Subsection 5A

Chapter 7

Mineral resources

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Key points

- **Pressures**

  Marine mineral resources have been explored and exploited in maritime areas within national jurisdiction, driven by demand. Deep-sea mineral exploration has occurred both within and beyond national jurisdiction, but commercial exploitation has yet to begin. Marine mining technologies are evolving rapidly due to growing commercial interest in metal extraction, driven by the global energy transition towards net-zero emissions.

- **Impacts**

  Environmental impact assessments for commercial and project-specific mineral extraction have been conducted for offshore diamonds, phosphorites and a polymetallic sulfide deposit, but only limited studies have been conducted for polymetallic nodules or ferromanganese crusts. Environmental impact assessments are closely linked to the design and modus operandi of evolving mining technologies and the scientific and technical standards and practices adopted by States in areas within national jurisdiction and by the international community as a whole in areas beyond national jurisdiction (the Area).

- **Socioeconomic considerations**

  Depending on economic feasibility, marine mineral resources have the potential to complement mineral resources extracted from land. When mineral resources from both the ocean and the land are developed or used together, this combined activity could have an impact on the international market value of both types of resources and affect the land and marine environments. Under the United Nations Convention on the Law of the Sea, States have international legal and economic rights and obligations relating to technology transfer, cooperation and revenue distribution arising from marine mineral resources exploitation in the Area.

- **Governance and sustainability**

  Governance of maritime areas within and beyond national jurisdiction comprise various legal regimes and scientific and technical standards and practices, which create a need for international agreement and consensus. The sustainable exploration and potential exploitation of marine mineral resources depend on scientific and technological innovation, stakeholder participation, environmental management and monitoring, and reliable data for effectively assessing social, economic and environmental impacts.

1. Introduction

The present chapter highlights developments further to chapter 23 of the first *World Ocean Assessment* (United Nations, 2017) on offshore mining industries, and chapter 18 of the second *World Ocean Assessment* (United Nations, 2021), on changes in seabed mining. It provides updates on the distribution of mineral resources and projected demand for them. It examines environmental and technological issues relating to ocean mineral exploration and exploitation. It continues with parts relating to sustainable development, including socioeconomic aspects, and concludes with a part on governance in the Area and marine regions within national jurisdiction.

The need for a comprehensive international legal framework for the oceans arose from the desire to ensure marine mineral resources for the benefit of all humanity. That concept goes back to 1 November 1967, when the ambassador of Malta to the United Nations, Arvid Pardo, delivered a speech at the General Assembly in which he proposed that the seabed and subsoil outside national jurisdictions could be considered as *res communis omnium* and the "common heritage of humankind". His idea was reflected in Assembly resolution 2340 of 18 December 1967, by which the Assembly established an Ad Hoc Committee to Study the Peaceful Uses of the Sea-Bed and the Ocean Floor beyond the Limits of National Jurisdiction and, at a later stage, was incorporated in Assembly resolution 2749 (XXV), the Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, beyond the Limits of National Jurisdiction.

With the subsequent resolution, 2750 (XXV), the General Assembly decided to convene the Third United Nations Conference on the Law of the Sea, which was held from 1973 to 1982. The United Nations Convention on the Law of the Sea was opened for signature at Montego Bay, Jamaica, on 10 December 1982. It entered into force on 14 November 1994 and is presently in force for 171 Parties. The Convention and the Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, adopted on 28 July 1994, establish the international legal framework for the rights and responsibilities of States with respect to, inter alia, the exploration and exploitation of ocean mineral resources within and beyond regions under national jurisdiction.

The International Seabed Authority (ISA) has developed regulations for the exploration of polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts. These three international regulations may be useful starting points for the discussion and design of national regulations for area-based management tools such as regional environmental management plans and reserved areas, which may become integral components of international and national ocean management programmes (International Seabed Authority, 2024).

2. Current status and pressures

The present part of the chapter contains a review of the current status of mineral exploration and the pressures and impacts posed by past, present and future demand for world minerals, highlighting increasing demand and evolving market trends associated with the pursuit of net-zero emissions.

Sand and gravel

Sand and gravel resources are essential for producing building materials such as concrete, as well as for beach nourishment and coastal land reclamation. By volume, sand and gravel are the most extracted marine mineral resource. Annually, between 4 billion and 8 billion tons of marine sand and sediments are dredged or mined (United Nations Environment Programme, 2023), and their associated environmental impacts, such as increasing erosion, the potential for reduced protection from storm surges and other extreme events, and damaging habitats for microorganisms that are the basis of marine food webs, have also been analysed (United Nations Environment Programme, 2022).

Marine sand and gravel are dredged on most coastlines around the world, with the exception of a few regions such as Antarctica and much of the west coast of South America. Production rates in some States, such as China, the Kingdom of the Netherlands, the United Kingdom of Great Britain and Northern Ireland and the United States of America, have remained relatively stable, while States such as India, Indonesia, the Philippines and the United Arab Emirates saw growth in production over the period from 2012 to 2022. A few countries, such as Argentina, Brazil, Japan and Saudi Arabia, have reportedly reduced their production(United Nations Environment Programme: GRID Geneva, 2024a and 2024b).

Alluvial and placer deposits

Alluvial deposits commonly contain tin, iron minerals, gold and diamonds. A description of chromite, garnet, platinum and other platinum-group minerals and amber is provided in Andreev and others (2008). An overview of placer deposits, formed by the concentration by gravity of heavy detrital minerals transported by rivers or ocean currents, is provided in Garnett and Bassett (2025). Tin is a critical mineral used in industrial alloying applications including bronze and solder. Alluvial tin deposits are most widely documented in Indonesia, but are also found in Malaysia, Myanmar and Thailand (Kamilli and others, 2018). A global review of tin resources and reserves by the International Tin Association shows that the majority of tin reserves in Indonesia, representing nearly 7% of globally reported mining inventory, are located offshore (International Tin Association, 2020).

The potential for iron deposits occurs in several marine regions, including the Black Sea and the coastal areas of Fiji, Indonesia, Japan, New Zealand and the Philippines. Titanomagnetite iron sand deposits on the west coast of North Island, New Zealand, are some of the world's largest. Among them, the Taranaki iron-sands deposit contains an estimated 3.2 billion tons of vanadium-rich titanomagnetite iron-sand resources, making it one of the largest vanadium deposits identified globally.

Marine deposits of alluvial gold are known to occur wherever rivers carrying gold grains enter the sea. The historical deposit of Nome, Alaska in the United States is currently being exploited alongside its associated riverine alluvial deposits (Nelson and Hopkins, 1972). Other notable examples include the historically mined beach and likely offshore placer deposits in Tierra del Fuego (De Dios Serra and others, 2026).

The best-known marine diamond deposits are located off the coasts of Namibia and South Africa, where operations began in the 1960s and were consolidated as the company Debmarine in 2002. South Africa issued its first marine diamond mining concessions in 1994 and has since continued to license active miners such as De Beers, Alexkor, Trans Hex, Bluewater Diamonds, Nautical Diamonds and Poseidon

Marine. Production steadily increased until at least 2019, using vessels that ranged from artisanal vessels, where divers use handheld suction hoses, to large factory vessels (Schneider, 2020; Gales, 2024a).

Mineral precipitate deposits

Precipitates in the present review include polymetallic nodules, ferromanganese crusts, and phosphorites.

Polymetallic nodules contain various metals, with the composition of those nodules differing among marine environments. Manganese and iron are the most abundant, while nickel, copper, cobalt, molybdenum, titanium and rare earth elements can also be present in significant amounts. These metals are used in a wide range of industrial applications including steel alloys, battery formulations and medical applications.

Recent developments have been focused primarily on three regions of the Area, namely, the Clarion-Clipperton Zone, the Central Indian Ocean Basin and the North-West Pacific basin (International Seabed Authority, 2024j), and three areas within national jurisdiction, namely, the Cook Islands and Minamitorishima (Japan), both in water depths over 4,000 m, the Gulf of Bothnia (Sweden and Finland), at relatively shallow depths (~ 20-120 m). The first integrated test mining exercise since the late 1970s was conducted by The Metals Company and its partner Allseas in late 2022 in the Clarion-Clipperton Zone (The Metals Company, 2022).

Ferromanganese crusts broadly speaking contain the same metals as polymetallic nodules but can have high concentrations of metals such as cobalt and platinum group elements. Hydrogenetic crusts that form on seamounts are the best studied (International Seabed Authority, 2008b), but crusts can also form on sediments and diagenetically (RSC Mining and Mineral Exploration, 2023). Crusts have been identified from the Area, in the North-Western Pacific and the Rio Grande Rise (International Seabed Authority, 2026b), as well as from areas within national jurisdiction, such as those of the Cook Islands, Minamitorishima and Norway (Norwegian Offshore Directorate, 2023). Both China and Japan have recently developed seabed drilling systems to prospect for mineral resources and to perform mining tests within and beyond their respective national jurisdictions (Japan Oil Gas and Metals National Corporation, 2020; Ren and others, 2021; Xie and others, 2022).

Marine phosphorite sediments contain potentially economic levels of phosphate, which is used mostly in fertilizer and other chemical applications. The largest terrestrial deposits of phosphate are fossil uplifted marine deposits (U.S. Geological Survey, 2024). While global demand for and production of phosphates are increasing, so are efforts to use the material more efficiently (see, e.g., Cordell and Neset, 2013), with reduction in growth rates of phosphates (FAO 2019).

The three currently most advanced projects involving exploitation are within the national jurisdictions of Mexico, Namibia and New Zealand (Kudrass and others, 2017). While all three phosphate deposits are interpreted to have formed from authigenic processes, they vary in water depth (from tens to hundreds of metres of depth), grain size (from sand to gravel) and resource size (from tens to hundreds of millions of tons). In all three projects, it is planned to recover the phosphorites with a trailing suction hopper dredger and enriched by on-board size screening (e.g., (Golder Associates (NZ) Limited, 2014). These three projects stalled at the stage of environmental impact assessment and permit approval (Environmental Protection Authority, 2015; Namibian Marine Phosphate, 2016; Odyssey Marine Exploration, 2018). The respective developers are currently exploring alternative options to advance their projects (Namibian Marine Phosphate, 2022; Chatham Rock Phosphate, 2024; Odyssey Marine Exploration, 2024).

Hydrothermal deposits

Volcanogenic polymetallic sulfide deposits are formed by the precipitation of sulfide minerals from metals dissolved in hot water that circulates through rocks. These types of deposits are known to occur throughout the geological record (Shanks and Thurston, 2012), with offshore deposits known mostly from active tectonic settings associated with spreading centres and volcanic arcs (Hannington, 2014) both within and beyond national jurisdiction. The metal content varies and may include copper, gold, zinc and lead. Active hydrothermal systems can be important hotspots for marine life and food webs supported by chemosynthetic microbes ((Van Dover and others, 2020).

Recent developments regarding the exploration of these deposits include drilling and the development of new mining technologies (Bauer Maschinen GmbH, 2021) tested in situ, notably in Japan and Papua New Guinea (Washburn and others, 2023; Alberts, 2024). Norway is preparing to issue mining licences for sulfides and manganese crusts in areas within its national jurisdiction in the first half of 2025 with a view to starting commercial exploitation in 2030.

Sediment-hosted brines were discovered in the 1960s. The zinc-rich Atlantis II, Discovery, Valdivia and Wadi Wando deposits in the Red Sea and along the border between the Sudan and Saudi Arabia are the largest known marine hydrothermal ore deposits and the only known modern analogue of brine pool-type metal deposition(Bertram and others, 2011; Laurila and others, 2015).

Biogenic deposits

The presentation below includes rare earth element deposits but excludes natural gas hydrates.

Rare earth elements (as well as scandium and yttrium) are used in a wide range of applications, including electronics. Clays rich in rare earth elements are found in various parts of the Pacific Ocean (Kato and others, 2011; Azami and others, 2018; Pak and others, 2018). Rare earth elements are found in both ferromanganese precipitates and, more significantly, in biogenic fluorapatite. In addition to deposits found in the Area, muds rich in rare earth elements have been identified in areas within the national jurisdictions of the Cook Islands and Japan.

Under the second Cross-ministerial Strategic Innovation Promotion Program, led by the Cabinet Office of Japan, a mud-lifting test was conducted off the coast of Ibaraki in 2022 using the deep-sea scientific drilling vessel Chikyū, owned by the Japan Agency for Marine-Earth Science and Technology. The Program has been under way around Minamitorishima island as the third Cross-ministerial Strategic Innovation Promotion Program since 2023. A characteristic of the red clay ooze rich in rare earth elements found in both Minamitorishima and the Cook Islands is that it can be very sticky. Testing by the Strategic Innovation Promotion Program involves the use of a piston corer and mining system.

Past demand for minerals

The period from 1900 to 1929 was considered an era of strong growth in demand. The driver was the rapid urbanization of the United States and Western Europe. The initial impetus came from farm mechanization, which created a push-and-pull mechanism that contributed to urbanization. The period from 1929 to 1938, however, was an era of low growth in demand. In that decade, the United States and Western Europe were in the grip of the Great Depression. The period from 1950 to 1975 experienced a return to high growth in demand with the post-war economic boom. The period from 1975 to 2000 was an era of weaker growth in demand after the post-war boom, and it came to an end by the mid-1970s amid widespread industrial strife and persistent inflation. Thereafter, a boom in demand for metals from emerging economies, led by mining in China, began in the late 1990s and early 2000s (Lynch, 2024).

Rising demand for minerals

According to the Global Resources Outlook 2019, metals extraction increased 3.5 times between 1970 and 2017 (IRP, 2019). Global domestic extraction of metal ores is projected to grow at a yearly average of 1.7% from 2015 to 2060. It is also projected that 9% of total global resources extraction will be of metal ores in 2060.

Depending on their economic feasibility, deep-seabed minerals could play a role in securing a sustainable supply of metals (Hernandez, 2023). Mineral deposits on the seabed tend to contain higher metal content than those on land (Heffernan, 2019). World demand for minerals may be difficult to predict but it will certainly be influenced by three general factors: (a) increasing use of mineral commodities; (b) demographic increase; and (c) economic growth.

Under certain scenarios, variations in economic growth might affect future mineral demand more than demographic increase alone. Per capita consumption of a high number of minerals has risen globally during the past decade, and the greatest increases have been related to economic growth (Briskey and Schulz, 2007; Kesler, 2007).

Future mineral demand, including of critical minerals (International Energy Agency, 2024), in support of the green energy transition will be very high in 2040 or 2050. Due to this predicted increase in demand, a potential risk of imbalances in supply and demand is possible. For instance, copper is required for all power generation and transport technologies. Lithium, cobalt and graphite are used in electric car batteries, as is nickel, which is also used in a number of power generation technologies. Rare earth minerals are needed for offshore wind turbines. Nickel and platinum group metals are important for hydrogen production, and rare earth elements play a role in hydrogen production, as well as in wind turbines and batteries. Aluminium also plays an important role across a wide range of green technologies (United Nations Environment Programme, 2024).

Market trends

A 2020 World Bank report on minerals for climate action found that production of metals could increase by nearly 500% by 2050 (Hund and others, 2023). The potential global market for deep-sea mining driven by the demand for critical minerals is projected to expand from $650 million in 2020 to $15.3 billion by 2030 (Global Mining Review, 2021).

Global mine production of rare earth elements, which are essential for manufacturing technological products, is estimated to have increased to about 350,000 tons of rare-earth oxide equivalent. Such production will have a transversal impact on the economy’s primary, secondary and tertiary sectors (Cuadros-Muñoz and others, 2024).

The Ministry of Industry and Information Technology of China raised 2023 quotas to 240,000 tons for rare-earth mining and separation and to 230,000 tons of rare-earth oxide equivalent. In 2023, mine production quotas of rare earth were set at 220,850 tons for light rare earths and 19,150 tons for ion-adsorption clays (U.S. Geological Survey, 2024).

Towards net-zero emissions

According to the *World Energy Outlook 2022*, mineral requirements for green energy technologies will quadruple by 2030 in the net-zero emission scenario, with particularly high growth in materials for electric vehicles (International Energy Agency, 2022). The type of mineral resource required varies by technology. Lithium, nickel, cobalt, manganese and graphite are crucial for battery performance. Rare earth elements are essential for permanent magnets in wind turbines and electric vehicle motors. Electricity networks require large amounts of copper and aluminium, with copper a cornerstone of all electricity-related technologies.

According to the World Energy Outlook special report *The Role of Critical Minerals in Clean Energy Transitions*, revised in 2022, the collective demand for critical metals is expected to increase almost twentyfold between 2020 and 2050, from less than 10 million tons to roughly 150 million tons, to meet the demand for low-carbon energy technology under the net-zero emission scenario (International Energy Agency, 2021). Critical minerals and metals required for battery storage are anticipated to increase nearly fortyfold, while those required for low-carbon electric power generation are expected to triple. The total market size of critical minerals and metals such as copper, cobalt, manganese and various rare earth metals will grow almost sevenfold between 2020 and 2030 in the net zero pathway. One of the most recent assessments of critical minerals involves scenario forecasts for recycling (International Energy Agency, 2025), and, in some cases, growth in primary demand for critical minerals may stabilize or even drop by 2035, although total required inventory will continue to grow into the next few decades.

The global infrastructure financing gap is estimated to be around $15 trillion by 2040. In order for everyone in the world to have basic infrastructure over the next 20 years, the world would need to increase its annual infrastructure spending by just under $1 trillion every year, compared with the previous year's spending. The *Global Material Resources Outlook to 2060* issued by the Organisation for Economic Co-operation and Development estimates that the greatest increase in resource consumption by 2060 will be in minerals, especially construction materials and metals, particularly in fast-growing economies (OECD, 2019). According to the National Mining Association of the United States of America, the United States Department of Defense alone uses nearly 750,000 tons of minerals each year (National Mining Association, 2017).

3.Impacts

The present part of the chapter contains a review of potential environmental impacts and technological developments relating to the exploration for and exploitation of ocean mineral resources and describes the need to achieve a balance among them. This is crucial in order to ensure that if and when exploration and/or exploitation takes place, the social and economic needs of present and future human generations are addressed.

Environmental issues

The question of whether environmental impacts from proposed deep-sea mineral extraction are acceptable is currently still largely unanswered for many seabed mineral types. Environmental impact assessments for the exploitation of marine mineral resources at a commercial scale have been carried out only for offshore diamonds (Debmarine Namibia, 2024) , phosphorites (Chatham Rock Phosphate Limited, 2014) and a single polymetallic sulfide deposit, for example, at the Solwara 1 project (Nautilus Minerals Niugini Limited, 2008). No environmental impact assessments have been completed for polymetallic nodules or ferromanganese crusts. Limited environmental impact assessments have been completed to support pilot testing of nodule mining equipment (Global Sea Mineral Resources, 2018; BGR, 2019; Sharma and Goswami, 2021).

Good-practice environmental impact assessments follow a structured approach (Clark and others, 2017; Clark and others, 2020). They usually start with a scoping exercise, proceed to the collection and compilation of baseline data and then culminate in the project-specific environmental impact assessment, which is used to justify an environmental permit (or, for example, an exploitation contract with the International Seabed Authority (ISA)). Environmental impact statements might be required for exploration and pilot mining tests before the project environmental impact assessment is carried out. A project environmental impact assessment or statement will usually include a description of the types and scope of activities contemplated, an environmental risk assessment of those activities (usually done in line with a framework such as DPSIR (drivers, pressures, state, impact, response) (Maxim and others, 2009; Elliott and others, 2017) and the incorporation of peer and public review stages.

It is important to note that a prefeasibility or feasibility study is normally needed for a detailed description of activities (see subpart below on technological issues). That study would then need to be aligned with the environmental impact assessment.

The environmental impact assessment is usually part of a broader framework, called an ecosystem-based management framework (see, e.g. United Nations Environment Programme, 2025). This widely recognized practice integrates various environmental programmes to assess risk, organize knowledge, inform stakeholders, direct monitoring requirements and activities, and ultimately maintain a healthy ecosystem. In addition to the environmental impact assessment process, other parts of an ecosystem-based management framework may include:

- A regulatory regime (including overarching principles and more detailed requirements and recommendations within standards and guidelines, such as the Mining Code of ISA (International Seabed Authority, 2026c).
- Baseline datasets (from marine scientific researchers and other developers).
- Related cases from other developers and mining tests.
- Regional assessments, such as strategic environmental assessments (SPREP, 2020) and regional environmental management plans, including consideration of cumulative impacts (International Seabed Authority, 2022d).
- Stakeholder engagement aspects, including independent review by subject-matter experts and public involvement.

The current state of knowledge regarding seabed mineral districts and projects is considered within the ecosystem-based management framework. For example, contributions to understanding baseline conditions and possible environmental impacts may begin broadly and generically, then become more focused as specific projects approach the permit application stage. Through constructive dialog with stakeholders, issues are addressed and flaws can be recognized at an early stage.

Currently there is considerable focus on the possible exploitation of polymetallic nodules in areas beyond national jurisdiction, where several advanced projects are undergoing environmental impact assessments (International Finance Corporation, 2013). A key issue is that regulations for exploitation have not yet been finalized by the regulator, ISA. In addition, important work is still needed to inform supporting standards and guidelines. Some current initiatives include the following (International Seabed Authority, 2024c):

- Methodological work for biodiversity assessment, as part of an action plan for marine scientific research.
- Development of environmental threshold values (including those related to generated plumes and noise).
- Interactions between fishing and activities related to mineral resources.
- Biogeochemical modelling, to better understand carbon storage and release in the deep sea (OceanICU, 2023).
- Internalization of environmental costs.
- An intersessional expert group, formed by ISA, on the development of binding environmental thresholds on (a) toxicity; (b) turbidity and settling of resuspended sediments; and (c) underwater noise and light pollution.

Technological issues

Any sustained development of seabed minerals depends on cost-effective technologies. Particular risks arise when novel technology is used.

While, in theory, technology can be developed (see, e.g., European Marine Energy Centre, 2008) independently from projects (see, e.g., McCarthy, 2015), in practice the two are often intertwined. Scoping studies and subsequent prefeasibility studies usually consider alternative technological options that may be at different levels of technology-readiness. Even though seabed minerals originate from the ocean, their onshore processing involves the same challenges as in land-based mineral processing(McNulty, 1998).

In the previous century, significant efforts were made with respect to exploration and mining tests , although interest subsided after the 1970s (Lipton and others, 2016). Recently, the interest in the extraction of polymetallic nodules has been rekindled. The United Nations and, later, ISA have organized technology-focused workshops approximately once per decade since the 1970s (United Nations Ocean Economics and Technology Branch, 1984; Office of Resources and Environmental Monitoring, 1999; International Seabed Authority, 2008a). After issuing preliminary economic assessments in 2015 (Golder Associates, 2015) and 2019 (AMC Consultants, 2019), Nauru Ocean Resources Inc. and its parent, The

Metals Company, plan to issue prefeasibility studies in 2025 for both mining and metallurgical processing (The Metals Company, 2023 and 2025).

The entire value chain, from seabed exploration and exploitation to product sales, requires some level of development. Additional effort is being focused on reducing environmental impacts, including through the refinement of available technology (Rizea and others, 2023; NOV, 2026) and the development of new technologies (see, e.g., Beijing Pioneer Hi-Tech Development Corporation Ltd., 2024). Other areas of technological development include:

- Environmental monitoring systems (JPI Oceans, 2023; Silva and others, 2023)
- Adaptation of existing ships (OE Staff, 2022).
- Alternative lift system development (NOV, 2026).
- Alternative nodule collection techniques (Impossible Metals, 2023; Ocean Mining Intel, 2023).
- “Ship-to-shore" programmes, including class and safety considerations (Gales, 2024a), and the forthcoming ship-to-shore joint industry programme.
- Metallurgical programmes (The Metals Company, 2023).

Technological developments are also continuing for other types of deep-sea minerals. Below are a few examples.

- One focus of technology development for seafloor massive sulfide mining is to reduce environmental impacts, including plumes (Bauer Group, 2021).
- Research is ongoing on cutting ferromanganese crusts, as variable crust thicknesses makes it challenging to achieve consistent cuts at sufficient production rates (JOGMEC, 2020; Xie and others, 2022).
- Research is being carried out to improve liquefaction for the lifting of muds rich in rare earth elements (JAMSTEC, 2023).

Apart from the technological issues related to the start of production, longer-term consideration needs to be given to the scale of production. Future possible economies of scale should ideally be factored into seabed mineral exploitation permits. Production rates should also be considered in both environmental impact assessments and cumulative impact assessments. In shallow-water marine industries, some operations have progressively expanded in scale, such as De Beers’ marine diamonds operations (Richardson, 2007), while others have maintained flatter production profiles, such as PT Timah’s tin operations (Anderson and Oosthuizen, 2024).

4. Socioeconomic considerations

The second *World Ocean Assessment* contained an overview of the economic landscape for seabed mining and the associated social impacts. The present part of the chapter contains an update to the information provided in the second *World Ocean Assessment*. It is important to note, however, that, at present, only exploration activities are taking place in the Area. The decision on whether seabed mining may proceed to the exploitation phase rests with States Parties of the United Nations Convention on the Law of the Sea..

According to article 136 of the Convention, the Area and its resources are the "common heritage of humankind". In line with this principle, any activity in the Area should be for the benefit of all countries, with a focus on equitable sharing, particularly with developing nations. ISA has the mandate to regulate activities in the Area and to ensure that resources are exploited fairly, that international cooperation is promoted and that the environment is protected. Accordingly, economic considerations are an integral part of negotiations on exploitation regulations.

In 2015, the Council of ISA adopted seven priority deliverables for the development of the exploitation code. The second priority entailed the development of a payment mechanism for exploitation activities that follows detailed financial and economic modelling based on proposed business plans. During the following two years, various workshops were organized to develop such a payment system. In 2018, the ISA secretariat commissioned the Massachusetts Institute of Technology to develop an economic model for the exploitation of polymetallic nodules that could be used to model various payment systems and royalties (International Seabed Authority, 2023c). The Institute compared results with three other models, received from China, Germany and the Group of African States. In 2019, the Council agreed to set up an open-ended working group to discuss the financial model and, in particular, to review the comparative study. In 2020, the ISA secretariat commissioned two consultants to examine comparable land-based mining systems (CRU and RMG Consulting, 2020). In 2022, some member States suggested that the cost associated with environmental externalities should be internalized in the model. In 2023, two studies on the evaluation of natural capital were completed, which are expected to inform further policy discussions (Banfder, 2023; Brander and Guisado Gõni, 2023). Between 2019 and 2024, the open-ended working group met on 10 different occasions.

Several financial mechanisms govern how contractors contribute to the economic benefits derived from activities in the Area. While the contractor payment regime is the overall financial structure determining how contractors compensate the international community for extracting resources from the Area, there are other, non-monetary, benefits to humankind. One specific type of payment within the contractor payment regime consists of royalty payments paid to ISA for the rights to exploit nodules. Various ad valorem royalty-fee structures, including fixed, variable and staged structures, are currently under negotiation with respect to percentages (Hogan, 2008). Once commercial mining begins in the Area, the administrative costs of ISA, to be covered by ISA member State contributions, will be financed by the revenue generated from royalties. According to article 151 (10) of the Convention, another portion will flow to support the establishment of an economic assistance fund. This fund will assist developing countries when their economies are adversely impacted by deep-seabed mining, for example, through reductions in mineral prices or decreases in export volumes. Another portion of the revenue generated from the royalties will flow to an environmental compensation fund which is intended to fill any liability gaps. The remaining revenue will be distributed among the member States, with a particular focus on developing States.

In 2022, the Group of African States assessed the various payment regime options and how they interact with the tax systems of sponsoring States. In 2023, the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development analysed various equalization measures as an addition to the payment regime options to ensure a level playing field between contractors and sponsoring States (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development, 2023; Roth and others, 2023; Wilde, 2024). Various options were deliberated during the twenty-ninth session of ISA, in

2024 (International Seabed Authority, 2024f), and these discussions continued at Council negotiations during the thirtieth session (2025).

Benefit-sharing is a crucial element of the legal regime, as it addresses the interests and needs of developing States. In 2022, the ISA secretariat published a policy brief outlining its work on benefit-sharing, which has been under the supervision of the Finance Committee since 2018 (International Seabed Authority, 2022a). The brief draws on the findings of ISA technical study 31, which examines the concept and mechanisms for implementing benefit-sharing and also highlights non-monetary benefits (International Seabed Authority, 2022f).

Alternative approaches to benefit-sharing include the establishment of a seabed sustainability fund. The ISA Secretary-General presented a proposal for the fund's establishment to the Finance Committee in 2023, and member States have yet to discuss it International Seabed Authority, 2023b; 2024a and 2024b). Some studies suggest, based on modelling for various distribution approaches for the 170 member States, that the economic benefit for an individual country may be limited, and also highlight the potential value of the seabed sustainability fund in supporting broader sustainability goals (Wilde and others, 2023). The draft exploitation regulations frequently reference social impacts, emphasizing that all activities in the Area should serve humankind. One key mechanism to achieve this is capacity-building, which fosters the development of human capital and creates lasting, intergenerational benefits.

Under the Convention (see arts. 144, 273 and 274), ISA has a duty to design and implement mechanisms that support capacity-building for developing States. These mechanisms promote technology transfer and expand opportunities for participation in activities in the Area. Experts trained through ISA programmes contribute by sharing their knowledge and skills with local specialists, strengthening expertise within their home countries.

A key social component is the legal obligation for contractors to provide training opportunities for personnel from developing States, notably through the contractor training programme (International Seabed Authority, n.d.a.). This programme has delivered world-class training in deep-sea research and technology development to experts from developing countries. To date, over 350 professionals have benefited, including 115 women and 118 trainees from least developed countries, landlocked developing countries and small island developing States. In 2024, a stocktaking policy brief highlighted the accelerated efforts of ISA in this domain, emphasizing the essential role of collaborative partnerships (International Seabed Authority, 2024c).

5. Legal and regulatory frameworks for activities relating to marine mineral resources

The Area

In accordance with article 1 of the Convention, "Area" means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction. The Convention recognizes the Area and its resources as the common heritage of mankind, and provides that activities in the Area shall be conducted for the benefit of all humankind as a whole.

Activities in the Area are managed by ISA, an autonomous international organization established under the Convention and the Agreement relating to the Implementation of Part XI of the Convention (the 1994 Agreement). As at the time of writing, ISA has 172 members (comprising 171 States and the European

Union) with a seat in the Assembly, the supreme organ and plenary body of the Authority. The Council, the executive body, comprises 36 members selected according to a formula that requires representation of special interests, including States with large populations and those that are major importers or net exporters of the commodities to be derived from the Area. Council decisions may result from recommendations by its subsidiary organs: the Legal and Technical Commission and the Economic Planning Commission. As established by the 1994 Agreement, the functions of the Economic Planning Commission have been carried out by the Legal and Technical Commission. The 1994 Agreement also set the functioning of the Finance Committee, whose recommendations shall be considered by the Assembly and Council of ISA. The Finance Committee is tasked with considering the administrative and budgetary implications of proposals involving expenditure from funds of the Authority and with considering the rules, regulations and procedures on the equitable sharing of financial and other economic benefits derived from activities in the Area. As a general rule, decision-making in the organs of the Authority should be by consensus.

The Authority has adopted regulations on prospecting and exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts and is currently discussing draft regulations, standards and guidelines for the exploitation of these resources. In July 2023, following the announcement by Nauru of its intention to submit in 2025 an application for the exploitation of polymetallic nodules in the Area, the Council decided that exploitation should not commence in the absence of regulations.

The activities developed under the 31 contracts currently in place for exploration for minerals in the Area are monitored through reports submitted annually by contractors to the Authority (International Seabed Authority, 2024e).

Recent developments in areas under national jurisdiction

In the present subpart, only two jurisdictions will be considered.

Cook Islands

The development of deep-seabed minerals is viewed as a possible material contributor to diversifying the economy of the Cook Islands, and successive governments have therefore maintained an interest in the sector.

The initial Seabed Minerals Act came into force in 2013, leading to the establishment of the Seabed Minerals Authority. In 2019, the Act was repealed with the promulgation of a new one that had undergone more extensive stakeholder and public review. The Authority manages the industry in consultation with an Advisory Committee that is composed of community leaders and a technical advisory group consisting of relevant government agencies. Some aspects of due governance are managed through the interaction between legislation and institutions. The Seabed Minerals Act, the Environment Act (2003) and the Environment (Seabed Minerals Activities) Regulations 2023, are thus administered by the National Environment Service. The Marae Moana Act 2017 is administered by the Marae Moana Council, and the fishing-oriented Marine Resources Act (2005) is administered by the Ministry of Marine Resources. The entire exclusive economic zone of the Cook Islands (an area of almost 2 million km^2) is defined in law as a multiple-use marine park and includes marine protected areas (MPAs) within 50 nautical miles of each of the 15 islands (~ 14.8% of the exclusive economic zone). All environmental data, as well as the details of exploration licences and any approved variations, goes into the public domain.

Following a competitive tender for the exploration of seabed minerals in October 2020, a total of three licences were issued to Cook Islands-based companies in February 2022. The exploration licence is valid for an initial five-year period, and a licence-holder may apply to have it renewed, subject to statutory requirements.

Norway

In July 2019, the Norwegian Seabed Minerals Act, relating to mineral activities on the continental shelf of Norway, entered into force. In January 2024, the parliament of Norway voted in favour of the Government's proposal to open up an area of approximately 281,000 km^2 for exploration of deep-sea minerals, with a particular focus on polymetallic sulphides and ferromanganese crusts. The Seabed Minerals Act stipulates that any targeted area must be subject to an opening decision by the Government, based on an impact assessment that identifies the potential effects of such an opening on the environmental, economic and social pillars of sustainable development. The impact assessment was finalized in October 2022 and followed by the receipt of consultation inputs.

The licence regime includes a non-exclusive survey licence and an exclusive extraction licence. The former is granted for a period of up to five years and covers a specific area for the exploration and mapping of minerals for commercial purposes. The latter gives the licensee the exclusive right to conduct a survey and to extract all minerals for commercial purposes in the area covered by the licence. An extraction licence can be granted for an initial period of up to 10 years with a possibility of applying for an extension. Unlike the survey licence, the extraction licence may be granted only to Norwegian entities.

6. Sustainability pathways in the Area and regions under national jurisdiction

Sustainable development is aimed at meeting human needs without compromising future generations' ability to do the same (see A/42/427). A key aspect of sustainability under the Convention is the precautionary approach, which guides all activities in the marine environment. States and ISA are obligated to use the best available scientific data to prevent significant harm to the marine environment while promoting the responsible and sustainable use of deep-sea resources.

The sustainable exploration and potential exploitation of deep-sea minerals depend upon four key pillars: (a) scientific and technological innovation; (b) inclusive stakeholder participation; (c) environmental management; and (d) reliable data. These pillars are integral to the responsibility of ISA for overseeing activities related to deep-sea mineral resources in the Area and ensure that exploration and exploitation are conducted in a manner consistent with international law, including the precautionary approach.

Advancements in science are key to guiding sustainable development. The Convention, in article 143, highlights the mandate to conduct and promote marine scientific research in areas under national jurisdiction and in the Area. In 2017, in paragraph 292 of its resolution 72/73, the General Assembly proclaimed the United Nations Decade of Ocean Science for Sustainable Development. In support of the Decade, the Assembly of ISA adopted its Marine Scientific Research Action Plan in 2020 (ISBA/26/A/17). The plan sets out six strategic research priorities and has since served as a global framework and agenda for the advancement of deep-sea research (see ISBA/27/A/4, ISBA/28/A/8 and

ISBA/29/A/5) . In 2024, a stocktaking report was published that put forward recommendations for shaping the future marine research landscape (International Seabed Authority, 2024h). One recommendation, for example, is that the Authority should channel its short-term focus towards addressing knowledge gaps identified in the regional environmental management plan process in order to support the science-policy interface through projects that have contributed to a joint programme initiative.

Technological innovation plays a vital role in implementing the precautionary approach in deep-sea resource management by enhancing the ability to prevent harm to marine ecosystems. Advances in technology support the development of sophisticated monitoring and assessment tools, allowing for real-time data collection and more precise evaluations of potential environmental impacts. For example, improved remote sensing technologies, autonomous underwater vehicles and advanced satellite systems can provide detailed insights into the health of deep-sea habitats and ecosystems. However, it is also important to consider the potential risks associated with technological advancements, such as unintended ecological impacts and ethical concerns regarding the use of artificial intelligence and automation. Significant technological advancements have been made, and, in April 2024, experts of an ISA scoping workshop identified five priority areas for future development: ocean observation and communication; monitoring; autonomy; automation, robotics, artificial intelligence and machine learning; and mining, energy and metal processing (Sharma, 2017; International Seabed Authority, 2022c, 2022e, 2024l).

Inclusive stakeholder participation is essential for ensuring transparency and accountability in the governance of marine resources. ISA actively engages a diverse range of stakeholders to support informed decision-making and strengthen its mandate. This ongoing commitment aligns with the strategic priorities of ISA, which are focused on advancing marine resource governance through collaboration and science-based policies (International Seabed Authority, 2018, 2019, n.d.b).

Environmental management is essential to sustainable development, balancing the need for resource extraction with the protection of marine ecosystems. Regional environmental management plans are designed as measures to protect the marine environment in specific parts of the Area from the potential harmful effects of activities in the Area. They are aimed at providing a framework for ensuring environmental protection while enabling the sustainable use of marine resources. Although regional environmental management plans are informed by environmental assessments, their development is not based solely on regional environmental impact assessments but also incorporates broader scientific, environmental and regulatory considerations (International Seabed Authority, 2026a). The Legal and Technical Commission of ISA is currently advancing standardized procedures for the development and review of such management plans, which include elements such as environmental goals, management measures and monitoring processes. To support these efforts, the Commission is also creating technical guidance to complement the standardized procedure (see ISBA/29/C/10 and ISBA/29/LTC/8). One notable success is the regional environmental management plan of the Clarion-Clipperton Zone, in which a scientific review identified additional ecologically significant areas that were subsequently granted protection.

Reliable data are essential for informed decision-making and sustainable development in deep-sea mining. It underpins rigorous environmental impact assessments, supports the creation of robust regulatory frameworks and enables responsible management of deep-sea mineral extraction, thereby safeguarding fragile marine ecosystems and promoting long-term economic viability. ISA shares the non-confidential data of contractors, following the FAIR (findable, accessible, interoperable and reusable) principle. The Authority's DeepData database serves as a central repository for environmental data relating to the Area, with an average of 5,580 monthly visitors as of April 2024.[1] ISA continues to enhance data quality through partnerships with organizations such as the World Register of Marine Species (WoRMS) and the Ocean Biodiversity Information System of the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization, as well as the Natural History Museum, London and the Pew Charitable Trusts, which have led to an in-depth assessment of the quality of biological data (Rabone and others, 2023).

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[1] See https://data.isa.org.jm/isa/map/, https://data.isa.org.jm/isa/map/.

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