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Review

Conflicting Narratives of Deep Sea Mining

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Abstract: As land-based mining industries face increasing complexities, e.g., diminishing return on investments, environmental degradation, and geopolitical tensions, governments are searching for alternatives. Following decades of anticipation, technological innovation, and exploration, deep seabed mining (DSM) in the oceans has, according to the mining industry and other proponents, moved closer to implementation. The DSM industry is currently waiting for international regulations that will guide future exploitation. This paper aims to provide an overview of the current status of DSM and structure ongoing key discussions and tensions prevalent in scientific literature. A narrative review method is applied, and the analysis inductively structures four narratives in the results section: (1) a green economy in a blue world, (2) the sharing of DSM profits, (3) the depths of the unknown, and (4) let the minerals be. The paper concludes that some narratives are conflicting, but the policy path that currently dominates has a preponderance towards Narrative 1—encouraging industrial mining in the near future based on current knowledge—and does not reflect current wider discussions in the literature. The paper suggests that the regulatory process and discussions should be opened up and more perspectives, such as if DSM is morally appropriate (Narrative 4), should be taken into consideration.

Keywords: deep seabed mining (DSM); International Seabed Authority (ISA); environmental impacts; sustainability; governance; narratives

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1. Introduction

Following decades of anticipation, technological innovation and exploration, deep seabed mining (DSM) in the high seas may no longer be a science-fiction-like vision, but according to the mining industry and other proponents, it may be a possible reality in the coming years [1,2]. While the global economy is concerned over an eventual decline in key metal ore-grades on land alongside increased environmental and social concern tied to terrestrial mining, a new 21st century 'Klondike gold rush' is on the horizon; a race to the bottom that, while alarming to many marine scientists, aims to exploit the vast and highly unknown tracts of the deep seabed [1,3,4].

The debate on DSM often emanates from the notion that modern society depends on an ever-increasing steady flow of metals and minerals; as alongside future global population growth, the demand for metals is expected to rise [1]. Economic growth, green technology, and the production of electronic goods are driving the mining industry into new frontiers. Land-based mining industries have a harder time discovering high-grade ores, a trend fuelling the exploitation of lower-grade sites and mining in new distant areas at greater depths. Terrestrial mining is already causing social conflict and environmental harm ridden by issues such as land grabbing, toxic waste, and the destruction of natural habitat [3]. Many scholars assume that the recycling potential of already existing 'hibernating', urban metal stocks is significant. So called urban mining would help slow the mining of virgin materials [5]. According to a World Economic Forum (WEF) 2019 report, only around 20% of global metals are recycled from scrap and electronic waste [6]. The anticipated intensifying trend towards 'peak minerals' could spur new political clashes as available land for mining increasingly becomes a scarce commodity, one that pits giant mining firms against food production, safe environments, and housing for future populations [7] (pp. 183–210). The interest in exploiting deep sea minerals, such as polymetallic nodules containing nickel, copper, cobalt, and manganese is driven by the rapidly increasing demand for metals used in, for example, batteries to power electric cars, making smartphones, or for storing solar and wind energy. Hence, governments are now searching to diversify supply to secure future profits and production [1]. This demand is a key driving factor behind interest in the deep seabed, an interest that has awoken from its slumber after a loss of attention in the 1980s [8]. As metal demand surges, WEF writes in a 2020 report directed at manufacturers that the time to get involved into the DSM process is now. They foresee DSM minerals to enter the metal market within a decade and call for all relevant stakeholders to engage in the technical, environmental, and social sustainability aspects of it [9].

No commercial-scale mining of the deep sea (approximately 200 to 6000 metres below sea level) has yet taken place, even though there are several existing projects on shallower seabeds within nation-states' jurisdictional waters [4]. Nevertheless, the International Seabed Authority (ISA), the UN body responsible for regulating the deep sea beyond national jurisdiction, have to date awarded 30 exploration contracts with 21 different contractors. In accordance with UNCLOS, actors comprise of state enterprises and private corporations that have sponsoring from their state of nationality. The contracts span over 15 years and have been agreed upon by nations such as China, Japan, Germany, Russia, France, and the United Kingdom [8,10]. The ISA has for the last 25 years been the sole deciding authority on exploration licenses, reviewing environmental impact assessments, and ensuring sufficient monitoring of the mining activities in the Area. The 'Area' is defined as 'the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction' [11].

The DSM industry is waiting for the ISA to finalise the 'Mining Code', a code that sets out to be an overarching legal document with guidelines for future exploitation. Currently delayed, the ISA was anticipating a finalised document in 2020, and appears to be pushing towards a faster, rather than slower, consensus decision to commence exploitation, according to some observers at the expense of scientific robustness [1,12,13]. The Secretary General at ISA summarized the current situation:

> "It must be stressed however, that it is useless and counter-productive to argue that an a priori condition for deep-sea mining is an existential debate about whether it should be permitted to go ahead or not. The international community passed that point already many years ago [. . .]" Lodge & Verlaan [13].

Hence, the opportunity to set the best possible mining practices from the start is at risk [14], and more importantly, the wider scientific and societal debates concerning moral implications, equity, and risk trade-offs are also at risk of being overlooked. Since DSM is still in its infancy and no exploitation has begun (in international seas), one could say that humanity is standing at one of many developmental crossroads. Can deep sea resources—potentially trillions of dollars' worth of metals and materials on the ocean floors [15]—diversify and support a sustainable future? Alternatively, would exploitation mean that we risk trampling yet another valuable resource, especially a biological one that we know very little about?

The ambition of this paper is to open up the debate by illustrating the breadth of often conflicting perspectives on DSM in scientific literature. Our review aims firstly to provide a brief overview of the current status of DSM, its historical background, an overview of potential DSM resources, and the main driving forces for extraction. Secondly, and most importantly, it aims to structure ongoing key discussions prevalent in the scientific literature on DSM into four themes or narratives, found in the reasoning and rationalities tied to its contested development. By synthesizing this, the article aims at invoking and inspiring scholars to continue placing DSM in a broader context of sustainable development and to discuss its pivotal role for future scenarios of equitable sharing, geopolitics, preservation, and the protection of global environmental commons.

2. Materials and Method

This article provides an overarching picture of the discussions and perspectives on DSM in the scientific literature and should not be viewed as a bibliometric analysis or a quantitatively exhaustive review. Instead, the method is guided by the principles of the narrative review. The narrative review does not aim at covering all articles on a certain topic [16], instead, it is an approach to capture the width of a debate—in our case the scientific DSM debate, and to provide illustrations of central standpoints and positions. Consequently, it is not the authors' intention to quantitatively map citation patterns or types of literature, keywords, or citations that frequently occur in the scientific literature or identify the most recurring positions and arguments. The narrative review analysis follows four steps: (1) conducting the search, (2) identifying key words, (3) reviewing abstracts and articles, and (4) documenting results. The initial search (Step 1) was conducted in the Scopus, Web of Science and Google scholar databases, and applied to the search string "deep sea mining". As the search rendered far more than 1000 hits, the second search (Step 2) was narrowed down by exclusively including articles published no earlier than 2011—with a focus on recent publications—and by conditioning it with a few key concepts identified in the abstracts of some of the articles from the first search round: "deep sea mining" in combination with one of the following "regulations"; "environmental impact"; "social impact"; "governance"; "common heritage of mankind, also the common heritage of humanity, common heritage of humankind or common heritage principle"; "International Seabed Authority"; "controversy". This search still rendered more than 100 hits, hence the abstracts, discussions, and concluding sections were read (Step 3) in order to exclude articles that were strictly scientific or technical, or those that aligned with objectivity ideals without revealing the authors positions on the political or social situatedness of DSM. Thus, narrow case specific assessments, for example, were often excluded unless the narrow cases were also related to a broader context. Guiding criteria for inclusion in the final sample were an explicit positioning of DSM in relation to either regulations, governance, valuation of uncertainties, distribution of risks, and responsibilities across scales and argumentations for or against DSM or perspectives on the future of DSM. This process filtered out the majority of the texts and eventually, 30 scientific papers were selected for review and subsequent categorisation and coding. Certain relevant publications may be missing in the review, but we do not aim to quantify the arguments, however we argue that we have identified a sample large enough to support and illustrate the characteristics of the most dominant and recurring positions on DSM.

The first order analysis and coding paid extra attention to discussions and arguments revolving around uncertainty, the precautionary principle, benefits, risks, equity for society, regulation, governance, responsibility, and the UN. In the final Step (4) internally coherent and distinctive narratives on DSM emerged after inductively mapping the most prevalent recurring themes and central arguments: a green economy in a blue world, sharing of the deep sea profits, depths of the unknown and, let the minerals be. The analysis in Step 4 was guided by highlighting arguments and positions that make the narratives more distinct, e.g., views on justice (i.e., potential to redistribute global resources and wealth), ecological sustainability and contribution to a green transformation, the largest obstacles for DSM implementation, moratorium/ban on DSM, and explicit recommendations. It is important to note that an individual paper can contain more than one narrative, hence the ambition was not to pinpoint which specific narrative a paper leans towards. The reviewed papers and basic information about their content and recommendations are presented in Table A1 in Appendix A. Additional sources to verify, contrast, or contextualize statements and views in the sample of papers were also collected from official documents and reports published by the International Seabed Authority, UN bodies, newspapers, and webpages of industry corporations.

3. Background

In order to grasp the debates and ongoing discussions of DSM, it is important to understand the context, i.e., the historical background, current regulations, and complexities of the resources being eyed for exploitation. This section provides a brief summary of how DSM has developed over time and the type of mineral resources the industry hopes to extract.

3.1. Historical Overview

Manganese nodules (described as the most feasible deep sea resource for exploitation) were, until after the Second World War, described almost in the same mysterious fashion as moon rocks. However, during the era of modernist beliefs guided by technological advancements during the 1950s and onwards into the 1970s, governments began envisioning the potential of harvesting resources firstly from outer space, and secondly, from the deep sea [8,10]. United Nations General Assembly (UNGA) Resolution 1348 from 1958 illustrates the visions of nations: 'to promote the fullest exploration and exploitation of outer space for the benefit of humankind energetically'. A few years later in 1966, a similar message was agreed upon in UNGA Resolution 2172, stating that the exploitation of the deep ocean would be an effective way to raise the resources and financial means needed for global development and prosperity [10]. In 1965, Dr. John L. Mero, an American engineer, published the book "The Mineral Resources of the Sea". In it, Mero painted a picture of an infinite and easily obtained metal resource; nodules were growing at a faster rate than any possible exploitation effort could harvest them [8].

Following the end of the colonial era, recently independent developing countries were promised by developed UN nations that future exploitation of the seabed (and space) would help address inequality gaps between the Global North and the Global South. Concerns for potential environmental impacts were brought up at the time, however, these remained generally ignored due to the vastness of the ocean [10]. With support from their respective governments, companies in the West began exploring the possibilities of mining the ocean. Several multinational consortia were created to overcome financial and technical risks. The global spending on DSM peaked at the end of the 1970s only to see a dramatic drop in the coming decade [8]. Technical constraints that remained unsolved, alongside the potential for regulations, resulted in several nations shifting focus back to land [17]. However, the interest never entirely ceased, and governments in China, India, and South Korea, to name a few, continued exploring manganese nodules and two other types of deep-sea resources, seafloor sulphides and cobalt-rich crusts [8].

The revived interest in all three deep sea resources from the millennial turn and up until the present day can be tied to their revamped financial viability, technological innovations, and the political economy of the global metal market. Price volatility, the control of essential resources, and growing demand for metals linked to green technology and sustained economic growth instill vulnerability and concern for continued development [8,10,18].

3.2. Resources of the Deep

Each mineral deposit differs from the other in terms of unique surrounding ecosystems, connections to biogeochemical cycles, and technical difficulties in obtaining them. A fourth resource related to DSM, phosphorite deposits found on continental margins, is left out of this review as the other three are considered to be more feasible for extraction.

3.3. Manganese Nodules

Manganese nodules, also referred to as polymetallic nodules, are most easily described as potato-sized rocks found on the abyssal plains approximately 3000–6000 m below sea level [13,19]. Covering approximately 70% of the ocean seafloor, these plains, despite the name, are not flat but have varied topography, which not only diversifies the fauna, but also makes potential mining more difficult. Even though most of the deep sea plains remain unexplored, they are believed to be the largest ecosystems on earth boasting a vast species richness and undocumented taxa [19]. Nodules may contain high grades of manganese minerals, nickel, cobalt, copper, zinc, and traces of other attractive metals such as lithium, which are enticing to mining companies. The nodules form very slowly, and it is estimated that they grow at a rate of merely 2–10 mm per million years. They can be found in the abyssal plains of three large ocean basins; the Indian, Pacific, and Atlantic Oceans. Nodules provide the nearby benthic life with a heterogeneous environment and hard substrate—a limited habitat in the deep that otherwise mostly consists of sediment [20,21].

The majority of exclusive exploration licenses awarded by ISA for nodules are within the CCZ—an area of high biodiversity and species richness [22]. The exact role the nodules play is still not yet fully understood, and [19] it has been concluded that the sample sizes aimed to define appropriate areas to mine are too few, and a substantial comparison across the CCZ is still missing. Calculations roughly estimate that the CCZ could hold over 21 billion tonnes of nodules, which collectively would hypothetically contain 6000 million tonnes of manganese, 270 million tonnes of nickel, and 44 million tonnes of cobalt [4]. The extraction of these nodules is planned to be managed remotely, controlling nodule harvesters that plough or scrape the seabed and sediment. Harvested nodules and underlying sediment will be pumped up to the surface and sorted, and sediment water will likely be returned to the ocean on-site [20].

3.4. Seafloor Massive Sulfides

Part of the new interest in DSM is in the findings of seafloor massive sulfides (SMS). SMS are deposits found around so-called active or inactive hydrothermal vents [20]. Hydrothermal vents are small unique structures found along the deep-ocean floor ridges where tectonic plates pull apart. These vents, also called black or white smokers, are best described as small underwater volcanoes or chimneys. The vent areas may contain rich concentrations of sulfides as well as other metals and minerals such as copper, zinc, gold, barium, and silver [4]. At depths between 1000–4000 m, where the vents are generally located, no light penetrates, and life is dependent on chemically produced energy (chemosynthesis)

When tectonic plates pull apart, cold water seeps in. This cold water is rapidly heated by the magma beneath and re-emerges as alkaline (high pH) vent fluids containing hydrogen. The fluids may then precipitate metals and sulphides when they meet the cold bottom sea water. The minerals form chimneys, and as each chimney collapses and rebuilds around the vent, minerals and metals are compounded over time [23].

The active vents host unique ecosystems that are home to endemic species that rely on the chemical reactions between hydrogen and carbon dioxide facilitated by the 400 C vent fluid [23]. These places are, as Van Dover et al. [23] puts it, libraries necessary for deepening our knowledge on the connections between the processes of the Earth and life itself. To date, there are approximately 400 known active vent fields around the globe. Inactive vents were for a long time considered to be relatively devoid of life, however, findings in the recent decade shows inactive vents along ridges hosting lively populations of barnacles, corals, and sponges [20].

3.5. Cobalt-Rich Crusts

Cobalt-rich crusts (CRC), also referred to as ferromanganese crusts or polymetallic crusts, are found on the seamounts rising 1000 m or more above the seafloor. The crust layer of these mounts contains iron, manganese, and trace metals such as copper, cobalt, and nickel [4]. The thin crust takes millions of years to form through the precipitation of minerals from the surrounding seawater. The thickest parts of the crust are estimated to be around 25 cm and occur on top of the mountain summits or flanks. Seamounts, or knolls, can be found in all oceans, but the most pronounced area of the highest industrial interest lies in the Pacific Ocean with more than 55,000 mounts and smaller so-called knolls [20]. The international areas around the central equatorial Atlantic or within the

EEZs of Pacific island states such as Kiribati, French Polynesia, Tuvalu, and Samoa Islands, are highlighted in the literature as hotspots for potential CRC exploitation. CRCs may pose a more challenging mining procedure as (a) the entire crust must be removed from rock substrate and (b) the steep and rugged landscapes where machinery must operate makes the technological obstacles harder to overcome than the other two DSM resources [4,20].

4. Results: Deep Sea Mining Narratives

The following four sections present the narratives derived from the review of the literature, and illustrates amongst other things: arguments on why DSM can contribute to a green transformation, debates on DSM's potential to redistribute global resources and wealth, scientific debates on the inherent uncertainties and subsequent consequences of DSM and scholarly opinions on why humanity should let deep sea minerals remain on the sea floor. The narratives are internally coherent, but one individual paper can contribute perspectives to several narratives. It is important to note that the illustrations and arguments in the narratives below mirror the perspectives and statements expressed in the reviewed papers and are consequently not the two authors'. Unless explicitly mentioned, the references support the narratives they are presented in. The reviewed articles are also presented in Table A1 in Appendix A. Appendix A briefly presents the articles' findings, recommendations, and the obstacles and challenges identified by the articles' authors.

4.1. Narrative 1: A Green Economy in a Blue World

The mineral resources required to sustain a population of 7.8 billion people (as of 2020) will become increasingly scarce if only land-based sources are relied on. Infrastructural needs in a developing world, a quickly rising global middle class, and a general demand for new 'green' technologies everywhere in modern society all amount to greater demands for more key and rare metals [24]. DSM is not only portrayed by proponents as a means to secure economic growth [25] but also as the potential start of an alternate economy—a blue one—that could pave a way out of poverty and assist in transitioning to green technologies [26].

According to Hein et al., [24] and others (e.g., Lodge & Verlaan [13]), the higher-grade ores and convenience of the marine mineral deposits should be compared to terrestrially sourced metals, and their potential for decreased environmental and social impacts. Metal prices have steadily increased since 2003, and alongside new technological innovations, DSM has become what might seem to be a new feasible (and final) resource frontier [26]. Demand for copper, nickel, and cobalt, under the current conventional idea of development, will continue to rapidly increase and influence the chances for developing countries to improve their quality of life [27]. This narrative follows an envisioned need for less carbon intensive infrastructure and the assumption that an increase in the consumption of electronic goods will follow prosperity [28].

Despite the inherent uncertainties of an unproven industry, when comparing marine-based mining sites with terrestrial ones, it is argued that DSM would potentially have fewer needs for vast infrastructure and transport systems. Roads to mining sites, deforestation, large on-site buildings, and polluted nearby waterways would be avoided in the deep sea [3,24,26]. Additionally, DSM means fewer social and economic impacts on human populations with less displacement of indigenous people in close proximity to mining-sites, and hazards to personnel would be smaller or even non-existent [13]. Hein et al. [24] have argued that since the industry would operate in new environments, it can create a 'stronger than necessary' perception that DSM would lead to worse impacts than land-based mining. Even though DSM will doubtless be ridden by environmental impacts, Koschinsky et al. [3] have written that it may turn out to be a favourable alternative to terrestrial mining—nevertheless, this statement is conditioned on effective and efficient regulatory systems being in place. Comparing land-based mining with marine mining may, however, not be fair albeit the output resource is the same. The sustainable challenges to consider will be vastly different, and studies that thoroughly compare them are very limited. Batker & Schmidt [29] compared the two extractive activities following an ecosystem valuation approach in a study funded by the Canadian mining company Nautilus. The study found that DSM in the form of Nautilus' SMS extraction plans in Papua New Guinea would be a better alternative in general to land-based Cu mining in all four ecosystem service categories, i.e., provisioning, regulating, cultural, and supporting services. However, a general critique of their conclusions is that the selected parameters were an asymmetrical view on relevant ecosystem services, and those associated with land guided by an anthropocentric perspective [3]—a common critique seen in the coming Narrative 3, regarding environmental uncertainties.

The key to DSM's potential sustainable outlook is that restoration and mitigation practices are ecologically and financially sound. In an article that discusses the limitations and possibilities of DSM mitigation and restoration practices, Cuvelier et al. [14] describe the restorations of mined sites as plausible, but ridden by high levels of uncertainty. One proposed solution is setting aside several refuge areas for mitigating affected ecosystem populations, yet according to Cuvelier et al. [14], this is a practice that is highly speculative at this point. Ecosystems connected to active hydrothermal vents may recover faster due to the already unstable environment of intermittently active vents with long dormant periods [17]. Van Dover et al. [23] claim, in contrast with the current narrative, that the idea of relying on the rapid recovery of hydrothermal vents, due to their geophysical activity, could be a high-stakes gamble, as disturbing too many active vents in an area might push the ecosystem in the region to a tipping point that leads to the demise of endemic species. Active vents have also been labelled as vulnerable habitats by a number of international instruments and could provide key scientific understandings and could be of importance to wider society [23]. Economic valuation of DSM remains difficult until scientists have substantial knowledge of the actual economic costs and benefits that could be reaped. A cost-benefit analysis, firmly positioned within the current frame, that focuses on business-sided profits and economic growth tends to see DSM as the holy grail for metals, and environmental impacts as something that can be overcome by techno-managerial policies and interventions [30]. The ISA appears to argue from the standpoint of the inevitable growth of the so-called 'blue economy' and writes that DSM will enable development by providing new available resources and increase scientific knowledge of the deep sea ecosystems [31].

If DSM is ever to become a 'green economy in a blue world', mining projects must adhere equally to social, economic, and environmental perspectives [4], and the split view on the feasibility of fulfilling those ambitions is one important distinction between this narrative and Narrative 3—depths of the unknown. Viewing DSM from a geopolitical perspective, metals from the deep sea have begun to influence the future resource security discourse. DSM framed as a necessity to secure a steady global resource flow automatically legitimizes it to play a key part in the future of sustainable development. Seen from the current narrative, DSM is a political object with similarities to the politics of energy security—a political discourse shown to normalise certain types of appropriation and control following a techno-managerial approach [28].

4.2. Narrative 2: Sharing of the Deep Sea Profits

A debated phenomenon regarding DSM, particularly in the Area, is the prospect of sharing its profits amongst global actors, and most importantly, to emerging economies. The redistributive ambitions are one of the narratives supporting the start of DSM. Often packaged as a win-win scenario, the benefits from DSM to humankind are in tandem framed as the profits and expectations of stakeholders and mining operators such as Nautilus Minerals and DeepGreen Metals Inc. This section aims to explain the framing's foundations and present both positive and negative scholarly notions of that outlook.

The minerals found on the deep seabed in the so-called Area, have been set aside as the 'common heritage of mankind' (CHM) (UNCLOS, Part XI, Art. 136). This essentially means that these non-living resources belong to nobody and everybody—a common good. The ISA has the responsibility of governing these resources as the institution under the UN representing the will of the global population (UNCLOS Art. 137.2). Not only does the ISA control exploration and potential future exploitation, but they are also in charge of ensuring that the DSM regime becomes a space of equal participation, where profits derived from the seabed are shared equally across all countries [3]. This framing of the DSM and its potential for distributive justice has become a distinct narrative and a unique concept regarding the management of deep-sea resources. Proponents of DSM, and especially the ISA, frame their responsibility for distribution as a unique jurisdictional apparatus that will utilise a sharing scheme founded on the CHM principle: a payment mechanism that sets out to curb a situation where merely a few already technologically developed countries, or companies, would benefit from common seabed resources. Instead, DSM profits can be shared equitably amongst all nations including less developed and landlocked countries [13]. With ISA setting up a payment mechanism following the CHM principle stated in UNCLOS, it is expected that DSMg conducted in the Area would be controlled and organised around a notion of transparency and fairness [32]. In this way, the ISA has a task that sits at the intersection of contemporary and future forms of international relations, i.e., legislation and regulatory development concerning a common pool resource.

Firstly, the concept of CHM states that no one nation can territorialise and claim seabed resources in the high seas, i.e., international waters. Secondly, it calls for administration by an international institution that controls financial gains made in that area. Feichtner [10] argues that there is a contradictory aspect to how the ISA has laid the foundation for a system that is supposed to be equitable and fair, while handing out permits to exclusively exploit certain areas of the sea for the economic benefit of a few actors. During the 2017 UN Ocean Conference, the ISA stated that they are committed to seven voluntary commitments that aim to help achieve mainly SDG goal 14 ('Conserve and sustainably use the oceans, seas and marine resources for sustainable development'), as well as several other goals and targets found in the 2030 Agenda for Sustainable Development [32]. Five of these seven commitments are related to how the ISA will help support developing countries with a focus on the least developed countries, small island developing states, and the land-locked developing countries. This vision includes not only monetary means, but also knowledge-sharing, enhancing gender roles in research (by employing more women), and supporting, for example, African countries to partake in the blue economy [32]. Following the envisioned deep seabed regime put forth by the ISA, DSM could contribute to sustainable development by not only providing the global market with key resources needed in green technological transformation, but also by establishing a monetary system for equal sharing among all states. To see this idea come to fruition, a state actor that applies for an exploration/exploitation license will have to reserve and set aside an area where the ISA's own mining operation (not yet operationalized)—coined the Enterprise—would mine minerals side-by-side with corporations sponsored by state parties [25].

> "The Enterprise is the commercial arm of the Authority, empowered to conduct its own mining, initially through joint ventures with other entities. Until seabed mining becomes a commercial reality, the functions of the Enterprise are to be carried out by the Secretariat." [33].

Developing countries, far from being capable of setting up their own mining operation, can instead engage in DSM by becoming sponsoring states of corporations [28]. Examples of this are seen in the Clarion Clipperton Zone, where the small island states Tonga and Nauru jointly entered into contracts with the ISA and Tonga Offshore Mining Limited, a subsidiary of Nautilus Minerals [12].

4.3. Narrative 3: Depths of the Unknown

A point of departure for this narrative is that the deep sea, making up 95% of the oceans, constitutes the most massive set of ecosystems on Earth and is fundamental to sustaining both terrestrial and marine life. Environmental impacts from DSM exploitation in these poorly understood ecosystems remain highly uncertain [3,4,20].

Since little is known about the deep sea, the associated risks of environmental impacts could, in contrast to the view in Narrative 1 (a green economy in a blue world), be perceived as greater than those from terrestrial mining [24,34]. Parallel to DSM being on the brink of moving from an exploration into an exploitation phase, there has been an upsurge in, and deepening of, the general understanding of marine ecosystems and the interconnectedness of the vast oceans. A growing amount of scientific evidence indicates that the seafloors likely possess rich biodiversity beyond those of coral reefs and rainforests. These ecosystems play a vital role in carbon sequestration [35], fish stocks and cycling of nutrients. Deep sea ecosystems may already be influenced by external stressors such as acidification, overfishing, and a warming ocean [36]. One of the most pressing and direct impacts from DSM would be the destruction and removal of habitat, potentially leading to the extinction of endemic species [34]. Secondly, all of the previously described DSM resources are non-renewable in character and take millions of years to reproduce, altering biogeochemical cycles [37,38]. Another aspect of DSM that deserves more attention, according to Drazen et al. [39], is its impact on deep midwater ecosystems. These areas connect the deep sea ecosystems and the shallow, and the ecosystem represents more than 90% of the biosphere. Simply put, it is still too hard to prove that industrial scale mining would not cause harm or risk detrimental ecological and social effects [36,40]. The current state of the art technology requires a single operation to annually mine hundreds of square kilometres of seafloor in order to be financially viable. The estimated costs for these operations seldom reflect measures for environmental monitoring, restoration, or compensation to affected populations and overlapping industries such as fisheries. Moreover, another factor to consider is the economic value of short-term minerals versus potentially destroying important genetic resources that could be critical for humanity in the longer term [37]. Van Dover et al. [19] highlight that genetic resources used for pharmaceuticals and bio-prospecting probably could generate up to USD 50 billion.

After removing manganese nodules from their habitat, it remains unclear how long the biota would need to recover. The few studies carried out have been over time scales that were too short. A study called DISCOL conducted in the deep equatorial eastern Pacific Ocean during the 1980s [41] revisited the site some 26 years later, only to find that the wheel tracks from mining vehicles were still there, and the life under those marked paths was reduced compared to similar nearby sites. Another study by Vanreusel et al. [42] found that the area emptied of nodules was devoid of life after a similar experimental mining operation conducted 37 years ago. These studies are not enough to draw valid conclusions, but they indicate it is more likely than not that mining activities removing manganese nodules will damage nodule habitat and biodiversity in the vicinity [4,19]. Mining on SMS, i.e., the hydrothermal vent chimneys and their surrounding minerals, will flatten the vent area altogether, causing changes such as sediment plumes. The uniform surface left behind may not make recolonisation possible, and even if an active vent can rebuild its chimney, the habitat as a whole may take far longer to recover [23]. Another factor brought up by Van Dover et al. [23] is that recovery rates can be misleading when compared to volcanic eruptions on the seabed and its decadal-scale recovery. Volcanic eruptions on the East Pacific Rise ridge have been cited as reference by the mining industry for its quick habitat recovery. According to Van Dover et al. [23], this is not representative of the slow-spreading mid-ocean ridges where the largest high-grade ores may be found. The authors [23] question the resilience of endemic species around the long-lived vents which are not naturally facing frequent disturbances. Removal of seamounts in the exploitation of CRCs may have direct impacts on sessile life, where not only benthic biota is affected, but also fish stocks and mesopelagic species. As with other industrial practices, machinery, light, and noise pollution also play into the environmental impacts. Corals and fishes living around the seamounts are likely to lose their habitat, and suspended sediment will disrupt the surrounding ecosystem [4,36]. Removing the rock substrate and the ferromanganese crust can cause long-term or permanent degradation of the seafloor. Additionally, disturbances between organisms that have a faster growth rate versus ones with slower growth rates may also create an asymmetrical species dominance when a habitat tries to recover [3].

Jones et al. [41] write, in contrast to this narrative, that challenges can be addressed through further collection of scientific information and by ensuring that regulations are designed to be adaptive. The ISA has already created tools for regional and local management in the Clarion Clipperton Zone [41], but the knowledge gaps on deep sea ecosystems remain an obstacle to creating policies, management plans, and laws that are safe and feasible [40]. A standpoint exemplified in the article by Jones et al. [41] is that there is an urgent need for stringent policies and regulations for this emerging industry, while standards and protocols to ensure environmental safety could be put into place later, as the DSM operations in the pipeline remain relatively small. Utilising knowledge from other offshore industries, e.g., oil and gas, can also assist in developing adaptive management and organisational systems to prevent environmental degradation. Nevertheless, rushing the development of guidelines and standards because the industry is eager to start exploiting appears unreasonable to other scholars who insist on a moratorium until reliable scientific knowledge can guide regulation [36–38].

The DSM debate exemplifies how the precautionary approach can be interpreted differently. Jones et al. [41] mention the precautionary principle's function to seek out alternative routes and actions, including ongoing monitoring and the acceptance that evidence of environmental impact lies with the operator. In contrast, Boetius & Haecke [37] argue that firstly, the comparison with land-based mining restoration techniques as a blueprint for the deep sea is questionable. Secondly, to drive a terrestrial destructive activity to another 'backyard' violates part of the precautionary approach of principle 15 of the 1992 Rio Declaration. There is a severe lack of robust systems to monitor, control, and prevent an industry as invasive as DSM and previous disasters, such as the Deepwater Horizon, have revealed that there is no efficient system to restore, repair, or re-habituate seafloor life, even in waters of national jurisdiction [37]. In line with narrative 1, and in favour of the economic potential of DSM, ISA's Secretary-General, Michael W. Lodge argues that comparisons with accidents such as the Deepwater Horizon are 'totally different in character to deep sea minerals' and therefore 'wholly misleading and inappropriate' [43].

The uncertainties surrounding DSM do stop at environmental impacts, but also revolve around complex social ones. Social impacts are difficult to predict and may arise at any given point throughout an operation's lifespan. Impacts are situational and may greatly differ amongst affected communities, regardless of similar mining practices. Damage from DSM might arise in close proximity to, or at a far distance from coastal states [44,45]. DSM's unpredictable nature makes social impact assessments complicated: in 2015, the European Parliamentary Research Service (EPRS) made a cost-benefit analysis for the EU and local communities and concluded that DSM would generate fewer jobs in the EU than the terrestrial or recycling sector currently does. The analysis concluded that the social impacts could be detrimental for local fisheries if their stocks are affected. Apparently, fishers near the Nautilius project in Papua New Guinea have already noticed altering of fish stock behaviours and witnessed decline in catches. Obtaining what the mining industry on land calls a 'social license' may be more difficult as mapping out the correct stakeholders and valuing their compensation is fuzzier at sea than on land [25]. Another critique of the current DSM regime which feeds into the uncertainty of this industry, is directed at the ISA and how they have managed their responsibilities so far: Boetius & Haecke [37] request for a higher degree of transparency in ISA's decision-making process when issuing contracts. The authors [37] describe what they view as an obvious failure in communication with the outside scientific community; something that became apparent when exploration contracts for a 10,000 km^2 claim in the Mid-Atlantic Ridge were handed out, regardless of it including key research sites of hydrothermal vent systems in the Lost City, Trans-Atlantic Geotraverse, and Broken Spur.

4.4. Narrative 4: Let the Minerals Be

Finally, Narrative 4 outlines some of the reasons why scholars argue that deep sea minerals should be left alone altogether. Arguments do not only stem from fears of environmental disaster but of a lack of trust in the current seabed regime and the risk that the regulatory system will rely on the currently available, and what is considered as incomplete, data. It is primarily this lack of trust and take on justice issues that distinguishes this narrative from the previous narrative.

Woodwell [38], argues that DSM could be viewed as a 'twofold attack' on the global common resources. The question of what gives humanity the right to destroy unique ecosystems such as those surrounding hydrothermal vents should be broached before moving forward. Hydrothermal vents are sprawling with endemic life forms which can provide us with a window into the origin of life in new and exciting ways. How some proponents set out to justify the destruction and intrusion of these areas for corporate profit is beyond imagination and should be thoroughly questioned [46]. DSM is at the beginning of a process that once set in motion, can be hard to recover from. Therefore, opponents say that DSM should be put on hold until further notice, to avoid another corporate atrocity against nature [8,25,38]. Kim [25] points out that the ISA quotes old agreements on how resources from the seabed would be distributed beginning from 1982, especially considering the economic interests of the developing world, which overlooks that back then, little attention was given to the resilience of mining in the marine environments. Rather, it was a question of who would control the seabed, with the ocean seen as an infinite reserve. At the time, this presented an opportunity for the Global South to even out the global economic order. However, many developed countries did not sign the United Nations Convention of the Law of the Sea (UNCLOS) because they feared losing control over resources in the international seas. To address concerns from industrialised countries, the Secretary-General convened in July 1990, which later led to the 1994 Agreement relating to the implementation of Part XI of UNCLOS. What this implementation meant for DSM was that the ISA was created as a decision-making body, which was modified to essentially prevent a majority rule over deep sea resources [25]. Kim [25] goes on to argue that the way in which the ISA is currently structured makes it incapable of representing the common interest of humankind. One fundamental issue being that the ISA instead represents an individual state's desire to reap resources for themselves, and is thereby, in effect, structurally incapable of managing a common pool of resources for 'all of humanity'. The CHM principle, according to Feichtner [10], lays the foundation for an exploitation bias that is strengthened by the remoteness of the high seas and the deep seabed, as well as the institutional difference of the ISA from other deciding UN bodies. The ISA could be said to be disconnected in that it seldom interacts under formalised procedures with other international institutions that intersect with DSM. Even if non-governmental organisations and others are granted observer status or participation in joint events, no other institutions have formal rights of involvement in the ISA's licensing procedures or the creation of the Mining Code. Surely, the Mining Code must be approved by the UN State Parties, but currently the ISA promulgates the Code with little interference [10]. For example, in 2020 (currently postponed and expected in 2021), the UN aimed to conclude negotiations for a new international agreement on the Biodiversity Beyond National Jurisdiction (BBNJ)—a treaty that will improve the governance of the high seas while striving for increased resilience for marine life. How the BBNJ agreement will affect DSM is not clear. Regardless of this potential synergy, a joint statement from the International Maritime Organization (IMO) and the ISA said that the organisation does not wish to alter environmental plans or existing frameworks for responsibilities as 'tampering with them might open up more questions than answers for the effective conservation and sustainable use of marine biodiversity' [47].

Sceptics of DSM, and in particular those concerned about major ecological impacts, claim that the best way for the ISA to realistically, and on a satisfactory level of certainty, live up to its commitments from UNCLOS Article 145, i.e., protection of the marine environment, and Article 194, i.e., measures to prevent, reduce and control pollution of the marine environment, is to call for a moratorium on DSM until further notice [40]. Regardless of how abstract or complex it may be to know what is best for humanity as a whole, Kim [25] claims that the ISA has taken on the role of developer, instead of safeguarding the Area. Furthermore, the ISA is criticised for being severely understaffed, especially considering their critical role in such a vast resource. A large number of people are required to thoroughly evaluate each Environmental Impact Assessment (EIA), and any insufficient processes in evaluating EIAs can result in poorly made decisions on exploitation and exploration licenses [44]. A final argument is that DSM could risk reinforcing unsustainable production and consumption patterns. Instead of promoting and improving technologies to recycle current metals already in the market, DSM would possibly merely shift mining from one destructive industry by creating another. The argument here staunchly stands that resources and technology should instead first close the loop in metal recycling and foster international stability on the metal market [4,25,37].

5. Conclusions

In summary, the four predominant narratives and discourses that we have seen in the DSM literature revolve around: economic viability and sustainability (Narrative 1); the governance and potential for equal sharing of global resources (Narrative 2); the gross remaining uncertainties when it comes to the deep sea ecosystems (Narrative 3); and finally, the argument that the morally correct action would be to set the vast majority of these ecosystems under moratorium until further notice (Narrative 4). The debate over DSM sheds light on a plethora of issues regarding environmental policies, regulations, notions of risks, uncertainty, and the use of the precautionary principle to the surface. Whether or not DSM could become a sustainable practice depends on the ability to deliberate on, and understand how and if, ecological functions convert into risks, equity for society, and benefits for the whole of humanity. Since much baseline data about the natural world in the deep sea is still lacking, it is hard to map the services these alienated areas can potentially provide [41]. Proponents of DSM (primarily Narrative 1 and 2) mainly focus on potential large-scale economic gains, while the actual costs and benefits remain unknown. The regulatory system is not yet in place, and many investors remain on the fence. Social perspectives and added risks to society and communities in general, paint a picture that makes the calculus for DSM vastly more uncertain and weighted towards potential net economic losses [40]. Further, financial gains from DSM are more likely for the developed countries that would directly involve themselves in mining activities, while the payment scheme and global redistribution, as argued in Narrative 3, is not yet robust enough [25]. Continuing with the notion of sharing the benefits, Kim [25] highlighted that if the ISA offers competitive rates and fees to similar terrestrial mining options, the shared dividends to humanity, and poorer nations in particular, will be modest at best. From this perspective (Narrative 2), it seems the real benefit for humankind will be an increase in the flow of metals on the global market, which if current trajectories and structures are followed, will benefit and accumulate wealth in developed, industrialised countries [32].

Another issue is the lack of legislation on how funds allocated by governments are to be redistributed [3]. The deciding body for the ISA is to carry the responsibility of ensuring that redistribution leads to a sustainable outcome. Narrative 3 asks if the premise itself is naïve; to assume a linear translation of money paid out by the ISA to a government will then trickle down to 'benefit everyone' is a utopian notion of resource governance. Lastly, cultural losses and related compensation schemes have been said to be complicated and sensitive, i.e., monetary valuation of cultural practices related to both land and sea [3]. Instead, the responsible way forward is a moratorium and shift focus on closing the loop on metals on land and work, to improve recycling instead of venturing to new exploitation (Narrative 4).

In Table 1 below we summarize briefly the different emphasis that respective narrative places on DSM and its future prospect.

Table 1. Summary of respective emphasis seen in the 4 narratives.

	Emphasis on			
Narrative 1: A green economy in a blue world	DSM can be aligned with economic viability and sustainability	DSM can provide potential large-scale economic gains	Actual costs and benefits still remain unknown	
Narrative 2: The sharing of DSM profits	The governance and potential for equal sharing of global resources are main challenges	DSM can provide potential large-scale economic gains	Actual costs and benefits remain unknown	The real benefit for humankind (due to DSM) will be an increase in the flow of metals on the global market
Narrative 3: The depths of the unknown	There are significant remaining uncertainties when it comes to the deep sea ecosystems	The payment scheme and global redistribution is not yet robust enough	It is naïve to believe the ISA can govern the 'benefit everyone' ideal	
Narrative 4: Let the minerals be	The morally correct action would be to set the vast majority of these ecosystems under moratorium until further notice	A moratorium and shift focus on closing the loop on metals on land instead of venturing to new exploitation		

6. Authors' Remarks

We conclude that the most controversial, and arguably the most pressing issues, are views on the uncertain biological consequences, linkages to society and justice, and regulatory integration and capacity. Several articles point out the injustices of current regulatory regimes and lack of democracy in decisions made for a common pool resource. This mainly relates to how exploration contracts are handed out, who profits from them, and how the work of the ISA lacks transparency. In the grander scheme of development, commencing DSM based on a low number of EIAs and substantial lack of ecological knowledge, with the prioritised aim to promote economic growth, contradicts and disservices efforts to slow down global production and increase recycling of metals. When examining DSM from a holistic perspective, it is clear that all perspectives or narratives presented in this review cannot be reconciled, and that current controversies are likely to deepen as DSM moves closer to realisation.

There is a pressing need to deliberate on DSM in the public debate since few of the current narratives' conflicting rationales and worldviews can be resolved without voicing the many concerns raised in the literature. There is an apparent risk of the initial and decisive decisions regarding the regulatory development of DSM and its initial implementation being made with a preponderance towards only one of the narratives (Narrative 1: blue economy) constructed in this paper, thus disregarding the apparent wider plethora of narratives in the literature. It is the authors' hope that this paper provides a basic overview of current perspectives prevalent in the DSM discourse, and gives a brief understanding of DSM resources, its history and tensions. In conclusion, the authors intend to put forth an argument to open up the discourse in order to make it more inclusive and also stress the importance of further examining the DSM activities prior to setting regulations and making decisive political decisions.

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Appendix A

Table A1. Reviewed articles.

Author	Year	Title	Article Type	Journal	Purpose/Aim	Findings	Recommendations	Obstacles/Challenges
Beaulieu, S.E., Graedel, T.E. and Hannington, M.D.	2017	Should we mine the deep seafloor?	Commentary	Earth's Future	Summary of benefits, costs, and uncertainties.	Possible yet uncertain solution to meet needs for sustainable development.	Pilot testing on environmental impact, design stronger regulations.	Continued exploitation or move away from resource intense lifestyles; conflicting SDG:s.
Boetius, A. and Haeckel, M.	2018	Mind the seafloor	Perspective	Science	Argue for research and regulation in harmony with each other.	Strict environmental regulations need to be formulated by the ISA to finalize regulations.	Finalized regulations; matched conservation areas; transparent assessments.	ISA's decision-making process; should map and use land sources first.
Childs, J.	2018	Extraction in Four Dimensions: Time, Space and the Emerging Geo(-)politics of Deep-Sea Mining	Article	Geopolitics	Demonstrate resource temporalities and geopolitics of DSM.	DSM increasingly politicized; conflicting imaginaries.	Deeper understanding of temporal and spatial scales of DSM.	Corporations legitimizing extraction strategies based on unknowns and harshness of the deep sea.
Cuvelier et al.	2018	Potential Mitigation and Restoration Actions in Ecosystems Impacted by Seabed Mining	Review Article	Frontiers in Marine Science	Suggest best practices for DSM.	Lack of data; lack of studies; EIAs does not mirror potential large-scale damage.	Dialogue with regulators and industry; combined mitigation, restoration of mined sites; designate refuges for biota.	Uncertainty and uniqueness of areas make generalized recommendations for mitigation and restoration efforts.
Drazen et al.	2020	Opinion: Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining	Opinion Article	PNAS	Environmental research and management have focused on impacts to seafloor environments. This article focuses on the impacts to pelagic ecosystems.	"Deep-sea mining is rapidly approaching. Nonetheless, we lack scientific evidence to understand and manage mining impacts on deep pelagic ecosystems, which constitute most of the biosphere."	"Expanded and focused midwater research efforts, and adopting precautionary management measures now, are needed to avoid harm to deep midwater ecosystems from seabed mining."	"Consideration of the full scope of ecosystem risks from deep-sea mining requires comprehensive evaluation of impacts on midwater ecosystems. Despite some existing general knowledge, ecological baselines for midwater ecosystems likely to be impacted do not exist".
Durden et al.	2018	Environmental Impact Assessment process for deep-sea mining in 'the Area'	Article	Marine Policy	Scrutinize the environmental impact assessment process for DSM	Lack of processes to account for uncertainty; lack of clear and detailed requirements.	The ISA needs to expand input and personnel in charge of EIAs	Timings of submitting EIAs in relation to exploration contracts makes it hard to adjust operations.
Feichtner, I.	2019	Sharing the Riches of the Sea: The Redistributive and Fiscal Dimension of Deep Seabed Exploitation	Article	European Journal of International Law	Understanding principle of common heritage into the DSM fiscal scheme	There is a clear exploitation bias tied to the principle of common heritage and DSM.	Realize that the making of the Mining Code is tied to political economy and the idea of shared public revenue under current scheme needs more bearing.	Individual commercial expectations of profitability are transforming the idea of common heritage and benefit sharing. This could undermine the regime's redistributive ambitions.
Folkersen et al.	2019	Depths of uncertainty for deep-sea policy and legislation	Article	Global Environmental Change	Challenge DSM from social values and economic global perspectives	Damage from DSM on a global level remains unclear: uncertainties are too large	Comprehensive research into both scientific and economic aspects of the deep sea's ecosystems is needed.	Current clear lack of both geographical scale and time in current valuations; social dimensions and externalities ignored
Heffernan, O.	2019	Deep Sea dilemma	Perspective	Nature	Overview of the industry, resources, knowledge gaps and the ISA.	Difficult to define the risks of DSM based on current science; concerns over ISA's dual responsibilities.	Room for scientists to define what risks are acceptable before DSM begins exploitation.	ISA's lack of transparency; skeptical to ISA's 'wait and see' approach on regulations for industries.

Table A1. *Cont.*

Author	Year	Title	Article Type	Journal	Purpose/Aim	Findings	Recommendations	Obstacles/Challenges
Hein et al.	2013	Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: Comparison with land-based resources	Review Article	Ore Geology Reviews	Compare deep sea grades and tonnages of nodules and crusts with the global terrestrial reserves and resources.	DSM offers new sources of metals; high amount REEs compared to land.	Evaluate DSM minerals using methods applied to land-based deposits so that their relative importance can be understood as potential sources.	Some technical difficulties and understandings of the deep sea environment.
Hunter, J., Singh, P. and Aguon, J.	2018	Broadening common heritage: Addressing gaps in the deep sea mining regulatory regime	Commentary	Harvard Environmental Law Review	Pose critical questions to the concepts of the common heritage and legal regime of DSM.	New scientific knowledge, broadened scope of social justice, and pressing environmental issues alter the premise DSM law and regime first was created on.	The international seabed regime should be reformed based on current knowledge and fully embrace the precautionary principle regarding its many uncertainties.	The framing withstanding from the 1960s of common heritage favors an exploitation bias, rather than fully taking into consideration the many social and environmental externalities DSM might affect.
Jaeckel et al.	2016	Sharing benefits of the common heritage of mankind–Is the deep seabed mining regime ready?	Article	Marine Policy	Review of the seabed mining regime and the common heritage of mankind (CHM) principle.	No effective benefit sharing; lack of available data; lack of transparency.	For the CHM principle to work, it needs to include new approaches that are transparent, accountable and take into consideration the available marine science on deep sea processes.	The ISA's 'Enterprise' future and role is unclear, especially under a lack of reserved areas.
Jones et al.	2019	Existing environmental management approaches relevant to deep—sea mining	Article	Marine Policy	Reviews the management approaches in DSM	Gaps identified; tools for managing DSM exists; new standards on risks is needed.	Lessons can be learned from current off shore industry; developed tools can reduce environmental impact	DSM management and regulation may prove difficult once the industry expands from its current small state.
Kaikkonen et al.	2018	Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: current methods and recommendations for environmental risk assessment	Review Article	Marine Pollution Bulletin	DSM risk assessment and study of current practices. Applies DAPSI frame work.	Sustainable management of the marine environment is dependent on how ecosystem structure and functions benefits society; data on species and habitat characteristics severely lacking.	Current impact assessments need to incorporate ecosystem services to a larger degree	If appropriate scientific knowledge is lacking, even thoroughly executed impact assessments cannot succeed in describing the possible scenarios.
Kennedy et al.	2019	The Unknown and the Unexplored: Insights Into the Pacific Deep-Sea Following NOAA CAPSTONE Expeditions	Article	Frontiers Marine Science	Investigation and evaluation of the 3-year period, the National Oceanic and Atmospheric Administration (NOAA) organized and implemented a Pacific-wide field campaign expedition called CAPSTONE	This effort gave new insight into differences in biodiversity across depths, regions, and features, at multiple taxonomic scales. For all deep sea taxonomic groups large enough to be visualised, the study found that less than 20% of the species were able to be identified.	It is now clear that 86.22% of the Pacific has yet-to-be mapped, and over 99% of it yet-to-be-imaged.	Patterns of biodiversity across the Pacific are still not solved, as there are very few extensive studies that occur over a basin-wide scale.
Kim, R.E.	2017	Should deep sea mining be allowed?	Article	Marine Policy	As a scholar, pose the question whether DSM should be done at all.	Assumptions on benefits vary; DSM does not seem anchored well in SDG 2030 Agenda.	Common heritage of humankind and its premise to DSM needs to be scrutinized and revised; ISA needs to become more transparent;	Exploration bias and scholars doing research as if it has been decided that DSM will start, just a matter of when.

Table A1. *Cont.*

Author	Year	Title	Article Type	Journal	Purpose/Aim	Findings	Recommendations	Obstacles/Challenges
Koschinksy et al.	2018	Deep-sea mining: Interdisciplinary research on potential environmental, legal, economic, and societal implications.	Article	Integrated Environmental Assessment and Management	Provide an overall picture of DSM, current research, industry, controversies: adds the social perspective.	Public perception and knowledge is low: uncertainties of DSM and external impacts grave; opposition might arise from a myriad of expected and unexpected actors.	Greater need for higher numbers of interdisciplinary research on DSM to fully comprehend the future of mining the deep sea; EIA and SIA equally important.	Perceived risks of DSM contested amongst actors; problematic relationship between state and private actors could arise.
Levin et al.	2016	Defining "serious harm" to the marine environment in the context of deep-seabed mining	Article	Marine Policy	Potential environmental impacts of mining are examined for nodules, vents and seamounts.	Defining what the term 'serious harm' means is crucial: DSM likely to become a reality; low growth and slow recovery rates endanger deep sea fauna and biota in mining zones.	Academic understanding about the impacts of mining need to improve; let the precautionary approach lead how uncertainties are dealt with.	General regulations not enough for the specific DSM resources and their unique potential risks.
Lledó et al.	2019	Ecology of a polymetallic nodule occurrence gradient: Implications for deep- sea mining	Article	Limnology and Oceanography	Assess the influence of seafloor nodule cover on the megabenthos of a marine conservation area in the Clarion Clipperton Zone.	Faunal composition varied continuously along the nodule cover gradient.	Preservation of areas will have to comprise the full range of nodule cover, not just the low cover areas that are least attractive to mining.	Not yet clear if the environmental conditions and faunas in the currently designated individual conservation areas, are similar to those of the mining claims and therefore it is not safe to rely on their functionality.
Lodge, M.W. and Verlaan, P.A.	2018	Deep-sea mining: international regulatory challenges and responses	Article	Elements	Provide an overview of the DSM regulatory regime; contrasts burdens/issues with advantages.	Unique regulations in place before exploitation even starts; DSM multi-faceted issues must and can be addressed by the ISA.	DSM stands out as a resource since it has an international body solely dedicated to its regulations; issues of regulatory framework and environmental concerns need to be addressed.	DSM is probably the best regulated industry—that has not happened yet! It is counter-productive to discuss whether DSM should start or not, since this was already decided many years ago by the international community.
Miller et al.	2018	An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps	Review Article	Frontiers in Marine Science	Review of current state of development of DSM activities; possible environmental impacts both close to and far from mining sites; uncertainties and gaps in scientific knowledge that makes impacts in the deep sea difficult.	Substantial knowledge gaps exist regardless of current available data; mitigation may be hard in many places of the deep sea; recovery of ecosystems is not scientifically proven over space and time.	Fill the knowledge gaps; Truly account for all environmental and social externalities; explore routes using already mined resources from land in a sustainable way.	In ISA's statement on environmental impact, the author's question what exactly would could as 'significant adverse changes in the marine environment' and at which threshold acceptable levels will be set when exploitation potentially begins.
Mukho-padhyay et al.	2019	The economics of mining seabed manganese nodules: A case study of the Indian Ocean nodule field	Article	Marine Georesources & Geotechnology	Pros and Cons of DSM and the Deep Sea Economy (DSE).	DSE a challenging task, both investment and technological development; legislation, empowered institutions, and principles of good governance needed.	Metal potential in the three main DSM resouces, nodules, vents and seamounts need further and in-depth investigation—without that the financial grounds for it is difficult to determine.	Still not settled how, for example, polymetallic nodules are formed; long way to go for research community in order for economists to make fair evaluations.

Table A1. *Cont.*

Author	Year	Title	Article Type	Journal	Purpose/Aim	Findings	Recommendations	Obstacles/Challenges
Niner et al.	2018	Deep-Sea Mining With No Net Loss of Biodiversity—An Impossible Aim	Article	Frontiers in Marine Science	Deep-sea mining is likely to result in biodiversity loss, the article considers a goal of no net loss (NNL) of biodiversity and explores the challenges of applying this aim to deep seabed mining.	The authors conclude that the industry cannot at present deliver an outcome of no net loss. Deep-sea environments are fragile to mining impacts, currently limited technological capacity to minimize harm, gaps in ecological knowledge, and uncertainties of recovery potential of deep-sea ecosystems.	The level of "acceptable" biodiversity loss in the deep sea requires public and well-informed consideration, as well as wide agreement. Crucial to keep assessing residual losses remaining after the robust implementation of the mitigation efforts. Refers to the mitigation hierarchy pyramid.	If mining is permitted and losses accepted, national governments, the ISA, and deep-sea mining contractors will need to focus greater attention on preventive steps of the mitigation, using a precautionary and adaptive approach.
Petersen et al.	2016	News from the seabed–Geological characteristics and resource potential of deep-sea mineral resources	Article	Marine Policy	Examine how deep-sea mineral resources formed by very different geological processes, resulting in deposits with different characteristics.	Geological characteristics of DSM minerals vary widely; deep-sea mineral occurrences differ in resource potential; sizes of favorable areas of formation influence exploration efforts.	Environmental impacts need to be fully assessed in order to know if DSM is feasible in the future; loss of hard substrate and subsequent species living in those ecosystems might not recover; nodule harvesting closest to reality coming years.	Social license and clear agreement from the scientific community before DSM can at any time begin exploiting.
Santos et al.	2018	The last frontier: Coupling technological developments with scientific challenges to improve hazard assessment of deep-sea mining	Review Article	Science of the Total Environment	Question the basic assumptions of DSM regarding biological communities, regulation and available data.	Technological advancements suggested in their article can mediate and validate DSM in hydrothermal vents, how data is collected and risk assessed.	Scholars should focus on developing a framework that applies holistic perspectives to DSM; Each region needs strategic environmental management.	Environmental responsible between states.
Sharma, R.	2017	Deep-Sea Mining: Current Status and Future Considerations	Book Chapter 1	Springer	Synthesize DSM current data, knowledge gaps and evaluates potential environmental impact.	Sudden growth in contractors aiming to explore and exploit the deep seabed since 2015, calls for a new look at DSM regulations, status of data and economic viability.	DSM is in an advantageous position considering regulatory bodies have a chance to finally set up an extractive industry that is set to be sustainable before it starts, i.e., the Mining Code.	Results from contractor's tests are much too small compared to the impact of actual commercial scale.
Sparenberg, O.	2019	A historical perspective on deep-sea mining for manganese nodules	Article	The Extractive Industries and Society	Give an historical overview of DSM from 1980s till today.	Resources change meanings and the 'becoming' of DSM as a resource is tied to technological and financial feasibility.	Likely that exploitation will begin sooner than later, and regulations need to be in place	Old frameworks and regulatory systems from the 80s needs to be revised.
Van Dover et al.	2018	Scientific rationale and international obligations for protection of active hydrothermal vent ecosystems from deep-sea mining	Article	Marine Policy	Explore why active hydrothermal vents are such important resource for humanity.	DSM might destroy little-known areas that takes millions of years of evolution and adap- tations to extreme environmental conditions.	The ISA and States/companies set to mine must apply a strong precautionary principle to protect the environment; Actors need to live up to commitments in UNCLOS.	Hard to actually determine whether a hydrothermal vent is passive or still active.

Table A1. *Cont.*

Author	Year	Title	Article Type	Journal	Purpose/Aim	Findings	Recommendations	Obstacles/Challenges
Vanreusel et al.	2016	Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna	Article	Nature	Deepen insight in the fauna tied to polymetallic nodules	When considering time and spatial scales and the impact of fauna around nodules, there has to be more advanced systems for management and mitigation of impact.	Removal of nodules may have a lasting impact on the epibenthic biodiversity in the contractor areas, as hard substrate will need millions of years to restore.	"Nodule mining on the CCZ will have winners and losers, and hard substrate epifaunal communities will definitely be among the losers."
Woodwell, G.M.	2011	Curb deep-sea mining now	Commentary	Nature	Explore the perspective and route where DSM does not start at all for now.	The risks of the deep sea ecosystem are too large; the premise of redistribution and the CHM is too thin; the ocean does not need more potential toxic chemicals; overwhelming human cost	Refocus to available land metals and recycle; what gives us the right to destroy the deep sea ecosystems?	Global problems start at a local place, we should not start a potentially disastrous new industry as long as the data is this uncertain.

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