 26 May 2021: https://www.bbc.com/news/world-europe-57257982.
56. London Metal Exchange, *Responsible Sourcing*: https://www.lme.com/en/company/responsibility/responsible-sourcing.
57. Fair Cobalt Alliance, *Our Members*: https://www.faircobaltalliance.org/supply-chain-wide-collaboration/our-members/.
58. Fair Cobalt Alliance, *Approach*: https://www.faircobaltalliance.org/approach/.

59. Responsible MICA Initiative, *About Us*: https://responsible-mica-initiative.com/about-us-rmi/about-us-approach-and-strategy.

60. Lee et al., "Reviewing the Material and Metal Security of Low-Carbon Energy Transitions", Renewable and Sustainable Energy Reviews 124, May 2020: https://www.sciencedirect.com/science/article/abs/pii/S136403212030085X.

61. A New World, *The Geopolitics of the Energy Transformation*: http://www.geopoliticsofrenewables.org/Report.

62. The World Bank, *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition,* 2020: https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf.

63. *United Nations Convention on the Law of the Sea*, 1994: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

64. Jaeckel, Aline, "Benefitting from the Common Heritage of Humankind: From Expectation to Reality", The International Journal of Marine and Coastal Law, 30 July 2020: https://brill.com/view/journals/estu/35/4/article-p660_3.xml.

65. The International Seabed Authority, *Submission of Members of the Council of the International Seabed Authority from the African Group in Relation to the Request Made by Nauru Pursuant to Section 1, Paragraph 15, of the Agreement Relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982*, 26th session, 19–13 July 2021: https://isa.org.jm/files/files/documents/ISBA_26_C_40-2110120E.pdf.

66. Deep Sea Conservation Coalition, *Momentum for a Moratorium*: http://www.savethehighseas.org/momentum-for-a-moratorium/.

67. Deep Sea Mining Science Statement, *Marine Expert Statement Calling for a Pause to Deep-Sea Mining*: https://www.seabedminingsciencestatement.org/.

68. Lewis, Jeff, "EU Should Promote Moratorium on Deep-Sea Mining, Lawmakers Say", Reuters*,* 9 June 2021: https://www.reuters.com/business/environment/eu-should-promote-moratorium-deep-sea-mining-lawmakers-say-2021-06-09/.

69. IUCN*, 069 Protection of Deep Ocean Ecosystems and Biodiversity Through a Moratorium on Seabed Mining*, 22 September 2021: https://www.iucncongress2020.org/motion/069.

70. Deep Sea Conservation Coalition, *Momentum for a Moratorium*: http://www.savethehighseas.org/momentum-for-a-moratorium/.

71. No Deep Seabed Mining, *Call for a Moratorium*: https://www.noseabedmining.org/.

72. World Economic Forum. *Deep-Sea Minerals: Why Manufacturers and Markets Should Engage Now*. April 2021: http://www3.weforum.org/docs/WEF_Deep_Sea_Minerals_2021.pdf.

73. TDi Sustainability, *Material Change Report*: https://tdi-sustainability.com/material-change2/.

74. Material Insights website: https://www.material-insights.org/.

75. OECD, *Trends in Stakeholder Reporting*: *Mineral Supply Chains*: http://mneguidelines.oecd.org/trendsinstakeholderreportingmineralsupplychains.htm.

76. Responsible Minerals Initiative, *Smelters and Refiners List*: http://www.responsiblemineralsinitiative.org/smelters-refiners-lists/.

77. The EPRM Due Diligence Hub: https://europeanpartnership-responsibleminerals.eu/cms/view/5a5784ac-d006-42db-8017-7e01c46c2c5a/due-diligence-hub.

78. ISEAL, *ISEAL Credibility Principles*: http://www.isealalliance.org/defining-credible-practice/iseal-credibility-principles.

79. UNDP, *Vulnerable Developing Countries Lead World on Climate Ambition: UN report*, 18 September 2019: https://www.undp.org/press-releases/vulnerable-developing-countries-lead-world-climate-ambition-un-report.

80. Haugan, Peter and Levin, Lisa, *What Role for Ocean-Based Renewable Energy and Deep-Seabed Minerals in a Sustainable Future?*, Ocean Panel, 2020: https://oceanpanel.org/sites/default/files/2020-10/Ocean%20Energy%20and%20Deep-Sea%20Minerals%20Full%20Paper.pdf.

81. Hein et al., *Deep-Ocean Mineral Deposits as a Source of Critical Metals for High- and Green-Technology Applications: Comparison with Land-Based Resources*, Ore Geology Reviews 51, June 2013, pp. 1–14: https://www.sciencedirect.com/science/article/abs/pii/S016913681200234X.

82. International Energy Agency, *The Role of Critical Minerals in Clean Energy Transitions*: https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf.

83. Miller et al., "Challenging the Need for Deep Seabed Mining from the Perspective of Metal Demand, Biodiversity, Ecosystems Services, and Benefit Sharing", Frontiers in Marine Science, 29 July 2021: https://www.frontiersin.org/articles/10.3389/fmars.2021.706161/full.

84. European Commission, *Policy and Strategy for Raw Materials*: https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en.

85. European Commission, *Sustainable Mineral Resources by Utilizing New Exploration Technologies*: https://cordis.europa.eu/article/id/413477-high-tech-and-legacy-data-open-new-avenues-to-deep-mineral-exploration.

86. Hejlen et al., "Assessing the Adequacy of the Global Land-Based Mine Development Pipeline in the Light of Future High-Demand Scenarios: The Case of the Battery-Metals Nickel (Ni) and Cobalt (Co)", Resources Policy 73, October 2021: https://www.sciencedirect.com/science/article/pii/S0301420721002166.

87. Gaia Foundation, *Civil Society Concerns on EU Critical Raw Materials Plans*, 28 September 2020: https://www.gaiafoundation.org/app/uploads/2020/09/Concerns-on-EU-critical-raw-material-plans_civil-society-open-letter.pdf.

88. Morris, James, "Tesla's Shift to Cobalt-Free Batteries Is Its Most Important Move Yet", Forbes, 11 July 2020: https://www.forbes.com/sites/jamesmorris/2020/07/11/teslas-shift-to-cobalt-free-batteries-is-its-most-important-move-yet/.

89. Smith, Niall, "Nickel: A Green Energy Necessity with Grave Environmental Risks", Verisk, Maplecroft, 29 July 2018: https://www.maplecroft.com/insights/analysis/nickel-a-green-energy-necessity-with-grave-environmental-risks/.

90. Mining.com, "World's No.2 Electric Carmaker Goes Nickel, Cobalt Free", 13 April 2020: https://www.mining.com/world-no-2-electric-carmaker-goes-entirely-nickel-cobalt-free/.

91. Hutt, David, "After the Loss of a Ship, Deep Sea Mining Plans for PNG Founder", Mongabay, 26 December 2018: https://news.mongabay.com/2018/12/after-the-loss-of-a-ship-deep-sea-mining-plans-for-png-founder/.

92. International Seabed Authority, *Update on Financial Payment Systems: Seabed Mining for Polymetallic Nodules*, 16 July 2018: https://isa.org.jm/files/files/documents/mit-ppt.pdf.

93. IISD, *Report of Main Proceedings for 18 February 2020*: https://enb.iisd.org/events/1st-part-26th-annual-session-international-seabed-authority-isa/report-main-proceedings-18.

94. Burton, Melanie, "EV Battery Metals Firm DeepGreen to Go Public in SPAC Deal", Reuters, 4 March 2021: https://www.reuters.com/article/us-deepgreen-m-a-sustainable-opportuniti-idUSKBN2AW1I4.

95. DEME GSR, "De Tijd: DEME Collects 'Truffles from the Ocean' at a Depth of 4,500 Meters", 23 April 2021: https://deme-gsr.com/news/de-tijd-deme-collects-truffles-from-the-ocean-at-a-depth-of-4500-meters-by-marc-de-roo/.

96. From email correspondence with UKSR in January 2022.

97. Thaler, Andrew, "Deep-Sea Mining Has Time", DSM Observer, 27 August 2021: https://dsmobserver.com/2021/08/opinion-deep-sea-mining-has-time/.

98. Lapteva et al., *Report to the International Seabed Authority: Study of the Potential Impact of Polymetallic Nodules Production from the Area on the Economies of Developing Land-Based Producers of Those Metals Which Are Likely to Be Most Seriously Affected*, 12 May 2020: https://www.isa.org.jm/files/documents/impactstudy.pdf.

99. The Government of the Republic of Nauru, *FAQs on Two-Year Notice*, 2021: http://naurugov.nr/government/departments/department-of-foreign-affairs-and-trade/faqs-on-2-year-notice.aspx.

100. Office of the Prime Minister Hon. Mark Brown, *Opening Remarks at the International Seabed Authority Side-Event to the 2021 High-level Political Forum on Sustainable Development*, 13 July 2021: https://www.isa.org.jm/files/2021-07/PM-Mark-Brown-Cook-Islands-13.07.21.pdf.

101. The Metals Company, *Response to Greenpeace Report*, December 2020: https://metals.co/response-to-greenpeace-report/.

102. Paulikas et al., "Life Cycle Climate Change Impacts of Producing Battery Metals from Land Ores Versus Deep-Sea Polymetallic Nodules", Journal of Cleaner Production 275, December 2020: https://www.sciencedirect.com/science/article/pii/S0959652620338671?via%3Dihub

103. Alvarenga et al., "Prospective Life Cycle Assessment of Metal Commodities Obtained from Deep-Sea Polymetallic Nodules", Journal of Cleaner Production 330, 1 January 2022: https://www.sciencedirect.com/science/article/pii/S0959652621040543?via%3Dihub.

104. International Seabed Authority, *African Group Submission on the ISA Payment Regime for Deep-Sea Mining in the Area*, July 2019: https://www.isa.org.jm/files/files/documents/agsmitmodelfinal.pdf.

105. Home, Andy, "Column: Cobalt, Congo and a Mass Artisanal Mining Experiment", Reuters, 13 May 2021: https://www.reuters.com/business/energy/cobalt-congo-mass-artisanal-mining-experiment-andy-home-2021-05-13/.

106. International Seabed Authority, *Report to the International Seabed Authority: Study of the Potential Impact of Polymetallic Nodules Production from the Area on the Economies of Developing Land-Based Producers of Those Metals Which Are Likely to Be Most Seriously Affected*, 12 May 2020: https://www.isa.org.jm/files/documents/impactstudy.pdf.

107. Permanent Mission of Algeria to the International Seabed Authority, *Statement on Behalf of the African Group*, 25 February 2019: https://isa.org.jm/files/files/documents/1-algeriaoboag_finmodel.pdf.

108. Reid, Helen and Lewis, Jeff, "African Nations Criticise Push to Fast-Track Deep-Sea Mining Talks", Reuters, 27 July 2021: https://www.reuters.com/business/sustainable-business/african-nations-criticise-push-fast-track-deep-sea-mining-talks-2021-07-27/.

109. *United Nations Convention on the Law of the Sea*, 1994: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

110. Based on correspondence with the International Seabed Authority, October 2021.

111. Munoz-Royo et al., "Extent of Impact of Deep-Sea Nodule Mining Midwater Plumes Is Influenced by Sediment Loading, Turbulence and Thresholds", Communications, Earth and Environment 2 (148), 27 July 2021: https://www.nature.com/articles/s43247-021-00213-8.

112. North American Consortium for Responsible Ocean Mining (NACROM): https://www.nacrom.com/.

113. Amon et al., "Insights into the Abundance and Diversity of Abyssal Megafauna in a Polymetallic-Nodule Region in the Eastern Clarion-Clipperton Zone", Scientific Reports 6 (1): https://www.researchgate.net/publication/305741883_Insights_into_the_abundance_and_diversity_of_abyssal_megafauna_in_a_polymetallic-nodule_region_in_the_eastern_Clarion-Clipperton_Zone/link/57a24f0a08aeef8f311facd0/download.

114. Sweetman et al., "Key Role of Bacteria in the Short-Term Cycling of Carbon at the Abyssal Seafloor in a Low Particulate Organic Carbon Flux Region of the Eastern Pacific Ocean", Limnology and Oceanography 64, 2019, pp. 694–713: https://eprints.soton.ac.uk/429601/1/Sweetman_et_al_2019_Limnology_and_Oceanography.pdf.

115. Gjerde et al., "Opinion: Midwater Ecosystems Must Be Considered When Evaluating Environmental Risks of Deep-Sea Mining", Proceedings of the National Academy of Sciences, July 2020: https://www.researchgate.net/profile/Malcolm-Clark-5/publication/342804967_Opinion_Midwater_ecosystems_must_be_considered_when_evaluating_environmental_risks_of_deep-sea_mining/links/5fead14345851553a001a9a1/Opinion-Midwater-ecosystems-must-be-considered-when-evaluating-environmental-risks-of-deep-sea-mining.pdf.

116. Fuchida et al., "Onboard Experiment Investigating Metal Leaching of Fresh Hydrothermal Sulfide Cores into Seawater", Geochemical Transitions 19, 6 December 2018: https://geochemicaltransactions.biomedcentral.com/articles/10.1186/s12932-018-0060-9.

117. Cuvelier et al., "Potential Mitigation and Restoration Actions in Ecosystems Impacted by Seabed Mining", Frontiers in Marine Science, 10 December 2018: https://www.frontiersin.org/articles/10.3389/fmars.2018.00467/full.

118. Haugan, Peter and Levin, Lisa, *What Role for Ocean-Based Renewable Energy and Deep-Seabed Minerals in a Sustainable Future?*, Ocean Panel, 2020: https://oceanpanel.org/sites/default/files/2020-10/Ocean%20Energy%20and%20Deep-Sea%20Minerals%20Full%20Paper.pdf.

119. Deep Sea Mining Science Statement, *Marine Expert Statement Calling for a Pause to Deep Sea Mining*: https://www.seabedminingsciencestatement.org/.

120. International Seabed Authority, *Decision of the Assembly Relating to the Action Plan of the International Seabed Authority in Support of the United Nations Decade of Ocean Science for Sustainable Development*, 17 December 2020: https://isa.org.jm/files/files/documents/ISBA_26_A_17-2017623E.pdf.

121. International Seabed Authority, *Action Plan for Marine Scientific Research*, 2021: https://isa.org.jm/files/files/documents/ISA_MSR_Action_Plan.pdf.

122. Tunnicliffe et al., "Strategic Environmental Goals and Objectives: Setting the Basis for Environmental Regulation of Deep Seabed Mining", Marine Policy 114, April 2020: https://www.sciencedirect.com/science/article/pii/S0308597X1830321X.

123. Levin et al., "Defining Serious Harm to the Marine Environment in the Context of Deep-Seabed Mining", Marine Policy 74, December 2016, pp. 245–259: https://www.sciencedirect.com/science/article/pii/S0308597X1630495X.

124. International Seabed Authority, *Deep CCZ Biodiversity Synthesis Workshop*, 1–4 October 2019: https://www.isa.org.jm/files/files/documents/Deep%20CCZ%20Biodiversity%20Synthesis%20Workshop%20Report%20-%20Final-for%20posting-clean-1.pdf.

125. Amon, Diva, "Assessment of Scientific Gaps Related to the Effective Environmental Management of Deep-Seabed Mining", Marine Policy, 1 March 2022: https://doi.org/10.1016/j.marpol.2022.105006.

126. The Pew Charitable Trusts, *The Clarion-Clipperton Zone*, December 2017: https://www.pewtrusts.org/-/media/assets/2017/12/sea_the_clarion_clipperton_zone.pdf.

127. From email correspondence with DEME in February 2022.

128. Childs, John, "Deep Sea Mining Threatens Indigenous Culture in Papua New Guinea", The Conversation, 19 February 2019: https://theconversation.com/deep-sea-mining-threatens-indigenous-culture-in-papua-new-guinea-112012.

129. Le, Jennifer T. and Sato, Kirk N., *Ecosystem Services of the Deep-Ocean*, Ocean Climate: https://www.ocean-climate.org/wp-content/uploads/2017/03/ecosystem-services-deep-ocean_ScientificNotes_Oct2016_BD_ppp-9.pdf.

130. Hauton et al., "Identifying Toxic Impacts of Metals Potentially Released during Deep-Sea Mining – A Synthesis of the Challenges to Quantifying Risk", Frontiers in Marine Science, 16 November 2017: https://www.frontiersin.org/articles/10.3389/fmars.2017.00368/full.
131. Van der Grient, J.M.A., "Potential Spatial Intersection Between High-Seas Fisheries and Deep-Sea Mining in International Waters", Marine Policy 129, July 2021: https://www.sciencedirect.com/science/article/pii/S0308597X21001755.
132. Munoz-Royo et al., "Extent of Impact of Deep-Sea Nodule Mining Midwater Plumes Is Influenced by Sediment Loading, Turbulence And Thresholds", Communications Earth and Environment, 27 July 2021: https://www.nature.com/articles/s43247-021-00213-8.
133. Folkersen et al., "Deep Sea Mining's Future Effects on Fiji's Tourism Industry: A Contingent Behaviour Study", Marine Policy 96, October 2018, pp. 81–89: https://www.sciencedirect.com/science/article/abs/pii/S0308597X18300836#ab0015.
134. *United Nations Convention on the Law of the Sea,* 1982: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.
135. International Seabed Authority, *Development of Rules, Regulations and Procedures on the Equitable Sharing of Financial and Other Economic Benefits Derived from Activities in the Area Pursuant to Section 9, Paragraph 7 (f), of the Annex to the Agreement Relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982*, 6 July 2021: https://isa.org.jm/files/files/documents/ISBA_26_A_24-2109788E_0.pdf.
136. International Seabed Authority, *Summary on Options for a Seabed Sustainability Fund*, 25 March 2021: https://isa.org.jm/files/files/documents/ISBA_26_FC_8-2104419E.pdf.
137. International Seabed Authority, *Equitable Sharing of Financial and Other Economic Benefits from Deep-Seabed Mining*: https://isa.org.jm/files/files/documents/ISA-Technical-Study-31.pdf.
138. International Seabed Authority, *Update on Financial Payment Systems: Seabed Mining for Polymetallic Nodules*, 16 July 2018: https://isa.org.jm/files/files/documents/mit-ppt.pdf.
139. International Seabed Authority, *African Group Submission on ISA Payment Regime for Deep-Sea Mining in the Area*, 5 July 2019: https://www.isa.org.jm/files/files/documents/agsmitmodelfinal.pdf.
140. Permanent Mission of Algeria to the International Seabed Authority, *Statement on Behalf of the African Group*, 25 February 2019: https://isa.org.jm/files/files/documents/1-algeriaoboag_finmodel.pdf.
141. African Union, *African Blue Economy Strategy*, October 2019: https://www.au-ibar.org/sites/default/files/2020-10/sd_20200313_africa_blue_economy_strategy_en.pdf.
142. International Monetary Fund, *Datamapper*: https://www.imf.org/external/datamapper/NGDPD@WEO/OEMDC/ADVEC/WEOWORLD/AFQ.
143. Neate, Rupert, "Seabed Mining Could Earn Cook Islands 'Tens of Billions of Dollars'", The Guardian, 5 August 2013: https://www.theguardian.com/business/2013/aug/05/seabed-mining-cook-islands-billions.
144. Norwegian Petroleum Directorate, *Act Relating to Mineral Activities on the Continental Shelf (Seabed Minerals Act)*: https://www.npd.no/en/regulations/acts/act-relating-to-mineral-activities-on-the-continental-shelf-seabed-minerals-act/.
145. According to correspondence received from the Norwegian Petroleum Directorate, 20 August 2021.
146. Centre for Social Responsibility in Mining, *Review of the Draft Seabed Minerals Bill 2019 (Cook Islands)*, The University of Queensland, Australia, 20 March 2019: https://www.csrm.uq.edu.au/publications?task=download&file=publication_file_2&id=1017.
147. Kung et al., "Governing Deep Sea Mining in the Face of Uncertainty", Journal of Environmental Management 279, 1 February 2021: https://www.sciencedirect.com/science/article/pii/S0301479720315188.
148. Deep Sea Conservation Coalition, *DSCC Position Statement on Deep Seabed Mining*: http://www.savethehighseas.org/wp-content/uploads/2019/08/DSCC-Position-Statement-on-Deep-Seabed-Mining_July2019.pdf.
149. No Deep Seabed Mining, *Call for a Moratorium*: https://www.noseabedmining.org/.
150. Microsoft, *Building a Supply Chain with Integrity, Accountability and Respect*: *Microsoft Devices Responsible Sourcing Report FY21*: https://query.prod.cms.rt.microsoft.com/cms/api/am/binary/RWO6Gn.
151. The Pew Charitable Trusts, *Precautionary Approach Needed for Deep-Sea Mining*, June 2016: https://www.pewtrusts.org/-/media/assets/2016/06/precautionary_approach_needed_for_deep_sea_mining.pdf.
152. DEME GSR, "GSR Vows Not to Produce Ocean-Mined Minerals Before the Environmental Risks Are Comprehensively Understood" [Press release], 31 March 2021: https://deme-gsr.com/news/gsr-vows-not-to-produce-ocean-mined-minerals-before-the-environmental-risks-are-comprehensively-understood/.
153. The Metals Company, *Frequently Asked Questions*: https://metals.co/frequently-asked-questions/.
154. International Seabed Authority, *Protection of the Marine Environment*: https://www.isa.org.jm/our-work/protection-marine-environment.

155. Jaeckel, Aline, *Discussion Paper No. 5/The Implementation of the Precautionary Approach by the International Seabed Authority*, International Seabed Authority, March 2017: https://www.isa.org.jm/files/documents/EN/Pubs/DPs/DP5.pdf.
156. The Government of the Republic of Nauru, *Nauru Requests the International Seabed Authority to Adopt Rules in Two Years*: http://naurugov.nr/government/departments/department-of-foreign-affairs-and-trade/faqs-on-2-year-notice.aspx.
157. The Metals Company, *Research*: https://metals.co/research/.
158. Shukman, David, "Companies Back Moratorium on Deep Sea Mining", BBC, 3 April 2021: https://www.bbc.com/news/science-environment-56607700.
159. International Seabed Authority, *Recommendations for the Guidance of Contractors for the Assessment of the Possible Environmental Impacts Arising from Exploration for Marine Minerals in the Area*, 30 March 2020: https://isa.org.jm/files/files/documents/26ltc-6-rev1-en_0.pdf.
160. Deep Sea Conservation Coalition, *DSCC Position Statement on Deep Seabed Mining*: http://www.savethehighseas.org/wp-content/uploads/2019/08/DSCC-Position-Statement-on-Deep-Seabed-Mining_July2019.pdf.
161. Friedman, Andrew, "After Chaotic Year, Seabed Mining Oversight Body Must Strengthen Policies", The Pew Charitable Trusts, 12 February 2021: https://www.pewtrusts.org/en/research-and-analysis/articles/2021/02/11/after-chaotic-year-seabed-mining-oversight-body-must-strengthen-policies.
162. International Seabed Authority, *DeepData Database*: https://www.isa.org.jm/deepdata.
163. Laird, Frank N., "Participatory Analysis, Democracy and Technological Decision Making", Science, Technology and Human Values 18 (3), 1993, pp. 341–361: https://www.jstor.org/stable/689725?seq=1.
164. OECD, *Policy Framework on Sound Public Governance*, 22 December 2020: https://www.oecd-ilibrary.org/governance/policy-framework-on-sound-public-governance_c03e01b3-en?_ga=2.30647551.1101297875.1627028598-162612449.1617594557.
165. National Research Council, *Public Participation in Environmental Assessment and Decision-Making*, 2008: https://www.nap.edu/catalog/12434/public-participation-in-environmental-assessment-and-decision-making.
166. Moffat, K. and Zhang, A., "The Paths to Social License to Operate: An Integrative Model Explaining Community Acceptance of Mining", Resources Policy 39, March 2014, pp. 61–70: https://www.sciencedirect.com/science/article/pii/S0301420713001141.
167. The Government of the Republic of Nauru, *FAQs on Two-Year Notice*, 2021: http://naurugov.nr/government/departments/department-of-foreign-affairs-and-trade/faqs-on-2-year-notice.aspx.
168. Institute for Advanced Sustainability Studies, *The International Seabed – The Common Heritage of Mankind,* July 2018: https://www.umweltbundesamt.de/sites/default/files/medien/2875/dokumente/chm_policy_brief.pdf.
169. International Seabed Authority, *The Assembly*: https://www.isa.org.jm/authority/assembly.
170. International Seabed Authority, *Structure and Mandate of the Council*: https://www.isa.org.jm/authority/council/structure-and-mandate.
171. International Seabed Authority, *Strategic Plan Booklet*: https://www.isa.org.jm/files/files/documents/Strategic_Plan_Booklet.pdf.
172. International Seabed Authority, *Workshops and Webinars*: https://www.isa.org.jm/events/workshops.
173. International Seabed Authority, *Communications and Stakeholder Engagement Strategy*: https://isa.org.jm/files/files/documents/Draft_Comms_and_Stakeholder_Engagement_Strategy.pdf.
174. International Seabed Authority, "ISA Opens Draft Communications and Stakeholder Engagement Strategy" [Press release], 7 December 2020: https://www.isa.org.jm/news/isa-opens-draft-communications-and-stakeholder-engagement-strategy-public-consultation.
175. The Pew Charitable Trusts, *ISA Stakeholder Strategy Comments*, 28 January 2021: https://www.pewtrusts.org/-/media/assets/2021/01/isa-stakeholder-strategy-comments-pew_jan-2021.pdf.
176. Deep Sea Conservation Coalition, *Deep Sea Conservation Coalition Submission on Zero Draft Communications and Stakeholder Engagement Strategy*, 29 January 2021: http://www.savethehighseas.org/wp-content/uploads/2021/01/DSCC-Submission-on-ISA-Draft-Stakeholder-Engagement-Strategy.pdf.
177. Greenpeace, *Deep Trouble: The Murky World of the Deep Sea Mining Industry*, December 2020: https://www.greenpeace.org/static/planet4-international-stateless/c86ff110-pto-deep-trouble-report-final-1.pdf.
178. Woody, Todd, "A Mining Startup's Rush for Underwater Metals Comes with Deep Risks", Bloomberg, 24 June 2021: https://www.bloomberg.com/news/articles/2021-06-24/a-mining-startup-s-rush-for-underwater-metals-comes-with-deep-risks.
179. Interviews conducted by the World Economic Forum in May and June 2021.
180. National Research Council, *Public Participation in Environmental Assessment and Decision-Making*, 2008: https://www.nap.edu/read/12434/chapter/5#76.

181. Moffat, K. and Zhang, A., "The Paths to Social License to Operate: An Integrative Model Explaining Community Acceptance of Mining", Resources Policy 39, March 2014, pp. 61–70: https://www.sciencedirect.com/science/article/pii/S0301420713001141.

182. Ardron et al., "Public Participation in the Governance of Deep-Sea Mining in the Area", in *Research Handbook on International Marine Environmental Law*, 2nd ed. (Edward Elgar, forthcoming 2022).

183. International Seabed Authority, *Observers*: https://isa.org.jm/index.php/observers.

184. Kung et al., "Governing Deep Sea Mining in the Face of Uncertainty", Journal of Environmental Management 279, 1 February 2021: https://www.sciencedirect.com/science/article/pii/S0301479720315188.

185. *Seabed Minerals Act*, 2019: https://static1.squarespace.com/static/5cca30fab2cf793ec6d94096/t/5d3f683993ea3f0001b7379c/1564436729995/Seabed+Minerals+Act+2019.

186. Seabed Minerals Authority, *Advisory Committee*: https://www.sbma.gov.ck/advisory-committee.

187. Adomaitis, Nerijus, "Norway Eyes Sea Change in Deep Dive for Metals Instead of Oil", Reuters, 12 January 2021: https://www.reuters.com/article/us-norway-deepseamining-insight-idUSKBN29H1YT.

188. Parliament Counsel Office of New Zealand, *Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012*: https://www.legislation.govt.nz/act/public/2012/0072/latest/whole.html?search=sw_096be8ed817c9082_consult_25_se&p=1#DLM3956168.

189. McCabe, P. and Hita, J., "New Zealand Ruling Against Deep-Sea Mining Set a Global Precedent – Now Ardern Should Ban It", The Guardian, 4 October 2021: https://www.theguardian.com/world/commentisfree/2021/oct/05/new-zealand-ruling-against-deep-sea-mining-set-a-global-precedent-now-ardern-should-ban-it.

190. *Trans-Tasman Resources Limited v. Taranaki-Whanganui Conservation Board, [2021] NZSC 127*, 30 September 2021: https://www.courtsofnz.govt.nz/assets/cases/2021/2021-NZSC-127.pdf.

191. Definition adapted from the Ellen MacArthur Foundation.

192. Definition adapted from Oxford Bibliographies.

193. Definition adapted from the OECD.

194. The Japan Times, "Japan Successfully Undertakes Large-Scale Deep-Sea Mineral Extraction", 26 September 2017: https://www.japantimes.co.jp/news/2017/09/26/national/japan-successfully-undertakes-large-scale-deep-sea-mineral-extraction/#.XuiYffkzY2w.

195. JOGMEC, "JOGMEC Conducts World's First Successful Excavation of Cobalt-Rich Seabed in the Deep Ocean;
Excavation Test Seeks to Identify Best Practices to Access Essential Green Technology Ingredients While Minimizing Environmental Impact" [Press release], 21 August 2020: http://www.jogmec.go.jp/english/news/release/news_01_000033.html.

196. Seabed Minerals Authority, "Licensing Process for Seabed Exploration", 20 October 2020: https://www.sbma.gov.ck/news-3/article42.

197. Adomaitis, Nerijus, "Norway Eyes Sea Change in Deep Dive for Metals Instead of Oil", Reuters, 12 January 2021: https://www.reuters.com/article/us-norway-deepseamining-insight-idUSKBN29H1YT.

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