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The Common Heritage applied to the resources of the seabed. Lessons learnt from the exploration of deep sea minerals and comparison to marine genetic resources.

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Abstract

This paper draws a parallel between mineral resources of the deep sea and marine genetic resources. The paper first discusses the discovery and first deep sea exploration of minerals bearing metals of economic interest. Secondly, the paper gives a brief historical overview of metal prices, and other external factors, such as the technological challenge and the global economic conditions, that have so far prevented from entering into an exploitation phase of deep seabed mining in areas beyond national jurisdiction. Subsequently, the paper provides an outline of the state of the art in the scientific investigation of marine genetic resources, and gives an overview of possible harmful consequences of exploiting hotspots of marine life through bioprospecting in the deep sea. The two examples analysed serve to substantiate the idea that international authorities tend to be established at a too early stage of scientific knowledge, pressured by misleading preconceptions, which are not based on sound and free marine scientific research.

Keywords: deep sea mineral resources; polymetallic nodules; International Seabed Authority; marine genetic resources; ABNJ

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1. Introduction

Metallurgy is rooted in ancient history. Ever since man first discovered copper in 9,000 BC, metals have been of such fundamental importance for human evolution that they define the principal steps of human technological progress. Such is the case for the Bronze Age (an alloy of copper and tin) and for the Iron Age. In modern times, our lives are becoming more and more dependent on metals and other elements, for which there is an increasingly strong demand and decreasing supply, given their critical role for low carbon and digital technologies. Copper continues to be of great importance and is used in a wide range of applications, including the renewable energy industry, as heat dissipater

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and electrical conductor; cobalt is used in lithium ion battery cathodes; nickel and manganese are used in stainless steel. A group of chemical elements, the Rare Earth Elements (REEs) and Yttrium (Y) are essential in several high-tech sectors, such as TV and smartphones' screen colour, laser technology, cancer treatment, hydrogen storage, light-emitting diodes (LEDs). The discovery of polymetallic nodules forming on the deepest abyssal plains of the ocean first suggested the idea of harvesting minerals from the seafloor. The initial phase of scientific investigation at sea lasted from 1972 to 1982, following the prediction of global mineral shortage, and culminated in the successful testing of a pilot-plant system in 1978. By the early 1980s, metal prices plummeted and marine research on deep seabed minerals of economic interest lost momentum. Although proved technically feasible, it remained debatable whether seabed mining could be economically competitive with land mining.

Nevertheless, this inspired the establishment of an international legal regime and the creation of an international institution to govern the mineral resources of the deep seabed in areas beyond national jurisdiction (ABNJ) as the common heritage of mankind, as declared in resolution 2749 (XXV) of 17 December 1970 of the General Assembly of the United Nations.[1] The International Seabed Authority (ISA) was established under the United Nations Convention on the Law of the Sea (UNCLOS).[2] The ISA was a response to an idealistic vision whereby the mineral wealth should be shared by all countries, whether developed or developing, coastal or landlocked. Furthermore, the human costs behind land mining, the issues of illegal and child miners, environmental pollution and displacement of local populations, issues that, is worth to say, have remained substantially unchanged to date,[3] were becoming more and more evident to the public opinion. Today, 50 years later, several factors, including prevailing economic conditions and technological challenges, still make the exploitation of seabed mining in the Area unfeasible. Furthermore, despite working within the framework established by UNCLOS and despite the progress made for example with respect to the reporting on mineral resources by contractors,[4] more recently, in 2015, the ISA has been the subject of political attacks and mudslinging campaigns.[5] Principal promoters of the campaigns are international environmental agencies, which consider that the ISA is not doing enough in terms of environmental protection or that lacks transparency compared to other maritime organizations, such as Regional Fisheries Management Organisations.[6]

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1 UN General Assembly, Declaration of Principles governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, beyond the Limits of Nations Jurisdiction, 17 December 1970, A/RES/2749(XXV).

2 The United Nations Convention on the Law of the Sea (UNCLOS) (adopted 10 December 1982, entered into force 16 November 1994) 1833 UNTS 397 and see UN General Assembly, 'Agreement Relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982' 33 ILM 1309.

3 Todd C Frankel, 'The Cobalt Pipeline: Tracing the path from deadly hand-dug mines in Congo to consumers' phones and laptops' (*The Washington Post*, 30 September 2016) <www.washingtonpost.com/graphics/business/batteries/congo-cobalt-mining-for-lithium-ion-battery/> accessed 9 November 2018.

4 Pedro Madureira and others, 'Exploration of Polymetallic Nodules in the Area: Reporting Practices, Data Management and Transparency' (2016) 70 Marine Policy 101.

5 'ISA: Protect our oceans' <https://secure.avaaz.org/en/deep_sea_mining_en_dn4/?byxqlab&v=62027> accessed 9 November 2018.

6 Jeff A Ardron, 'Transparency in the Operations of the International Seabed Authority: An Initial Assessment' (2018) 95 Marine Policy 324.

In addition to mineral resources, the deep sea mineral environments host biological communities that live in extreme chemical-physical conditions. The communities host enormous amounts of genes and metabolites dispersed in the biomass and sediments that represent the primary resource for bioprospecting in the deep sea beyond national jurisdiction. On 19 June 2015, the United Nations General Assembly (UNGA) adopted resolution 69/292, which launched a preparatory committee tasked with preparing elements of a draft text for an international legally binding instrument for the conservation and sustainable use of marine biological diversity of ABNJ, including marine genetic resources (MGRs), implying that there is a direct connection between the conservation of biodiversity and the access to human-exploitable biological resource. The UNGA adopted a new resolution at the end of 2017, with which it convened an intergovernmental conference, under the auspices of the United Nations, to consider the recommendations of the preparatory committee and to elaborate the text of an international legally binding instrument, with a view to developing it as soon as possible.

Are we navigating the same experience for deep sea MGRs as for mineral resources: a research, industry and investment sector which is still in its infancy and for which there is a clear intention to establish, by 2020, an international regime, at what is arguably far too early a stage of scientific knowledge?

2. The mineral resources of the deep sea

Marine mineral resources can be harvested from the seabed at different water depths (Tab. 1). The majority of them are found in relatively shallow waters (0-1000 m) and only polymetallic nodules, polymetallic sulphides and ferromanganese crusts form at water depths found in ABNJ. In particular, only the polymetallic nodules are found almost exclusively in ABNJ. The projection of World Economic Exclusive Zones (EEZs) boundaries v10[7] over 500-m-contours generated from the General Bathymetric Charts of the Oceans[8] indicates that, on average, only water depths exceeding 3000 m belong to ABNJ. Currently, most of seabed mining activities are carried out within EEZs. Contrary to what is commonly thought, the relatively shallower geologically-defined continental shelves (0-200 m water depths) have not been, so far, solely the domain of oil and gas producers.[9] On the contrary, a significant and underestimated damage to the environment has been already caused by extensive seabed mining activities. For example, dredging of sand and gravel for the construction industry and land reclamation projects is a common practice, especially in northern Europe, United Arab Emirates, Singapore, and in the South China Sea, around the disputed Spratly Islands. Global indirect estimates of aggregates extraction, based on cement production alone, accounts for about 45 billion tonnes every year.[10] Most of this extraction comes from marine sources. Reliable data on

7 'Shapefiles Maritime Boundaries v10' <www.marineregions.org/downloads.php> accessed 9 November 2018.

8 Pauline Weatherall and others, 'A New Digital Bathymetric Model of the World's Oceans' (2015) 2 Earth and Space Science Research 331.

9 Mark Hannington, Sven Petersen and Anna Krätschell, 'Subsea Mining Moves Closer to Shore' (2017) 10 Nature Geoscience 158.

10 UNEP/GRID-Geneva, 'Sand, Rarer than One Thinks' (2014) 11 Global Environmental Alert Service 208 <https://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=110> accessed 9 November 2018.

marine aggregate extraction are unavailable and estimates account for only 140 million tonnes (as 2016), coming from few European countries and U.S., which are the only countries providing figures for statistics.[11]

Table 1 – Principal marine mineral resources, use and average water depths where they are found.

Commodity	**Use**	**Water depth (m)**
Tin	Computers Components	0-up to 50
Iron-Gold	Metals	0-50
Phosphates	Manufactured Fertilisers	100-500
Diamonds	Safe-Haven Asset	0-200
Sand and Gravel	Constructions, Land Reclamation	30-150
Polymetallic Nodules	Metals	3500-6500
Polymetallic Sulphides	Metals	5-6000
Ferromanganese Crusts	Metals, REE	800-2500 (seamounts)

In 1868, stony nodules rich in manganese and copper were discovered on the seabed of the Kara Sea, offshore Siberia.[12] A few years later, similar nodules were found in the abyssal plains of the ocean during the expeditions of the research vessel Challenger.[13] At first, scientists were not even interested in the nodules, but in the cosmic spherules attached to them;[14] almost a century had to pass before deep sea nodules were again discussed.

Polymetallic nodules typically occur on sediment-covered abyssal plains at 3500–6500 m water depths, where sediment accumulation rates are extremely low (as low as 10 cm per thousand year)[15] and where nodules grow at rates up to 250 mm per millions of years. Nodules are comprised of iron oxy-hydroxides and manganese oxides and form abiotically by hydrogenetic (from seawater) and diagenetic (from pore fluids) precipitation about a hard nucleus on the surface of soft sediment. More recently however, the role of microbial metabolism in nodule development has also been recognized.[16] Polymetallic nodules contain metal elements such as manganese, cobalt, copper, nickel

11 SCICOM Steering Group On Ecosystem Pressures and Impacts, *Report of the Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem* (ICES CM 2016) SSGEPI:06.

12 Yu A Bogdanov and others, 'Ferromanganese Nodules of the Kara Sea' (1994) 34(5) Okeanologiya 789.

13 John Murray and Alphonse François Renard, *Report on the scientific results of the voyage of H.M.S. Challenger during the years 1872-76* (published by order of Her Majesty's Government, Eyre & Spottiswoode 1891).

14 Robert B Finkelman, 'Magnetic particles extracted from manganese nodules: suggested origin from stony and iron meteorites' (1970) 167 Science 982.

15 David Z Piper and Michael E Williamson, 'Composition of Pacific Ocean Ferromanganese Nodules' (1977) 23 Marine Geology 285.

16 James R Hein and others, 'Deep-Ocean Mineral Deposits as a Source of Critical Metals for High- and Green-Technology Applications: Comparison with Land-Based Resources' (2013) 51 Ore Geology Reviews 1.

and traces of molybdenum and lithium.[17] From very recent video surveys, we know that sessile fauna use nodules as their habitat and that the removal of this scattered hard substrate would cause a loss in biodiversity and connectivity.[18] Polymetallic nodules are present in quantities and density that can be commercially exploited (eg composite metal grade > 2.5%, which is equivalent to 25 kg per tonne, and density > 10 kg m^{-2})[19] in few abyssal plains of the ocean. These are: the Clarion Clipperton Fracture Zone (CCZ), the Peru and the Samoa Basins (all of these are in the Pacific Ocean) and the central Indian Ocean.[20]

In the 1970s and early 1980s, another important discovery occurred in the deep ocean: sites were discovered where the venting from the seafloor of toxic compounds such as hydrocarbons and superheated hydrogen sulphide (up to 400°C), driven by magmatic/volcanic heat, allow the life of complex ecosystems. Hydrothermal vents associated with chemosynthetic communities were first discovered along the Galápagos Rift in 1977,[21] while hydrocarbon seepage at the seabed and in the overlying water column was first documented along the Florida continental slope, in the Gulf of Mexico, in 1984.[22] Their existence was anticipated by the discovery of metalliferous muds in the Red Sea, in the mid-1960s.

Life in these extreme habitats is sustained by consortia of bacteria. Bacteria cannot survive in the proximity of superheated hydrothermal fluids (the upper limit for microbial life is actually 120° C), but outside the hottest waters, instead of using the energy of sun light to turn carbon dioxide into sugar (photosynthesis), they harvest chemical energy from the minerals and chemical compounds to release sugar and sulphur (chemosynthesis).[23]

The presence of abundant sulphur in these environments sustains life for animals, like tubeworms, clams and mussels, that live in symbiosis with sulphur-oxidizing bacteria, which provide them with metabolic energy in exchange of sheltering inside their bodies.[24] These chemical conditions allow not only the existence of extremely adapted ecosystems, but also the deposition of metals on the seabed. The superheated fluids leach out metals from the surrounding rocks in the sub-seabed and enter the water column as a plume. When the plume mixes with cold seawater, dissolved metals precipitate as

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17 Benjamin J Tully and John F Heidelberg, 'Microbial Communities Associated with Ferromanganese Nodules and the Surrounding Sediments' (2013) 4 Frontiers in Microbiology 1.

18 Ann Vanreusel and others, 'Threatened by Mining, Polymetallic Nodules Are Required to Preserve Abyssal Epifauna' (2016) 6 Scientific Reports 26808.

19 Geoffrey P Glasby, 'Lessons Learned from Deep-Sea Mining' (2000) 289 Science 551.

20 Hein and others (n 16).

21 John B Corliss and others, 'Submarine thermal springs on the Galápagos Rift' (1979) 203 Science 1073.

22 Charles K Paull and others, 'The first Biological communities at the Florida escarpment resemble hydrothermal vent taxa' (1984) 226 Science 965.

23 Frank W Adair and Kristian Gundersen, 'Chemoautotrophic sulphur bacteria in the marine environment, I. Isolation, cultivation and distribution' (1969) 15 Canadian Journal of Microbiology 345.

24 Antje Boetius, 'Microfauna-Macrofauna Interaction in the Seafloor: Lessons from the Tubeworm' (2005) 3 PLoS Biology 375.

polymetallic sulphides on the seabed. Sulphides are formed mainly by minerals such as pyrite, chalcopyrite, sphalerite which are sources of copper, zinc, lead, but also gold (tens of grams per tonne) and silver (hundreds of grams per tonne).[25] 65 % of global polymetallic sulphides form along mid-ocean ridges, which are located in ABNJ, but, especially in the western Pacific Ocean; they deposit along back arc basins spreading centres and volcanic arcs on seabeds of national jurisdiction.[26] It is apparent that, particularly for this type of resource, the exploitation would cause physical damage to the seabed and the loss of extremely rare and site-specific ecosystems.

The third deep sea mineral resource are the ferromanganese crusts, which occur only where rock surfaces are free of sediment on the flanks of seamounts at water depths of 600–7000 m. Seamounts and crusts of economic interest are located at a restricted water depth range of 800–2500 m. Their thickness varies from less than 1 mm to about 260 mm and they form pavements of manganese and iron oxides which grow at very slow rates of 1–5 mm per millions of years. Ferromanganese crusts are composed of iron oxyhydroxide and manganese oxide that precipitate directly from cold, ambient ocean water, from which they sorbe several metals (hydrogenetic accretion). Crusts contain manganese, cobalt, copper, nickel and significant traces of rare metals and elements (titanium, platinum, zirconium, neodymium, tellurium, yttrium, bismuth, molybdenum, vanadium, thorium).[27] In the Pacific Ocean, there are tens of thousands of seamounts and a high percentage of them belong to the seabed within the national jurisdiction of Small Pacific Island States. By comparison, the Atlantic and Indian Ocean have fewer seamounts.[28] It is difficult to arrive at a global marine mineral resource and reserve estimate, due mostly to the fact that only 15 % of the ocean seabed is mapped,[29] but recent rough estimates indicate areas of availability in the order of 38 million km^2 (nodules), 1.7 million km^2 (crusts), 3.2 million km^2 (sulphides).[30] It must be mentioned that the actual tonnage of global sulphides is poorly known compared to the other resources.

3. The concept of deep seabed mining and the establishment of the ISA

The publication in 1965 of *The Mineral Resources of the Sea*[31] by JL Mero, which portrayed a feast of manganese, cobalt, nickel and copper in the abyssal plains of the ocean, launched hundreds of research cruises in the following decade and inspired the creation of the ISA.[32] Mero in 1977 estimated that the nodules from the 6 million-km^2-large CCZ, 400 km off Mexico in the Pacific Ocean, where

25 Sven Petersen and James R Hein, *The Geology of Sea-Floor Massive Sulphides* (Secretariat of the Pacific Community 2013).

26 Mark Hannington and others, 'The Abundance of Seafloor Massive Sulfide Deposits' (2011) 39 Geology 1155.

27 James R Hein, Tracey A Conrad and Rachel E Dunham, 'Seamount Characteristics and Mine-Site Model Applied to Exploration- and Mining-Lease-Block Selection for Cobalt-Rich Ferromanganese Crusts' (2009) 27 Marine Georesources & Geotechnology 160.

28 Peter T Harris and others, 'Geomorphology of the Oceans' (2014) 352 Marine Geology 4.

29 Weatherall and others (n 8).

30 Sven Petersen and others, 'News from the Seabed – Geological Characteristics and Resource Potential of Deep-Sea Mineral Resources' (2016) 70 Marine Policy 175.

31 John L Mero, *The Mineral Resources of the Sea* (Elsevier, 1965).

32 Peter A Rona, 'Resources of the Sea Floor' (2003) 299 Science 673.

the majority of exploration licenses for polymetallic nodules have been granted so far by the ISA, would contain 12 billion tonnes of commercial metals.[33] These figures proved to be unrealistic and are no longer reliable for the area. The investigation of the 1970s culminated in the successful testing of a pilot-plant system in 1978 by a consortium of seven companies sponsored by U.S., Germany, France, UK and Japan. The test was conducted in the CCZ at 5400 m water depth, with a recovery of 800 tonnes of nodules. Unfortunately, the entire mining system was lost at sea at the end of operations.[34] Furthermore, in the same period, the U.S.-based company Lockheed Martin claimed the construction of the mining vessel Glomar Explorer. The mining system was hosted in an 82-m-long bay, openable from the ship's hull. But the Glomar Explorer had been built in 1971 by the U.S. Central Intelligence Agency primarily to recover the K-129 Soviet nuclear submarine sunken off Hawaii in 1969 (project Azorian). To keep the mission secret, the U.S. government kept pretending that the ship was a mining vessel, using billionaire Howard Hughes as a front man. The recovery mission was proceeding successfully, when the claw mechanism, designed to bring the submarine to the surface, failed and a section of the boat broke off during the ascent to the ship.[35]

In the aftermath, and possibly accelerated by this rollercoaster of alternating events, the International Seabed Authority (ISA) established its headquarters in Kingston, Jamaica, in 1994. The ISA has the mission of administering, on behalf of humankind, mineral resources beyond the limits of national jurisdiction (article 157 of UNCLOS), comprising about 54 % of the global ocean floor. Since then, the ISA has put in place a comprehensive legal and technical framework covering prospecting and exploration of marine minerals, with detailed guidelines and recommendations to help contractors to comply with their contractual obligations, in terms of reporting their activities and environmental assessment.[36] In 2012, the ISA approved an Environmental Management Plan for the CCZ, which includes the designation of Areas of Particular Environmental Interest (APEIs), which have a function similar to that of Marine Protected Areas (MPAs) in ABNJ.[37]

The ISA has so far approved twenty-nine contracts for exploration covering areas of the seabed in excess of 1.2 million km^2.[38] Sixteen contracts are for exploration for polymetallic nodules in the CCZ, one in the Central Indian Ocean Basin. Seven contracts are for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and five for cobalt-rich crusts in the Western Pacific Ocean and South Atlantic. Six of these exploration licenses reached the 15-year term in 2016/2017 and the contractors applied for an extension of their explo-

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33 John L Mero, *Marine Manganese Deposits* (Elsevier, 1977).

34 Glasby (n 19).

35 Tony Munoz, 'Grand Finale for Infamous Glomar Explorer - Part 1 The ship that secretly raised a Soviet submarine is being scrapped' (*The Maritime Executive*, 18 June 2015) <http://maritime-executive.com/features/grand-finale-for-infamous-glomar-explorer> accessed 9 November 2018.

36 ISA, *Consolidated Regulations and Recommendations on Prospecting and Exploration* (International Seabed Authority 2013).

37 Michael Lodge and others, 'Seabed Mining: International Seabed Authority Environmental Management Plan for the Clarion-Clipperton Zone. A Partnership Approach' (2014) 49 Marine Policy 66.

38 ISA, 'Deep Seabed Contractors'<www.isa.org.jm/deep-seabed-minerals-contractors> accessed 9 November 2018.

ration licenses, citing prevailing economic conditions as an obstacle to proceed into an exploitation phase.[39] Contractors are currently represented by private entities, sponsored by the state party to the UNCLOS where the company is based; governmental research institutions; the states themselves; governmental bodies and their branches (Tab. 2).

Table 2 – Categories of the ISA contractors and their sponsoring states.

Contractor	Type	Sponsoring state
Cook Islands Investment Corporation	Private entity	Cook Islands
UK Seabed Resources Ltd	Private entity	UK
Ocean Mineral Singapore Pte Ltd	Private entity	Singapore
G TEC Sea Mineral Resources	Private entity	Belgium
Marawa Research and Exploration Ltd.	Private entity	Kiribati
Tonga Offshore Mining Ltd	Private entity	Tonga
Nauru Ocean Resources	Private entity	Nauru
Deep Ocean Resources Dev. Co. Ltd	Private entity	Japan
Yuzhmorgeologiya	Private entity	Russian Federation
Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)	Research organization	Germany
Institut Français de la Mer (Ifremer)	Research organization	France
Government of India	Member state	India
Government of the Republic of Korea	Member state	Republic of Korea
Government of the Russian Federation	Member state	Russian Federation
Ministry of Natural Resources and Environment	Governmental body	Russian Federation
Oil, Gas and Metals National Corporation	Governmental body	Japan
Companhia De Pesquisa de Recursos Minerais	Governmental body	Brasil
China Ocean Mineral Resource R&D Association (COMRA)	Governmental body	China
Interoceanmetal Joint Organization	Governmental body	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation, Slovakia

39 ibid.

The sponsoring state exercises control over the contractor, by requiring it to comply with the provisions of UNCLOS regarding its activities in the Area. To what extent the sponsoring state is accountable for the failure of the sponsored contractor to meet its own obligations, has been recently the subject of some debate. On this matter, the Council of the ISA consulted the Seabed Disputes Chamber (SDC) of the International Tribunal for the Law of the Sea (ITLOS). In 2011, the SDC issued an advisory opinion[40] that made it clear that the sponsoring state is not liable for the failure of the sponsored contractor and that an eventual damage caused by the sponsored contractor is not automatically attributable to the sponsoring state. The SDC put on the same liability level developing and developed states, except with regards to the application of the precautionary approach, which has to apply according to the capacity of the state, in terms of scientific and technical knowledge.[41]

The next phase for the ISA is to develop a regulatory and fiscal framework for exploitation.[42] A 'zero draft' of the regulations was completed by February 2016, after the ISA launched a stakeholder consultation in 2014, followed, in January 2017, by a discussion paper. In August the same year a new version of the 'Draft Regulations on Exploitation of Mineral Resources in the Area' was finalized.[43] This includes exploitation rights, contract duration, initial financial terms and expected fiscal regime, size of permitted exploitation areas, environmental impact assessment and environmental management plans. The mining code is a prerequisite for entering an exploitation era; investors need a level of certainty about future profits and revenues, especially in the case of deep seabed mining, which is an emerging industry with little developed business models.

4. The challenge of deep sea technology and the state of the art of imminent deep seabed mining projects in areas of national jurisdiction

There are still many challenges that deep seabed mining has to face, in terms of technological requirements for harvesting mineral resources in the deep sea, lifting and retrieval of minerals to the operating vessel, and mineral processing for metallurgy. For example, bioleaching as well as pyro- and hydrometallurgical techniques, for the extraction of metals, are being tested only at a laboratory scale.[44] Some companies and governmental institutions maintain that they have developed the technology for deep sea nodules recovery, but most of their advancements are at the stage of design, concept, prototype or, indeed, they are testing small-scale systems for shallow waters.

40 Seabed Disputes Chamber, *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, Advisory Opinion* (ITLOS Case 17, 1 February 2011, p 76).

41 Ximena Hinrichs Oyarce, 'Sponsoring States in the Area: Obligations, Liability and the Role of Developing States' (2018) 95 Marine Policy 317.

42 ISA, *Towards the development of a regulatory framework for polymetallic nodule exploitation in the Area* (International Seabed Authority Technical Study 11, 2013).

43 ISA, 'Ongoing development of regulations on exploitation of mineral resources in the Area'<www.isa.org.jm/legal-instruments/ongoing-development-regulations-exploitation-mineral-resources-area> accessed 9 November 2017.

44 Klaus Bosecker, 'Bioleaching: metal solubilisation by microorganisms' (1997) 20 FEMS Microbiology Reviews 591.

For example, BGR appointed Aker Wirth GmbH (now MH Wirth) to develop a self-propelling collector vehicle concept, in 2010.[45] In 2008, the National Institute of Ocean Technology, India, started developing a pumping system for nodule mining, which is designed to be effective at 1032 m water depth.[46] In 2007, the South Korea-based Institute of Ocean Technology (KIOST) developed a deep sea mining robot called MineRo to collect nodules up to 1300 m water depth. In 2012, they progressed with the design and manufacture of a pilot mining robot, MineRo-II, equipped with a module able of crushing nodules into smaller pieces. Since deep sea tests are enormously expensive and time-consuming, numerical simulations for predicting the dynamic behaviour of the materials have to run for years, before a real test takes place at sea.[47]

Mining the crusts is more challenging, because crusts can be firmly attached to the underlying rock substrate. This has substantially, so far, hampered the technological development for this mineral resource, because it is economically unsustainable.

The Canada-based Nautilus Minerals, which was granted an exploration license for polymetallic sulphides in the Bismark Sea, Papua New Guinea, back in 1997, runs the Solwara 1 Project, located approximately 50 km north of Rabaul, at 1600 m water depth. For this purpose, in 2016, Nautilus Minerals developed a complete mining system comprised of three prototype robots designed and built by the UK-based company Soil Machine Dynamic (SMD). The seafloor production tools comprise an auxiliary cutter, a bulk cutter and a collecting machine. The tools arrived in Papua New Guinea in April 2017, where they are undergoing submerged trials. Various components of the remote-controlled mining system such as the deployment system of the tools, the pumping and lifting systems are under development and they strictly depend on the final design of the operational support vessel, which is under construction in China.[48]

The project raised substantial private capital investment to achieve its goals and in 2011 Nautilus Minerals obtained a 20-year mining lease for extracting copper and gold. However, the project has been halted for several years due to major environmental concerns, protests by the local communities and public consultations with stakeholders. The project will possibly enter in production in 2019, but the company has had to postpone the date several times in the last years, because of the current ongoing litigation with the Papua New Guinea local communities, registered at Waigani National Court House, over a socially acceptable environmental impact assessment study.[49]

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45 'Manganese nodule exploration in the German license area' <www.bgr.bund.de/EN/Themen/MarineRohstoffforschung/Projekte/Mineralische-Rohstoffe/Laufend/manganknollen-exploration_en.html> accessed 9 November 2018

46 'Deep Sea Technologies'<www.niot.res.in/index.php/node/index/33/> accessed 9 November 2018.

47 Chang-Ho Lee, Hyung-Woo Kim and Sup Hong, 'A Study on Dynamic Behaviours of Pilot Mining Robot according to Extremely Cohesive Soft Soil Properties' (ISOPE Ocean Mining and Gas Hydrates Symposium, Szczecin, September 2013).

48 'Seafloor Production Tools'(Nautilus Minerals)<www.nautilusminerals.com/irm/content/seafloor-production-tools.aspx?RID=333> accessed 9 November 2018.

49 'Nautilus' stock plummets as deep sea mining litigation proceeds' <www.deepseaminingoutofourdepth.org/nautilus-stock-plummets-as-deep-sea-mining-litigation-proceeds/> accessed 26 November 2018.

The 62 km^2 large Atlantis II Deep, 115 km west of Jeddah in the Red Sea, at 2000 m water depth, is the largest seabed mineral deposit on Earth. Here, muddy sulphide deposits were first discovered in the late 1960s. Samples collected in 1979 indicated that the major mineral is zinc with significant, but secondary, amounts of copper, gold and silver. The most promising deposits lie in a series of deep basins along the central spreading ridge. Here, 40 m of fine-grained metalliferous sediments have accumulated from inactive hydrothermal vent sites beneath 200 m thick hot brines, which rise water temperatures up to 56°C and salinities seven times greater than normal seawater. In 2010, the Saudi-Sudanese Red Sea Commission awarded a 30-year licence to Manafa International Ltd., a Saudi Arabian company. Diamond Fields International later joined the venture to pursue the project, which is located within the national jurisdiction of Sudan and Saudi Arabia. Both countries support the technological advancement as well as research and exploitation activities, but progress on the project is currently on hold pending a dispute over contractual issues. There are several additional technological challenges at Atlantis II Deep: minerals occur in extremely fine size of 2 microns, seabed sediments have high salinity and low strength. These elements combined together may cause difficulties to the seafloor tools' efficiency and their control systems, which need to be designed considering also the highly corrosive environment.[50]

In 2014, JOGMEC (Japan Oil, Gas and MEtals National Corporation) launched the 'Zipangu-in-the-Ocean' (Zipangu is the old name of Japan, and refers to Marco Polo's land of gold) under the auspices of METI (Ministry of Economy, Trade and Industry). The targeted seabed resources include nodules, sulphides and crusts. Japan is massively investing in technology advancement with a look to the environment, such as sensors to detect ore bodies covered by thick sedimentary bodies and so avoiding sensitive active hydrothermal vent faunas.[51] The inferred sulphide ore reserve at the Hakurei site, Okinawa Trough, comprises 3.74 million tonnes of zinc, copper, silver and gold, making it second only to Atlantis II Deep. In the southern Japanese continental margin, there is another polymetallic sulphide deposit, the so-called Sunrise, located in the Izu-Ogasawara Arc at about 2600 m water depth, but so far there has not been great progress on the assessment of this area.

5. How socio-economic conditions have influenced metal prices and deep seabed mining in the last 50 years

The world economy experienced an unprecedented boom in 1972–73, with a consequent rapid growth in demand for raw materials, and a corresponding price boom for several commodities, including metals. The sharp rise was soon followed by an abrupt fall during the recession of 1974–75. The period of booming prices experienced acceleration of the overall rates of inflation, the adoption of a floating exchange rate system for most of the currencies and speculation activity in the market.[52]

50 Lev Egorov and others, *Sustainable Seabed Mining: Guidelines and a New Concept for Atlantis II Deep*, (vol 4, The LRET Collegium 2012).

51 Testsuro Urabe and others, 'Next-Generation Technology for Ocean Resources Exploration (Zipangu-in-the-Ocean) Project in Japan' (MTS/IEEE OCEANS, Genoa, May 2015).

52 Richard N Cooper and Robert Z Lawrence, 'The 1972-75 Commodity Boom' (1975) 3 Brookings Papers on Economic Activity 671.

In 1977–1978, the Shaba conflict broke out when the Congolese National Liberation Front (FNLC) crossed the border from Angola into the modern Democratic Republic of Congo, in an attempt to achieve the Katanga province's secession from the dictatorship of Mobutu. The FNLC occupied the mining town of Kolwezi and cobalt mines nearly stopped production. This caused some speculation activities and had long-term impacts on the cobalt market, which developed into a free market.

In 1980 gold hit record high at 850 $ per ounce (in August 1972, U.S. had devalued dollar to 38 $ per ounce of gold) during a period characterized by high inflation, strong oil prices, Soviet intervention in Afghanistan and the Iran revolution, which encouraged investors to buy safe-haven assets.[53]

Under these circumstances, deep seabed mining appeared to be the ideal response to global concerns about imminent shortage of metal supply over a predicted growing population and unprecedented economic boom.[54] When the 'Great Commodities Depression' occurred, the prices of raw materials remained depressed and declined from, roughly, 1982 until 1998.[55] At the same time, marine exploration activities were almost completely abandoned. Low prices were due to weak demand and poor economic conditions, especially in Asia, where the economic crisis hit in 1997. Copper prices, for example, fell to the lowest level in the U.S., since the Great Depression of the 1930s. During that time, recycling and recovery of some key metals, such as cobalt, substantially increased.[56]

During the first two decades of the 2000s (2000–2014), the world has experienced a commodities boom[57] or the so-called 'commodities super cycle'[58], with the rise, and subsequent fall, of many metal prices. The boom was largely due to the rising demand from emerging markets such as the BRIC countries, particularly China during the period 1992–2013, for electrical goods (copper, neodymium and tantalum). Demand for rare elements and metals increased as computers, mobile and smart phones became more popular in the mid to late 2000s, especially in densely populated Southeast Asia. These facts resulted in new concerns over long-term supply availability.

There was a sharp downturn in prices during 2008 and early 2009 as a result of the credit crunch and sovereign debt crisis, but prices began to rise as demand recovered from late 2009 to mid-2010 and peaked in 2011.

When China, which almost owns a monopoly over the REEs production and export, stopped their exportation to Japan in 2010 for almost two months and imposed export quotas to the production,

53 Buying Gold, 'What happened to the gold price in 1980?' <http://buying-gold.goldprice.org/2008/01/what-happened-to-gold-price-in-1980.html> accessed 9 November 2018.

54 Donella H Meadows and others, *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (Universe Books 1972).

55 USGS, *Metal prices in the United States through 1998* (US Geological Survey 1999).

56 ibid.

57 Bilge Erten and Jose A Ocampo, *Super-cycles of commodity prices since the mid-nineteenth century* (United Nations Department of Economic and Social Affairs 2012).

58 Walt W Rostow, 'Kondratieff, Schumpeter, and Kuznets: Trend Periods Revisited' (1975) 35 The Journal of Economic History 719.

the problem of the mineral supply chain burst out again.[59] As a result, renewed concerns about the scarcity of supply metals and rare elements, especially for the renewable energy sector, entered in full force. European Union reacted in 2011, publishing a list of 14 Critical Raw Materials (CRMs), a priority action defined in the EU 'raw materials initiative' of 2008.[60] A second, revised, list of CRMs was out in 2014[61] and a third list of 27 CRMs was published in 2017,[62] based on a refined methodology, in areas such as manufacturing applications, trade, substitution, recycling. In 2011, probably to respond to China's move, a group of Japanese scientists published a paper claiming that the Pacific seabed muds are enriched in REEs and Yttrium to a point that would constitute a resource 1,000 time bigger than the land-based reserves.[63]

By the early 2000s, new technology had been made available from the deep sea oil & gas industry, which is now operating down to 3600 m water depth in the Gulf of Mexico. Stellar metal prices and new perspectives in the offshore, due to high prices of crude oil, prompted again the idea that deep seabed mining was an industrial option.

In the meantime, coastal member states were supposed to present their proposals for the extension of their continental shelves by May 2009, following the publication, ten years prior, of the 'Scientific and Technical Guidelines' of the United Nations Commission on the Limits of the Continental Shelf (CLCS). Coastal states can extend their EEZs up to 350 nautical miles from the coast or 100 nautical miles from the water depth of 2500 metres, pursuant article 76(5) of UNCLOS. Australia, for example, was amongst the first countries to submit the proposal in 2004. In 2008 the CLCS expanded the Australian continental shelf to reach a size about 1.3 times larger than its land area. It is possible that also this circumstance acted as an incentive to considering again the deep seabed mining as the next frontier in the offshore industry, because mineral resources are present in areas that can fall within national jurisdiction, where coastal state's rules, in terms of licensing and environmental protection, apply. Regulations can considerably vary from state to state and in most cases, they are not even in place, making the opportunity of seabed mining very attractive especially to small capital enterprises.

Around the beginning of 2000s, as a consequence of these concomitant factors, several international research projects, initiatives and joint academic-industry expeditions were launched at sea, which summed or interacted with the exploration activities that the ISA contractors were committed to undertake starting from 2002. With a lot of new high-quality data and images of the seabed coming in[64], previously unexpected environmental concerns were raised and, starting by the end of 2010s,

59 Richard Herrington, 'Road Map to Mineral Supply' (2013) 6 Nature Geoscience 892.

60 European Commission, 'Tackling the challenges in commodity markets and on raw materials' COM (2011) 25 final.

61 European Commission, 'On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative' COM (2014) 297 final.

62 European Commission, 'On the 2017 list of Critical Raw Materials for the EU' COM (2017) 490 final.

63 Yasuhiro Kato and others, 'Deep-Sea Mud in the Pacific Ocean as a Potential Resource for Rare-Earth Elements' (2011) 4 Nature Geoscience 535.

64 Ann Vanreusel and others (n 18).

fierce international campaigns against deep seabed mining have been promoted worldwide by environmental organizations.[65]

In the current state of affairs, no deep seabed mining operations are active either beyond or within national jurisdiction. The 'deepest' seabed mining activities currently operating are for diamonds collection down to 200 m water depth,[66,] along the Atlantic margins of Namibia and South Africa[67] and, as previously said, for aggregates extraction on the majority of the continental shelves around the world, up to around 180 m water depth.

One argument, which is often used against the new wave of seabed mining venture, is that there is plenty of potential in recycling metals, especially from modern technological devices. Recycling of aluminium, ferrous metals, copper, gold, palladium and platinum in mobile phones and computers components had got under way by the mid-2000s. Battery recycling has helped, for example, to bring down the nickel and cadmium prices. Furthermore, Europe has promoted research and innovation in raw materials, to find candidate materials for substitution, but this initiative is not based on a full and comprehensive analysis of materials' substitution sustainability.[68]

For many analysts, recycling cannot meet the demand for rare metals, used in digital and green technologies[69] and the issues of metal supply would need a more careful governance,[70] as well as revised recycling strategies from the countries.[71] Investors[72] fiercely neglect metal shortage from land sources.[73] On the contrary, there are scientific studies projecting to only 150 years the availability of copper from land sources, at the current rate of dissipation during its use, for 8 billion people with standard of living of the western world.[74]

The prices for metals fell sharply during the third quarter of 2015. The downturn reflected concerns about demand (notably from China), ongoing supply increases from land sources, renewed dollar

65 ISA: Protect our oceans (n 5).

66 Richard HT Garnett, 'Recent Developments in Marine Diamond Mining' (2002) 20 Marine Georesources and Geotechnology 137.

67 'Sub-sea diamond mining' (2010) 2 Ship & Offshore 25 <www.schiffundhafen.de/fileadmin/user_upload/Publikationen/ShipOffshore/2010-02/pdf/Air-lift-drilling-Sub-sea-diamond-mining.pdf> accessed 9 November 2018.

68 Elza Bontempi, *Raw Materials Substitution Sustainability* (SpringerBriefs in Applied Sciences and Technology 2017).

69 Andrew Bloodworth, 'Track Flows to Manage Technology-Metal Supply' (2014) 505 Nature 9.

70 Saleem H Ali and others, 'Mineral Supply for Sustainable Development Requires Resource Governance' (2017) 543 Nature 367.

71 Georg Rombach, 'Raw Material Supply by Aluminium Recycling-Efficiency Evaluation and Long-Term Availability' (2013) 61 Acta Materialia 1012.

72 Priscila Barrera, 'This Major Cobalt Producer Doesn't See a Tight Market Yet' (*Investingnews.com*, 30 October 2017) <https://investingnews.com/daily/resource-investing/critical-metals-investing/cobalt-investing/major-cobalt-producer-doesnt-see-tight-market/> accessed 9 November 2018.

73 'Indium Supply'<www.indium.com/metals/indium/supply/> accessed 9 November 2018.

74 Robert B Gordon, Marlen Bertram and Thomas E Graedel 'Metal stocks and sustainability' (2006) 103 Proceedings of the National Academy of Sciences of the United States of America 1209.

strength, and still high stocks of a number of metals.[75] Almost all metal markets tipped into surplus in late 2015. Copper is suggested to have a market behaviour comparable to crude oil, and for this reason is often used as an indicator of global slowdown in economy.

These prevailing economic conditions have made impossible for all the ISA contractors, which applied for an exploration licence in 2001 and 2002, to move into an exploitation phase in their permit areas after 15 years, and all applied for an extension of their exploration contracts for a further 5-year term.

Pursuant to regulation 2, of part 2 of the 'Consolidated Regulations and Recommendations on Prospecting and Exploration' for the three types of mineral resources of the Area,[76] prospecting shall not be undertaken in an area covered by an approved plan of work for exploration by a third party or in a reserved area by the ISA. This means that no other entities than the contractor may undertake marine research assessing composition, sizes and distributions of mineral deposits in an area, which is covered by an exploration license. Exception is made only for developing states, based on regulation 17 of the above, which are allowed to submit a plan of work for exploration with respect to a reserved area. In a certain sense, pragmatically speaking, contractors, having exploration licenses for a number of years and over a number of areas, are exerting a dominant position and a 'territorial right', by excluding any other kind of 'applied' marine research in their licensed areas.

Metal prices recovered in 2017, and was the first rise in the last five years, although they did not top the quotations of the 2000s. In 2017, metal prices were projected to jump 16 % by the end of the year due to strong demand, especially from China, and supply constraints, including mine disruptions in Chile, Indonesia and Peru.[77] Base metals have maintained a positive trend in the first months of 2018.[78] This is in line with the theory of the commodity super-cycle,[79] which predicts overall periods of about forty years, characterized by commodity prices steadily climbing for the first decade or two, followed by a second phase of the sub-cycle when prices slowly fall back to where they were at the beginning. According to this theory, commodity prices should start rising again in late 2010s,[80] in line with the theory of the super-cycle. In principle, the sum of these external factors, together with the completion of the mining code from the ISA, should favour the initiation of deep seabed mining activities in ABNJ, in the coming years.

75 Debbie Carlson, 'Is a global economic recession coming? Copper price say 'yes" (*The Guardian*, 14 January 2015) <www.theguardian.com/business/2015/jan/14/copper-prices-fall-fears-looming-global-recession> accessed 9 November 2018.

76 ISA (n 36).

77 World Bank, 'Industrial Commodity Prices to Rise in 2017'<www.worldbank.org/en/news/press-release/2017/04/26/industrial-commodity-prices-to-rise-in-2017-world-bank> accessed 9 November 2018

78 'Commodity and Metal Prices' <www.infomine.com/investment/metal-prices/> accessed 9 November 2018.

79 Colin Lloyd, 'Does the rising price of industrial metals herald the beginning of the next commodity super-cycle?' (*Seeking Alpha*, 1 September 2017) <https://seekingalpha.com/article/4103677-rising-price-industrial-metals-herald-beginning-next-commodity-super-cycle> accessed 9 November 2018

80 Erten and Ocampo (n 57).

6. Marine Genetic Resources

By conducting a search of the expression 'marine genetic resources' in Scopus, the largest database of peer-reviewed literature, and looking in article title, abstract and keywords, the first work dates back to 2000 and as of winter 2018, around 70 papers appear to have been published.[81] The papers are mostly in the field of environmental and policy sciences, and very few in medicine. Marine bioprospecting, as a science and practice, sprouted more than 60 years ago. Several marine compounds have reached successful clinical investigation starting from the 1980s,[82] but the majority of them are still in clinical trials and only few entered the market. Some successful examples include: the analgesic ziconotide developed from cone snail venoms by the former start-up Neurex; the DNA-interactive anti-cancer trabectedin, developed from the sea squirt, *Ecteinascidia turbinate*, by the Spanish company PharmaMar.[83] The sea squirt is an animal who lives attached to submerged mangrove roots in the Caribbean's areas. The derived pharmaceutical product is also known with the name of Yondelis® and commercialized by Zeltia and Johnson & Jonhnson in Europe, U.S., Russia and South Korea.

Other remarkable drugs include: the antiviral compound vidarabine, used against epithelial keratitis caused by herpes virus. This has been isolated from the sponge *Tectitethya crypta*. The antibody-conjugate anticancer agent brentuximab vedotin, commercialized with the name of Adcetris® in Europe, was extracted from the sea hare gastropod, *Dolabella auricularia,* which has a soft internal shell, made up of proteins. These proteins are used now for the cure of resistant Hodgkin disease, as a last chance when the patient is not responding to conventional medical treatments. The eribulin mesylate compound, extracted from sponge *Halichodria okadai*, is commercialized in Europe with the name Halaven® and used in late or terminal-stage breast cancer patients. As a matter of fact, the large majority of marine compounds, which entered in clinical trials in the late 1980s, are anticancer agents for rare diseases and have the status of orphan drugs.[84]

All the above-mentioned marine compounds, which are available on the market, come from organisms living in shallow to very shallow waters (0-10 m water depth) and therefore within national jurisdiction. There are several other marine compounds that have entered clinical trials; the following list does not intend to be an exhaustive review; it rather offers a non-specialist standpoint on marine bioprospecting.

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81 Elsevier's Scopus the largest abstract and citation database of peer-reviewed literature, 'marine genetic resources' <www.scopus.com/results/results.uri?numberOfFields=0&src=s&clickedLink=&edit=&editSaveSearch=&origin=searchbasic&authorTab=&affiliationTab=&advancedTab=&scint=1&menu=search&tablin=&searchterm1=%22marine+genetic+resources%22&field1=TITLE_ABS_KEY&dateType=Publication_Date_Type&yearFrom=Before+1960&yearTo=Present&loadDate=7&documenttype=All&accessTypes=All&resetFormLink=&st1=%22marine+genetic+resources%22&st2=&sot=b&sdt=b&sl=41&s=TITLE-ABS-KEY%28%22marine+genetic+resources%22%29&sid=c2111c404b52408ddd883a005b07bcad&searchId=c2111c404b52408ddd883a005b07bcad&txGid=0515243cd36b78d8b95b26c89f1623ed&sort=plf-f&originationType=b&rr=.> accessed 9 November 2018.

82 Andrew P Desbois, 'How Might We Increase Success in Marine-Based Drug Discovery?' (2014) 9 Expert Opinion on Drug Discovery 985.

83 Burkhard Haefner, 'Drugs from the Deep: Marine Natural Products as Drug Candidates' (2003) 8 Drug Discovery Today 536.

84 Stefania Nobili and others, 'Natural Compounds for Cancer Treatment and Prevention' (2009) 59 Pharmacological Research 365.

The most successful species in terms of bioprospecting is *Bugula neritina*, a bryozoan sessile animal living at water depths from intertidal to shallow subtidal, from which protein inhibitors, called bryostatins, have been isolated and which are currently under clinical trials for oesophageal cancer. The gastropod sea slug, *Elysia rubefescens*, feeds on the algae *Bryopsis sp.*, from which, most probably, derives the cyclodepsipeptide toxin isolated for the treatment of prostate cancer and other solid tumors. The marine tunicate, sea squirt, *Aplidium albicans,* which lives in shallow waters and from which PharmaMar extracted dehydrodidemnin B, is distributed only in Taiwan (as 2015) under the commercial name of Aplidin®, for myeloma treatment. The spiny dogfish, *Squalus acanthias*, is an edible species commercialized for centuries in Europe for the classic 'fish & chips' recipe, but for which there is little consumer demand elsewhere.[85] The shark lives at 50-150 m water depth and has been under investigation for squalamine lactate, and was actually in phase II clinical trials for ovarian and non-small cell lung cancer at Genaera Corporation, when the company went out of business in 2009.[86] The nemertine worm *Amphiporus lactifloreus*, which lives in the lower shore, under stones and pebbles, and in seaweed meadows provided the GTS21 selective partial agonist and was under clinical trials at Taiho Pharmaceutical Co Ltd in the early 2000s, when proved potentiality to treat dementia.[87] It is now commercialized by Sigma-Aldrich, as a selective agonist at α-7 nicotinic receptors, with anti-inflammatory and cognition-enhancing capabilities. From the sponge *Verongia aerophoba*, which lives in water depth ranges 2-10 m, a secondary metabolite Aeroplysinin-1 has been isolated with a wide spectrum of bio-activities, with promising anti-inflammatory, anti-angiogenic and anti tumor effects.[88]

There is still a lot of bioprospecting work to do on these and hundreds of other species, collected in the near shore areas of the world, mostly in the tropical and sub-tropical zones, which have been rich sources of biologically active natural products.[89] However, there is an increasing pressure on the establishment of a regulatory framework for deep sea genetic resources based on the presumption that the number of marine species used by humans is growing at unprecedented rates.[90]

Many authors barely distinguish between deep sea species and shallow water species from coastal areas. The 'deep sea' term is often used inappropriately and in some cases, deep sea genetic resources

85 'Dogfish' (*Seafood Source*, 23 January 2014) < www.seafoodsource.com/seafood-handbook/finfish/dogfish> accessed 9 November 2018.

86 'Genaera Corporation: Company Overview' <www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=31023> accessed 9 November 2018.

87 Harumi Kitagawa and others, 'Safety, Pharmacokinetics, and Effects on Cognitive Function of Multiple Doses of GTS-21 in Healthy, Male Volunteers' (2003) 28 Neuropsychopharmacology 542.

88 Javier A García-Vilas and others, 'Aeroplysinin-1, a Sponge-Derived Multi-Targeted Bioactive Marine Drug' (2016) 14 Marine Drugs 1.

89 Cristopher C Thornburg, Mark Zabriskie and Kerry L Mcphail, 'Deep-Sea Hydrothermal Vents: Potential Hot Spots for Natural Products Discovery?' (2010) 73 Journal of Natural Products 489.

90 Jesus M Arrieta, Sophie Arnaud-Haond and Carlos M Duarte, 'What Lies underneath: Conserving the Oceans' Genetic Resources' (2010) 107 Proceedings of the National Academy of Sciences 18318.

are considered to derive from water depths exceeding 200 m,[91] which is the average depth of the edge of the geologically-defined continental shelf. Defining the deep sea is not straightforward and mostly depends on the context and the scientific discipline or technology in use. Until a few years ago, hydrocarbon exploration, which was the driving factor in marine research, used to place the boundary of the deep sea at 200-400 m. Today, given the advances in the offshore technology, this boundary has been pushed to depths exceeding 3000 m. We have seen that, roughly, this limit coincides also with the outer boundaries of the national jurisdiction.

About 75 % of the ocean is comprised of water depths 3000-7000 m, and these remain unexplored for an astonishing 85 %; consequently, there is a lot still to discover in terms of biodiversity, chemical-physical processes occurring on the seabed, and metabolites dispersed in the biomass and in the sediments of the deep. Thus, statistically speaking, the largely unexplored deep ocean may likely contain the new frontier for MGRs compared to the terrestrial and shallow water sources. However, there are some aspects that have to be considered when talking about the future of bioprospecting in the deep sea.

Most of the current and future efforts in bioprospecting in the deep sea will focus on habitat communities of the hydrothermal vents[92] and hydrocarbon seeps for two main reasons: 1) these hotspots of life are among the most explored sites in the deep sea. 2) They contain microbes that are defined hyperthermophile and extremophile organisms, because are capable of surviving in super-heated and toxic conditions,[93]which makes their DNA attractive to bioprospecting.[82]

So far, a handful of products have been isolated from relatively deep hydrothermal vents, which are located in water depths exceeding 1000 m. The compounds are extracted from bacteria discovered in the East Pacific Rise at latitude 9°N and in the Guaymas Basin,[94] which are in the national jurisdiction of Mexico. The commercial products are distributed by BioLabs Inc. and are used as reagents in the DNA labelling procedure.

There are a number of reasons for being cautious about bioprospecting in these hotspots of extreme life, and not all of these relate to the overarching goal of protecting and conserving the biodiversity of the ocean.

Chemosynthetic habitats, such as hydrothermal vents and hydrocarbon seeps, are sparsely distributed across the seafloor. Multi-cellular organisms colonizing these sites have a low diversity despite the overall high biomass present. Approximately 50 % of the multi-cellular species are extremely

91 Harriet Harden-Davies, 'Deep-Sea Genetic Resources: New Frontiers for Science and Stewardship in Areas beyond National Jurisdiction' (2017) 137 Deep-Sea Research Part II: Topical Studies in Oceanography 504.

92 David Leary and others, 'Marine Genetic Resources: A Review of Scientific and Commercial Interest' (2009) 33 Marine Policy 183.

93 Robert A Zierenberg, Michael WW Adams and Alissa J Arp, 'Life in extreme environments: Hydrothermal vents' (2000) 97 Proceedings of the National Academy of Sciences of the United States of America 12961.

94 David Leary, 'Bioprospecting and the genetic resources of hydrothermal vents on the high seas: what is the existing legal position, where are we heading and what are our options' (2004) 1 Macquarie Journal of International and Comparative Environmental Law 137.

rare, represented by no more than five individuals in collections of tens of thousands of specimens. Finally, deep-water chemosynthetic ecosystems show high levels of endemicity.[95] This means that every hotspot is a separate, irreplaceable, micro universe, with little potential for a commercial-scale production.

Furthermore, deep sea bacteria of the chemosynthetic habitats have to deal with so far very little known harmful viruses. Viruses infect the dominant organisms in the ocean and their role in emerging and established diseases in marine and terrestrial ecosystems as well as the cycling of viruses between these reservoirs is largely unknown.[96] Are we considering with sufficient scientific attention the potential harmful consequences of accessing natural agents that have remained so far in the dark deep sea?

There are also more pragmatic considerations, for example, pharmaceutical companies do not have to bioprospect for natural products, they may just use chemical libraries as templates for creating synthetic analogues, which sometimes are deemed to be more effective, in terms of cytotoxicity on cancer cells.[97]

As a further warning bell, at least at the beginning of the research process, large quantities of the organisms have to be collected from the seafloor to obtain adequate amounts for clinical trials. For example, in the case of *Ecteinascidia turbinate*, more than half a tonne of the sea squirt needs to be harvested to obtain 1 gram of the compound. In the case of *Bugula neritina*, it took two years for divers to collect 17 tonnes of the organism off the southern California coast, where it is most abundant.[98] However, recently, aquaculture proved feasible for some MGRs in shallow waters, with costs that were deemed acceptable. On the contrary, in the deep sea, costs remain extremely high, due to deep water conditions and distance from the coast. Furthermore, harvesting for natural products is complicated by the spatial and temporal variability of these communities, which may substantially evolve and disappear in the time frame of months to a few years.[99]

7. Conclusions

The idea of the ISA, an international authority with the mandate of administering mineral resources of the dep sea, was a response to an era of catastrophic predictions over the future of the Earth's resources and concerns about a fast-growing global population. Its establishment was an answer to those fears with an idealistic vision whereby the mineral wealth of the deep seabed could be shared by all countries, as the common heritage of humankind. After more than 130 years from the discov-

95 Christopher R German and others, 'Deep-Water Chemosynthetic Ecosystem Research during the Census of Marine Life Decade and beyond: A Proposed Deep-Ocean Road Map' (2011) 6 PLOS ONE e232259.

96 Curtis A Suttle, 'Viruses in the Sea' (2005) 437 Nature 356.

97 Evelyne Delfourne and Jean Bastide, 'Marine Pyridoacridine Alkaloids and Synthetic Analogues as antitumor agents' (2003) 23 Medicinal Research Reviews 234.

98 Haefner (n 83).

99 Thornburg, Zabriskie and Mcphail (n 89).

ery of polymetallic nodules in the deepest abyssal plains of the ocean, although substantial progress has been made starting from the 1970s, accurate global estimate of mineral reserve and resource are not yet available and the ocean remains for the most part still unmapped.

MGRs were discovered around 60 years ago[100] and laboratory testing started in the 1980s; few marine compounds isolated from very shallow waters, near tropical and sub-tropical shores, have reached successful commercialization to date. Bioprospecting in deeper water depths has commenced, and now a handful of marine products, from areas within national jurisdiction, entered the commercialization phase. A large part of the deep mineral and associated biological resources form in marine areas of national jurisdiction. Morevoer, the extension of the ocean floor located within the national jurisdiction is bound to increase, once all submissions to the CLCS relative to claims of coastal States to their extended continental shelf will be concluded. This means that, most probably, the exploitable biological resources of the Area are few or unlikely to be exploited, compared to those within national jurisdiction, where the UN Convention on Biological Diversity and its 2014 Nagoya Protocol, on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization, apply. In ABNJ, a regulation similar to the Nagoya Protocol is perceived inequitable for states with no or limited economic capacity and know-how to undertake marine scientific research in the first place, let alone bioprospecting.

Marine scientific research is often invoked as an instrument to increase knowledge about the deep ocean for the benefit of humankind.[101] However, scientific knowledge is often considered on the same level of importance of, for example, public opinion and participation in the decision-making process,[102] which are rarely based on scientific data and competent analysis.

The revised guide for the implementation of UNCLOS provisions on marine scientific research, issued by the UN Division of Ocean Affairs and the Law of the Sea in 2010, reported on the challenges that states have encountered in the implementation of UNCLOS Part XIII. Difficulties concern knowledge and technology transfer, appropriate storage and handling of data, limited human and financial resources for capacity building and cooperation programmes, especially with developing countries. Marine scientific research is thought to flourish under conditions of minimal regulatory interference and in the absence of jurisdictional barriers.[103] In areas within national jurisdiction, compared to ABNJ, national legislation concerning for example environmental protection, may hinder efficient marine scientific research.[104] Thus, international legal instruments should focus on safeguarding the continued freedom of marine scientific research and supporting scientific efforts to achieve the complete knowledge of deep sea habitat, by leveraging, for example, already existing international initiatives with a vision to map the ocean by 2030.[105]

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100 Murray HG Munro and others, 'The discovery and development of marine compounds with pharmaceutical potential' (1999) 70 Journal of Biotechnology 15.

101 Harriet Harden-Davies (n 91).

102 Aline Jaeckel, Kristina M Gjerde and Jeff A Ardron, 'Conserving the Common Heritage of Humankind – Options for the Deep-Seabed Mining Regime' (2017) 78 Marine Policy 150.

103 Anna-Maria Hubert, 'The New Paradox in Marine Scientific Research: Regulating the Potential Environmental Impacts of Conducting Ocean Science' (2011) 42 Ocean Development & International Law 329.

104 ibid.

105 Martin Jakobsson and others, 'The Nippon Foundation – GEBCO Seabed 2030 Roadmap for Future Ocean Floor Mapping' (2017) <https://seabed2030.gebco.net/> accessed 9 November 2018.

Marine scientific data gathering, post-processing and interpretation are processes requiring a temporal scale, which is incomparably longer than the fast track lane imposed by the implementation of international laws. For example, it took only 10 years of conferences to conceive and write UNCLOS, and most of the principles were inspired by information available before the 1970s. Pursuant to article 133 (a) of UNCLOS, 'resources' means all solid, liquid or gaseous mineral resources *in situ* in the Area at or beneath the seabed, including polymetallic nodules. This very tight scientific language, which did not mention the biological component, caused the irony that today MGRs are considered more valuable than mineral resources. Even more ironic, the most promising MGRs are found around and float above the same seabed characterized by the deposition of mineral resources. The high seas (the water column) are open under the principle of conditional 'freedom of the high seas' (UNCLOS article 87), while the mineral resources of the Area (roughly the seabed and sub-seabed) are governed under the principle of 'common heritage of mankind' (UNCLOS article 136). The two types of resources, often referred to as biotic and abiotic, are thus perceived as distinct targets, but microbial and physical process are interdependent. It is well accepted that mineral precipitation, such as at hydrocarbons seeps, is catalysed by consortia of bacteria.[106] The role of microbial activity in the hydrothermal plumes[107] and in inactive hydrothermal sites[108] are understudied. Mineral deposits from inactive sites represent the next frontier for deep seabed mining, due to the fast rising call for protection of the hydrothermal vent ecosystems from the scientific community[109] and, thus, marine research on this subject will increase. New advancements in marine sciences will soon breach the gap, making the distinction between biological and mineral resources, and between physical and biological processes, scientifically outdated, favouring instead a much-auspicated holistic approach. In the opposite direction, the international community wish to spend efforts in the coming years to formulate a new legal instrument, and possibly establishing a new Authority, for administering, separately, the biological resource.

Finally, though a legally binding instrument may offer a unique opportunity to explore new models to promote innovation that does not rely on exclusive or sovereignty rights,[110] the concept of 'utilization of genetic resources' could incentivize applied research at the expense of basic curiosity-driven research, such as for example taxonomy studies, further endangering the freedom of marine scientific research in ABNJ.

106 Max L Coleman, 'Microbial processes: controls on the shape and copmposition f carbonate concretions' (1993) 113 Marine Geology 127.

107 Gregory J Dick and others, 'The microbiology of deep-sea hydrothermal vent plumes: ecological and biogeographic linkages to seafloor and water column habitats' (2013) 4 Frontiers in Microbiology 124.

108 Likui Zhang and others, 'Bacterial and archaeal communities in the deep-sea sediments of inactive hydrothermal vents in the Southwest Indian Ridge' 6 Scientific Reports 25982.

109 Cindy L Van Dover and others, 'Scientific rationale and international obligations for protection of active hydrothermal vent ecosystems from deep-sea mining' (2018) 90 Marine Policy 20.

110 Carlos M Correa, 'Access to and benefit sharing of marine genetic resources beyond national jurisdiction: developing a new legally binding instrument' (2017) South Centre Research Paper 79.