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New perspective on the recent challenges of regional environmental management plans under the background of deep-sea mining: from Northwest Pacific to global

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With the utilization of the mineral resources of the international seabed area entering a new phase of exploitation, the international community's concern for the protection of the marine environment in the international seabed area has also reached an unprecedented level. Regional Environmental Management Plans (REMPs), formulated by the International Seabed Authority (ISA), are considered as an important component of marine environmental protection in the deep seabed. However, REMPs are faced with challenges in practice under the background of deep-sea mining. In this work, we review the historical evolution of REMP, sort out the challenges faced by REMP from NWP to global and provide our suggestions to solve these issues. Specifically, the difficulties in the Northwest Pacific (NWP) REMP are mainly located in the lack of environmental scientific data. Meanwhile, from a global perspective, besides difficulties in local region, such as NWP, REMPs are facing more challenges, such as the arguments about the legal force of REMPs, conflicts between REMPs and the BBNJ Agreement, as well as absence of regulations for balancing exploitation and conservation. Focus on these challenges, suggestions are proposed including using the ISA to coordinate the application between REMPs and BBNJ Agreement and using the principle of scientific evidence to improve the regulations of REMPs. This work not only introduces a new insight for improving the framework system for the protection of the marine environment in the international seabed area, but also provides a reference for the solution to new challenges in the field of marine environmental protection.

KEYWORDS

deep-sea mining, REMP, Northwest Pacific, global, challenges

1 Introduction

Deep-sea mineral resources have emerged as significant substitutes or supplements for land-based metallic resources in the 21 century (Du et al., 2024).The island nation of Nauru, who sponsors the Canadian mining corporation The Metals Company (TMC) to conduct research into deep-sea mining, triggered the so-called “two-year rule” of the International Seabed Authority (ISA) in 2021 (Singh, 2021). Per the agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea (the Implementing Agreement), this rule obligated the ISA to allow consideration of mining permits on July 9, 2023, with or without completed regulations in place. TMC hopes to begin mining in coming years and is closely watching the developments at the ISA; the latest media statement from TMC, dated July 24, 2023, expressed disappointment that regulations were not finalized by July 9 and conveyed hope they would be completed in November, 2023 (Murdock R., 2024). However, Among the primary concerns driving opposition to deep-sea mining is the potential for environmental harm created by disturbing the seafloor as nodules are extracted (Blanchard and Gollner, 2022). In light of these potential risks and their uncertain nature, organized opposition to beginning industrial deep-sea mining now exists (Murdock, R.,2024). If clean energy transitions and electrification are pursued for decarbonizing economies, the need for deep seabed’s minerals cannot be escaped.

In short, deep-sea mining, as an international issue concerning the development of all human beings, is subject to many controversies covering technical, environmental, financial, legal, and other fields (IISD, 2019). The United Nations (UN) now observance of 2021–2030 as the Decade of Ocean Science for Sustainable Development, alongside the existing Sustainable Development Goal 14 (which aims to conserve and sustainably use ocean resources), presents an opportunity to accelerate efforts to develop strong, well-informed frameworks for deep-sea mining as a comprehensive strategy (Howell et al., 2020). In addition, according to the United Nations Convention on the Law of the Sea (UNCLOS) (UN, 1982) and the Implementing Agreement, many countries have formulated laws and regulations on deep-sea mining. For example, New Zealand established the Continental Shelf Act 1964 for the exploration and exploitation of continental shelf (New Zealand, 1964), and formulated the United Nations Convention on the Law of the Sea Act 1996 (New Zealand, 1996) to give effect in the law of the New Zealand to provisions of Part XI of the Convention. African countries have relatively limited deep-sea activities, and only a few countries submitted relevant texts of deep-sea legislation to ISA. They advocated that the benefits of deep-sea mining should be shared by all humanity, meanwhile these mining activities should also consider environmental protection (Wang and Zhong, 2022) due to the impact on the living environment of benthic communities of invertebrates (Cuvelier et al., 2018).

Under the circumstance, in March 2024, the first part of the 29th session of ISA made significant progress in the ongoing negotiations of the draft exploitation regulations (the Mining Code) for mineral resources in the international seabed area(the “Area”) (ISA, 2024). Against the backdrop of argument regarding deep-sea mining and environmental protection, an increasing number of States, social organizations and enterprises are publicly expressing their concerns about the opening of deep-sea mining (Greenpeace, 2024). After all, there are still significant gaps in the environmental, ecological and social impacts of deep-sea mining and its regulation, which is the most important issue to be solved.

The Implementing Agreement adopted in 1994, stipulates that the international seabed area beyond the limits of national jurisdiction and its mineral resources are the common heritage of mankind. The Implementing Agreement established the ISA to organize and control activities in the “Area”, manage the mineral resources of the “Area”, and formulate policies and measures for the protection and preservation of the marine environment. The ISA consists of the Assembly, the Council, the Finance Committee, the Legal and Technical Commission (LTC), and the Secretariat (UN, 1994).

The Regional Environmental Management Plans (REMPs) are environmental protection pdeep sealans formulated by the International Seabed Authority (ISA) (ISA, 2018) in accordance with Article 145 of the UNCLOS (UN, 1982), aiming to solving the prominent environmental protection issues in deep-sea mining. The establishment of the first REMP was formally proposed by the ISA in 2011 based on the Kaplan Project (2002–2007), which is a management tool for balancing the development of the mineral resources of the “Area” with the protection of the environment (ISA, 2011). In 2012, the ISA Council, on the recommendation of the LTC, approved a REMP for the CCZ in the eastern Pacific Ocean (ISA, 2012). The CCZ REMP used to consist of nine areas of particular environmental interest (APEIs) designed to protect biodiversity and ecosystem structure and functioning within the delineated area and to prohibit, in advance, the exploitation of mineral resources within the delineated area. At present, there are 13 APEIs in the CCZ (ISA, 2021).

In 2018, the ISA Council, in conjunction with the ISA Secretariat’s proposal for a “preliminary strategy for the development of a regional environmental management plan for the ‘Area’” (ISA, 2018b), agreed to the initial identification of the Mid-Atlantic Ridge, the Triple Junction Ridge and Nodule Belt of the Indian Ocean, the seamounts in the NWP, and the South Atlantic Ocean as the priority areas for the development of REMPs. Focusing on progress on the development of the REMP for the NWP, in May 2018, the Authority, in cooperation with the China Ocean Mineral Resources Research and Development Association (COMRA), organized the first workshop on the development of the REMP for the cobalt-rich ferromanganese crust region of the NWP in Qingdao, China (Permanent Mission of PRC to International Seabed Authority, 2018). A second workshop was convened online in 2020 (ISA, 2020b). Recently, the latest workshop was held in February 2024 in Tokyo (ISA, 2024), which validated and refined the design of the potential area-based management tools (ABMTs) and other issues related to the REMP for the NWP.

As for the development of the standardized approach for the whole REMP, in 2022, the LTC presented the Council with a draft proposal for a standardized approach for REMPs (ISA, 2022). The draft proposal (ISBA/27/C/37) is currently under further review by the LTC based on the Council’s deliberations, and eight stakeholders have submitted written comments on the draft. In the first part of the 29th Session of the ISA in March 2024, The ISA Commission decided at the technical level to support the practical implementation of the standardized approach by developing a guidance document for REMPs (ISA, 2024). The guidance document will be aligned with the standardized procedure and will contain practical and technical details, including the recommended scientific data and information, methodologies and approaches that should underpin the development, establishment and review of REMPs. All the relative documents will be reviewed during the second part of the twenty-ninth Session in July 2024.

In 2012, the ISA Council issued and implemented the Decision Relating to an Environmental Management Plan for the Clarion-Clipperton Zone (CCZ) (ISA, 2012). Since then, ISA has accelerated the construction process of REMPs in mineral resource-rich areas, such as the North Atlantic mid-ridge region and the Northwest Pacific (NWP) region (ISA Council, 2018a). However, the REMPs are hampered by multiple obstacles, thus few significant results have been achieved (Yan, 2021). For example. the REMP of CCZ encounters challenges, including insufficient legal binding and challenges in gathering and submitting environmental data (Zhang and Zhu, 2020). Moreover, due to insufficient data, the Indian Ocean region has not defined the scope for establishing REMPs currently (ISA, 2023). As for Northwest Pacific region, because of the complex ecological environment, the REMP for this region developed slowly. This study focuses on the development and implementation of REMPs. We summarize the difficulties of the construction of the REMP in the NWP region via considering impacts of deep-sea mining on environmental protection at the scientific and institutional levels. In addition, our discussions are extended to global on the ongoing challenges to the whole development of REMPs, in particular the one of where REMPs should go in the light of the impact of the Agreement under the UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (the BBNJ Agreement) on the ISA regime system.

2 Difficulties faced by the REMPs for the NWP

2.1 Overview of NWP

The broad area of the REMP for the NWP region is form 1°N to 40°N and from 132°E to 179°E. In terms of geomorphological and topographical features, the NWP region contains three major seamount groups, i.e., the Marcus-Wake Seamount Group, the Magellanic Seamount Group, and the Marshall Seamount Group, in which the contract areas of Japan, China, Russia, and the Republic of Korea are situated (ISA, 2020b). And the deep-sea pelagic basins of the Nadezhda, Kartagraf, Pigafetta, East Mariana, and Nauru basins are also located in the NWP region. Due to the Mesozoic tectonics and magmatism, the geography and morphology of this region are complex, and the distribution of the seamount chains and intermountain basins that have formed in different periods is irregular. The densest distribution of seamounts makes the region with the richest cobalt crust resources in the world (ISA, 2020c). The main mineral resources, e.g., cobalt-rich crusts, polymetallic nodules, and polymetallic sulfides, have broad mining prospects and are currently explored in the area. The back-arc region of the western Pacific Ocean has more polymetallic sulfides with mining value, while more polymetallic nodules are located in the abyssal plain region of the NWP (ISA, 2020).

In terms of habitats and species composition, the deep sea of the NWP has a complex ecology, with a wide variety of ecosystems, habitats, and species found in the deep waters of the region. Among these, benthic habitats are represented by two unique habitats, i.e., seamounts and abyssal plains. According to scientists' observations of plankton, pelagic fish, and benthic organisms, the surface of the ocean in the NWP region is rich in Prochlorococcus and Proteobacteria, while the benthic habitats are abundant with benthic invertebrates, sponges, corals, and other megafaunas (ISA, 2020c). Many benthic megafaunas are attached to or associated with cold-water corals and sponges, and some of them constitute vulnerable marine ecosystems, which are slow-growing, long-lived, and slow to recover. There is also a wide range of seabirds in the NWP. The area of the NWP, where ISA has awarded contracts for exploitation, overlaps with areas for sharks, marine mammals, and commercial fisheries (ISA, 2020c).

2.2 Impacts of deep-sea mining activities on the ecosystems of the NWP

Currently, some progress has been made in deep-sea mining activities in the NWP region (ISA Maps). For example, ISA has signed exploration contracts for the exploration of cobalt-rich ferromanganese crusts with the Japan Oil, Gas, and Metals National Corporation, COMRA, the Ministry of Natural Resources and Environment of the Russian Federation, and the Government of the Republic of Korea (ISA, 2024). Before actual mining activities, it is necessary to have a comprehensive understanding of the potential impact of deep-sea mining activities on seabed ecosystem, which is what scientists have been analyzing and researching all along. According to Tables 1, 2 (ISA, 2020b), by analyzing the potential impacts on the ecosystems of the NWP from natural and anthropogenic activities in the deep-sea mining process, negative impacts play more important role than positive impacts in the process. Vehicle compaction of soils, alteration of sediment chemistry, mining plumes, return plumes, noise and light from mining vehicles and surface vessels and other activities all have more negative impacts on benthic ecosystems. In particular, the noise and light generated by mining vehicles in the mining area can change the living environment of benthic organisms, thus harming the communication, foraging and reproduction behaviors of many species (ISA, 2020b).

Habitats of seamounts and abyssal plains are unique in the deep sea of NWP. Seamounts have abundant cobalt rich ferromanganese crusts, which are important potential sources of metals and rare earth elements (Hein et al., 2013). However, many seamounts grow very slowly, especially those forming biogenic structures such as

TABLE 1 Potential effects from mineral resource exploitation activities on the pelagic and abyssal plains of NWP.

No.	Pressure	Direct effect on	Description	Supporting Reference
1	Removal of hard substrate at the seafloor and of the top 10–30 cm of sediment	Microbial communities, Infauna, Epifauna Coral	All nodules will be removed over very broad areas (200 km2 per contractor per year), and nodules will not regrow to appreciable size for millions of years. Mining will destroy the top ~10–20 cm of the sediment column plus the organisms in it over the areas mentioned above. So ecosystems and biogeochemical functions do not regenerate well even over several decades. Removing of hard substances at the seafloor can lead to the rise, fall, and accumulation of sediments. Under the circumstances, the growth rate, reproductive yield, and mortality rate of deep-sea corals decrease.	Weaver and Billett, 2019: Vanreusel et al., 2016: Jones et al. (2017); Gollner et al., 2017. Carreiro-Silva et al., 2013
2	Compaction of the soil by vehicles and alteration of the chemical property of sediment	Microbial communities, Infauna	Sediment compaction under the tracks of the seabed mining tool will reduce porosity and permeability and thereby restrict porewater diffusive exchange and potentially hinder recolonization by benthic fauna. Additionally, the pore water content would be released in the bottom layer, altering the water chemistry of the bottom water, therefore influencing the microbial communities. Finally, the removal of sediment might bring to the surface the oxic–anoxic transition layer (deep oxic–transition layer in the CCZ, but this should be verified for the NW Pacific region).	De Stigter (2020)
3	Mining plume (seabed)	Infauna, Epifauna, Demersal fishes, Invertebrates	The ejected sediment mentioned above will also create a plume of suspended sediment with a high particle load near the mining vehicle where it will smother all seabed animals. At greater distance, filter feeders will be impacted or killed. This plume will also affect animals in the benthic boundary layer, with the plume extending hundreds of meters above the seafloor.	Weaver and Billett (2019): Gillard et al. (2019); Drazen et al. (2019)
4	Return plume (A)	Deep nekton, Deep predators	The water returned from nodule processing on the support ship could be discharged in mid-water where its particulate load will affect suspension feeding animals in the mesopelagic and bathypelagic zones.	Drazen et al. (2019)
5	Return plume (B)	Infauna, Epifauna, Demersal fishes, Invertebrates	If return plume contains toxic contaminants, mortality or severely reduced fitness with potential for sublethal impacts that can persist for years, causing continued degradation.	Drazen et al. (2019)
6	Noise from mining vehicle at the mine site	Demersal fishes and Invertebrates, Deep Nekton, Deep Predators	There is potential for noise from the nodule mining vehicle to impact animals on the seabed and in the benthic boundary layer. Additionally, the proximity of seamounts in the NW Pacific region would induce echo and deflections of the noise generated in the abyssal plains.	

(Continued)

TABLE 1 Continued

No.	Pressure	Direct effect on	Description	Supporting Reference
			Physical trauma to internal organs, reduced fitness, and reduced survivorship for vertebrates and invertebrates have been documented hundreds to thousands of meters from a sound source.	
7	Noise from surface vessel	Birds, Turtles, Whales	Diving sea birds exposed to underwater noise pollution are expected to suffer implications for survival and fitness. Detrimental injury, tissue damage, physical change, and masking of biologically significant sounds may change behavior and compromise fitness, communication, foraging and feeding, bonding, breeding, predator avoidance, habitat avoidance, etc. with long-term impacts and unknown recovery.	Røstad et al. (2006), Solé et al. (2013); Erbe et al. (2018)
8	Noise from pumps on riser pipes in SOFAR (sound-fixing-and-ranging) layer	Whales, deep nekton and deep predators	Sound is transmitted very long distances in the SOFAR layer and it may impact communication between cetaceans that use this layer for their long-distance communication.	Drazen et al. (2019)
9	Light from mine vehicles	Epifauna, Demersal fishes and Invertebrates	Amplifying effects of 3 Mining plume (seabed).	
10	Light from surface vessels	Birds, Fishes	Attracts birds at night, preventing foraging. Light collisions can be fatal or harmful. Lighting may also draw migratory birds to red wavebands. And vast majority of the pelagic community exhibits a strong light-escape response in the presence of artificial light.	Burke et al, 2012; Marquenie et al., 2014; Montevecchi, 2006; Poot et al., 2008; Ludvigsen et al. (2018)
11	Light from surface vessel may affect plankton	Predatory Fishes	Lights can attract and concentrate small fish and squid. These concentrations of fish and squid can, in turn, attract larger predators, such as dolphins, which leads to their higher predation.	Ludvigsen et al. (2018); (Valérie ALLAIN, 2005)
12	Toxicants	Demersal fishes and invertebrates	Metals can affect metabolism. At present, it is not known whether nodule mining will involve the release of metals. If released, toxins can progressively increase in chemical concentration with increasing trophic status (biomagnification), with lethal results.	
13	Marine debris	Phytoplankton, zooplankton, birds, turtles, whales, fishes, predatory fishes, nekton	Marine debris, especially plastics, is one of the rising pressures in the marine environment. The proximity of the western garbage patch to the NW Pacific Region renders this pressure important.	

cold-water corals and sponges (Clark et al., 2010, 2012; Carreiro-Silva et al., 2013). Abyssal plains have plentiful polymetallic nodules. If the nodules are removed during exploitation, all creatures (including demersal scavengers) relying on this hard substrate will be particularly susceptible to mining activities (Vanreusel et al., 2016; Leitner et al., 2017). To evaluate the impact of deep-sea mining activities on the seabed ecosystems, each individual potential mining site should be considered unique and will feature local characteristics that should be assessed accordingly (Cuvelier et al., 2018).

TABLE 2 Potential effects from mineral resource exploitation activities on benthic seamount ecosystem of the NWP.

No.	Types of activities	Direct effect on	Description	Supporting Reference
1	Removal of crust	Population recruitment	Loss of all community components and of habitat. Also removes ability for self-recruitment in the recovery process, and delays recovery by altering larval dispersal, mortality of larvae, and decreased settlement success.	Gollner et al., 2017
2	Plume removal (plume generated by direct removal of crusts), sedimentation	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids, invertebrate detritivores, microbial community, population recruitment	The sedimentation (i.e., particles falling out of suspension) would affect communities negatively by burying everything in the mining site.	
3	Plume removal, suspended sediment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Suspended sediment would affect the filter and suspension feeders (corals, sponges) negatively by clogging feeding system/smothering.	
4	Return plume sedimentation	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges non-stalked crinoids, stalked crinoids, invertebrate detritivores, microbial community, population recruitment	Smothering; increased sediment covers available hard substratum; clogs filter feeding apparatus, loss of suspension feeders. If plume contains toxic pollutants: mortality or severely reduced fitness with potential for sublethal impacts to persist for years causing continued degradation.	Topçu et al., 2019.
5	Return plume–suspended sediment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Increased handling time to sort the "chaff" from suspended matter; diminished fitness.	Anthony and Fabricius, 2000
6	Return plume–temperature	Benthopelagic fishes, local fishes and cephalopods, microbial community	Elevated temperature–effect probably short-lived and long-term impact unlikely. Individuals of some deep-sea species could suffer impeded growth, metabolism, reproductive success, and survival.	Impacts summarised by
7	Return plume sedimentation	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids, invertebrate detritivores, microbial community, population recruitment	Smothering; increased sediment drapes over desirable hard substratum; clogs filter feeding apparatus, loss of suspension feeders.	Topçu et al., 2019
8	Return plume–suspended sediment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Increased handling time to sort the "chaff" from suspended matter; diminished fitness.	Anthony and Fabricius, 2000

(Continued)

TABLE 2 Continued

No.	Types of activities	Direct effect on	Description	Supporting Reference
9	Noise	Benthopelagic fishes, local fishes and cephalopods, population recruitment	Fish are soundscape sensitive; changes in behavior and physiology documented.	Cox et al., 2018
10	Electromagnetism	Benthopelagic fishes, local fishes and cephalopods	Vibration and pulse would affect the mobile ecological component. The scale is not known.	
11	Light	Benthopelagic fishes, local fishes and cephalopods, invertebrate detritivores, invertebrate predators, invertebrate scavengers	Fish with visual systems affected; rods overwhelmed.	Widder et al., 2005
12	Toxicants	Benthopelagic fishes, local fishes and cephalopods	The toxicity associated with leaching crusts depends on the metal content of the crusts. However, how the elevated level of metal (e.g., As, Cu) would influence the organisms is uncertain. It might concentrate along the food chain, and as such influence mainly BPF and LFC. There is a risk of bioaccumulation at higher trophic levels.	
13	Abandoned equipment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals and soft corals, plus colonial hard corals, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Assuming there are no toxic chemicals or paints associated with the structures: anthropogenic structures provide elevation off bottom to access currents—promote settlement; eventually structure loss (erosion or cleanup) will destroy the recruits.	Schlining et al., 2013
14	Abandoned equipment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals and soft corals, plus colonial hard corals, encrusting sponges, glass sponge, non-stalked crinoids, stalked crinoids	Addition of hard substrate can create new habitat, assuming there are no toxic chemicals or paints associated with the structures.	

2.3 Difficulties faced by the REMP for the NWP

The hot-discussed REMP area in previous workshops is from 10°N to 27°N and from 146°E to 164°E (ISA, 2020b). In 2018, the ISA Council preliminarily agreed that the NWP should also be prioritized to establish REMP, and in May of the same year in Qingdao, China, the ISA organized a workshop on the development of REMP for the cobalt-rich ferromanganese crusts in the NWP (ISA, 2018b). The workshop aimed to understand national, regional, and international policies and laws, reach a common understanding of the design of REMP for the NWP region, form an initial framework for the development of REMP, and develop a two- to three-year cooperative plan to collect and share the data needed to design the REMP (ISA, 2018b). In November 2020, in collaboration with the Korean Ministry of Oceans and Fisheries and the Korea Institute of Ocean Science and Technology, the ISA hosted the second online workshop to develop REMP for the NWP. Based on the first workshop, this workshop comprehensively reviewed and analyzed relevant scientific data for the NWP (ISA, 2020a). During the workshop period, current exploration activities and resource distribution in the contract areas within the region are reviewed, and 14 potential areas in need of precaution (AINPs) were defined because these AINPs may be affected by future mineral resource exploitation and require enhanced management and preventive measures (ISA, 2020b). Moerover, this workshop also discussed a framework for addressing the cumulative impacts of future exploitation in order to achieve effective protection of the marine environment. So far, the two workshops have made some progress in the REMP for the NWP, however, there are more specific difficulties that need to be solved. In 2024, ISA accompanied with Japan Organization for Metals and Energy Security (JOGMEC) and Deep Ocean Resources Development etc., held a workshop on the development of the REMP for the NWP region (JOGMEC, 2024). Discussions and proposals from this workshop will contribute to the creation of rules for the development of mineral resources on the deep-sea floor of the NWP (ISA, 2024). By summarizing the content of the three workshops, we demonstrate some difficulties currently faced in construction of REMP in the NWP region in the following.

2.3.1 Difficulty in data acquisition on regional environmental assessment for the NWP

The regional environmental assessment (REA) report is one of the most important scientific bases for the development of the REMP for the NWP region. The report focuses on the scientific research that have been and are being conducted in the NWP region. The content of the REA report is organized according to the recommendations of the ISA in ISBA/25/LTC/6/Rev.1 (ISA Legal and Technical Commission, 2019) and centers on the need to carry out environmental baseline studies (ISA, 2020c). It collects and analyzes existing scientific data in the NWP region mainly from geology, oceanography, and biology. The REA report contains both environmental scientific data for the NWP region as a whole and site-specific scientific data, such as seamounts and abyssal plains. In addition, other environmental scientific data that may be lacking in the NWP region is also identified in the REA report (ISA, 2020c). However, there are still gaps in the content of the REA report. For example, the "depth band analysis" approach used at the workshop to analyze the selection of potential AINP locations is limited by the low resolution of the bathymetric data used. It would make mistakes that these data identify hilltops rather than individual seamounts, which would be an overstatement of the actual situation if interpreted as representative of individual seamounts. Just modeling with the data alone will lead to deviations from the reality of the ecosystems, constituting a challenge for the completion of the REA report (ISA, 2020c). Therefore, bathymetric data still need to be perfect through further scientific research on the NWP region.

2.3.2 Difficulties in data acquisition for the draft data report for the NWP

The data report for the NWP was prepared for the 2020 online workshop and is another important scientific basis for the development of the REMP for the NWP region. The data report covers several aspects, including environmental, biological, and biogeographic, human activities, and areas defined for management or conservation purposes. Most of the scientific data is unique to the NWP region and comes from open-access data sources such as contractors, relevant international organizations and scientific institutions such as Duke University (ISA, 2020a). However, expert Patrick Halpin, who participated in the 2020 workshop, pointed out that the existing data is not sufficient to establish REMP for the NWP region (ISA, 2020a). There is also a large amount of scientific data and papers on the NWP region that are not currently available in open resources. The difficulties in scientific data acquisition further hinder the advancement of the REMP for NWP.

2.3.3 Difficulties in predicting the impacts of deep-sea mining on benthic ecosystem in the NWP

Abundant seamounts and abyssal plains are lying in the deep sea of NWP region. At present, the NWP region contains five contract areas [Table 3 (ISA, 2020b)], which is surrounded by the Marcus-Wake Seamounts Chain, the Magellan Seamounts Chain, and the Marshall Seamounts Chain, sometimes referred to as the Triangle Area (TA) (ISA, 2020b). The ecosystems in the TA are also unique in the NWP region. On the one hand, the underlying geology of seamounts consists of a variety of morphologies, including rubble, nodules, and rocks, while complex topography of seamounts implies the complex ecosystems. For instance, some ecosystems are slow-recovering, less resilient, fragile, and more vulnerable to be damaged (ISA, 2020a). On the other hand, the biodiversity of seamounts is affected by many environmental factors, such as hydrodynamics, chemical condition changes, and the topography and geology of the seamounts (ISA, 2020a). However, due to the lack of current scientific data in the NWP region, the resilience of the ecosystems in the area is still confusing, leading to the extreme challenge to conservation of marine biodiversity in the area (ISA, 2020a).

Meanwhile, deep-sea areas have been already adversely affected by warming, acidification, pollution, and overfishing, and may be negatively impacted by future deep-sea mining activities, including changes in seawater temperature and material, light and noise pollution from human mining activities, and potentially toxic contaminants. These disturbances may alter the survival mode of deep-sea biological communities, impair physiological functions, and decrease reproductive rates (ISA, 2020a).In addition, there is still lack of scientific data on the multi-scale distribution, trophic relationships, ecosystem functioning, connectivity, and resilience of biological communities in the deep-sea environment. Therefore, the prediction of the damage to deep-sea ecosystems caused by deep-sea mining activities is facing great difficulties.

TABLE 3 ISA exploration contracts in the NWP.

Contractor	Mineral resources	Date of entry into force	Date of expiry	Sponsoring state
Japan Oil, Gas and Metals National Corporation (JOGMEC)	Cobalt-rich ferromanganese crusts	27 Jan 2014	26 Jan 2029	Japan
China Ocean Mineral Resources Research and Development Association (COMRA)	Cobalt-rich ferromanganese crusts	29 Apr 2014	28 Apr 2029	China
Ministry of Natural Resources and Environment of the Russian Federation (MNRE)	Cobalt-rich ferromanganese crusts	10 Mar 2015	09 Mar 2030	Russia
The Republic of Korea (RoK)	Cobalt-rich ferromanganese crusts	27 Mar 2018	26 Mar 2033	Republic of Korea
Beijing Pioneer High-tech Development Corporation (BPHDC)	Polymetallic nodules	18 October 2019	17 October 2034	China

3 Challenges faced by REMPs in global

Under the background of coping with climate change, reducing greenhouse gas emissions and vigorously advocating new clean energy, such as secondary batteries and solar energy, have become hot spots and achieved great commercial success. Materials such as lithium, cobalt and graphite are essential components of electric car batteries, wind turbines, solar panels and other low-carbon technologies that can power the world's clean energy systems. According to Table 4, with the dramatic increase of demand for mineral resources, the deep-sea mining activities have attracted great attention in global (Ashford et al., 2024). Due to the progress made in deep-sea scientific research, scientific community and governments gradually realize the negative impacts of deep-sea mining activities on the marine environment and biodiversity of habitats in deep sea. At the same time, the conservation of marine biodiversity of areas beyond national jurisdiction has received increasing international attention with the adoption of the BBNJ Agreement in 2023 (Table 5).

REMPs, as one of the most important tools for environmental protection in deep-sea mining, play more and more significant roles for ISA and other stakeholders. Eleven years have passed since the approval of the first REMP for the CCZ, although all relevant countries are actively promoting the establishment of REMPs in the Mid-Atlantic Ridge, the NWP and other regions, the ISA has not approved a second REMP yet. Obviously, in a reshaping period of global ocean governance rule, the development of the REMP, as an important institutional practice for deep seabed environmental governance, is faced with a few challenges.

TABLE 4 Deep-sea mining activities in other seas and oceans except NWP.

Other seas and oceans	Related mining activities
the Clarion-Clipperton Zone in Pacific Ocean (under ISA)	This mineral-rich region already hosts exploration contracts for 17 deep-sea mining contractors, with their combined exploration areas covering approximately 1 million square kilometers (about the same area as Ethiopia).
the Indian Ocean (under ISA)	Germany, India, China, and Korea have five exploration contracts in sum in the two regions of the Indian Ocean.
the Mid Atlantic Ridge (under ISA)	Poland, Russia, and France have three exploration contracts in sum.
the arctic regions (not under ISA)	Norway announced in June 2024 the opening of vast areas of its continental-self in the Arctic region for its first seabed mineral licensing round. The government proposed putting forward 386 blocks in the Arctic as part of the round. The area comprises about 38% of the 280,000 square kilometers approved by the parliament for exploration earlier. The country plans to grant exploration permits in the first half of 2025.
the domestically controlled waters (not under ISA)	All countries can go ahead with deep-sea mining projects in their own domestically controlled waters' seabed, for example the exclusive economic zones. In January 2024, Norway initiated a process to open its own waters for exploration of deep-sea mineral resources, likely starting in the early 2030s.

3.1 Arguments about the legal force of REMPs

There are always arguments about the legal force of REMPs. The fact is that no REMP has not clearly emerged from the institutional framework for the exploitation of the mineral resources of the "Area" (including the three sets of Exploration Regulations and the draft Mining Code that is currently being formulated). Currently, the REMP is only recognized as an environmental protection policy issued by the ISA. This directly leads to questions being raised by parties to UNCLOS and the Implementation Agreement, contractors, states, and the ISA itself as to whether the REMP is legally binding, and what liability should be incurred in the event of non-compliance. For example, the Regulations on Prospecting and Exploration for Polymetallic Nodules in the "Area" (ISA, 2013) require contractors to

TABLE 5 All abbreviations used in this article.

Abbreviations used	Original Words
REMPs	Regional Environmental Management Plans
ISA	The International Seabed Authority
NWP	Northwest Pacific
the BBNJ Agreement	the Agreement under the UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction
TMC	The Metals Company
the Implementing Agreement	the implementation of Part XI of the United Nations Convention on the Law of the Sea
UN	The Untied Nations
the Mining Code	the draft exploitation regulations for mineral resources in the international seabed area
the"Area"	the international seabed area
LTC	the Legal and Technical Commission
UNCLOS	the United Nations Convention on the Law of the Sea
CCZ	the Clarion-Clipperton Zone
APEIs	areas of particular environmental interest
COMRA	China Ocean Mineral Resources Research and Development Association
ABMTs	area-based management tools
AINPs	areas in need of precaution
JOGMEC	Japan Organization for Metals and Energy Security
REA	The regional environmental assessment
TA	the Triangle Area
EIA	the Environment Impact Assessment

submit an environmental plan when applying for a mine site. According to the plan, contractors need to assess and monitor the impacts of their activities on the marine environment of the "Area" during their activities. After that, a report is submitted to the Secretary-General of the ISA on environmental monitoring, as well as the environmental baseline data that may be used as scientific data to support the REMP. However, UNCLOS, the Implementation Agreement, and the Regulations on Prospecting and Exploration for Polymetallic Nodules in the "Area" do not explicitly require states and contractors to implement the REMP provisions of the CCZ. Therefore, as a matter of implementation, contractors within the CCZ do not currently have any obligations for the protection of the marine environment beyond the scope of the contract, and the REMP for the CCZ is only an environmental policy tool that is not legally binding on contractors. In other words, contractors are only obligated to protect the environment in the contractual area, while areas beyond the contracts in the CCZ are not protected by contractors.

3.2 Conflicts between REMPs and the BBNJ agreement

REMPs aim to implement the area-based management tools (ABMTs), and compile scientific information to accurately describes potential areas that are protected from future development activities. From the content of a series of workshops, it appears that the ISA intends to use REMP as an ABMT for the protection of the deep-sea environment in the future. One of the tasks of the 2024 REMP workshop for the NWP region is to validate and refine the design of potential ABMTs identified in the previous online workshop, and review and further improve the scientific rationale for the identification of such potential ABMTs based on agreed scientific criteria. The BBNJ Agreement is an important piece of current legislation in the field of the law of the sea, which aims to address the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. "Areas beyond national jurisdiction" is defined by the BBNJ Agreement, which includes the International Seabed Area. However, if ISA explicitly defines the REMP as an ABMT in the future, there will be conflicts between the application of the REMP to deep-sea environmental protection in the "Area" and the ABMT set out in the BBNJ Agreement.

Firstly, in view of the ecological connectivity of the oceans, it is difficult to allocate marine organisms in areas beyond national jurisdiction to the high seas or the "Area" separately. Therefore, the REMP formulated by ISA is different from the ABMTs provided by the BBNJ Agreement, especially in aspects of their purpose, legal basis, scope and application background. Compare with the latter, the existing area-based management practice of ISA is also more abundant (including Impact Reference Zones, Preservation Reference Zones, APEIs, etc.). As a result, the environmental protection of the "Area" is faced with the problem of dealing with and choosing the relationship between multiple area management tools.

Secondly, the inter-institutional cooperation mechanisms are not clear. Although the international community has been encouraging the harmonization of policies promoting oceans, climate and biodiversity, there appears to be inertia and a tendency to maintain the status quo among parties in the governance of the ABNJ, as reflected in the BBNJ agreement and the ISA-led formulation of the REMP. If the REMP is defined as a ABMT, the current BBNJ Agreement does not provide detailed mechanisms on how to improve inter-institutional cooperation, nor does it contain specific provisions for the implementation of integration or monitoring, but rather it allows the state parties to promote coherence and complementarity in the establishment of ABMTs and ecosystem management in ABNJ.

Thirdly, there are problems in the application of Environment Impact Assessments (EIAs) established by the ISA and the BBNJ Agreement for specific EIA projects (Christiansen et al., 2022). Based on UNCLOS, Part XI and the 1994 Agreement, ISA has developed detailed and substantive provisions, regulations and recommendations related to the assessment of possible environmental impacts arising from exploration for marine minerals in the Area, which define the sort of activities that require EIAs, the form and content of such EIAs when required, as well as guidance on baseline studies, monitoring and reporting (ISA, 2019). EIA thus plays an important role in the establishment of REMP. The BBNJ Agreement also has detailed regulations on EIAs (UN, 2023). Compared with the regulations by BBNJ Agreement, the guidance of EIA formulated by ISA addresses impacts on marine biodiversity on the seabed and in the water column. One of the problems is that there is a contradiction between following the EIA by the BBNJ agreement or the ISA guidance at the time to conduct an EIA during the process of establishing REMP. The BBNJ Agreement stipulates that it is not necessary to conduct an EIA of a planned activity in areas beyond national jurisdiction if the potential impacts of the planned activity have been assessed in accordance with the requirements of other relevant legal instruments or frameworks or by relevant global, regional, subregional or sectoral bodies (UN, 2023). Under this regulation, if the EIA is completed in accordance with the guidance of ISA, another problem is that information exchange mechanism of EIA is not perfect for relevant contracting parties.

Overall, the autonomy of sectoral organizations hinders integrated management and effective cooperation in ocean governance. Deep-sea environmental protection requires comprehensive and integrated governance, but the current ABMTs were established by various international organizations in a relatively isolated legal background. The current legal force of REMP is still uncertain, and if it is given legal force in the future, the strength difference of the respective legal force between the REMP and BBNJ agreements, as well as the order of their applications, are all issues that need to be taken into account under the UNCLOS system in the "Area".

3.3 Absence of regulations for balancing exploitation and conservation

In 2022, the Council of ISA made a draft decision relating to a standardized approach for the development, approval and review of

REMPs in the "Area" (ISBA/27/C/L.5), in which the goal of REMPs has been listed. However, the draft decision were not adopted by the Assembly yet. And the construction process and top-level objectives of the REMP are not clarified in the latest relevant strategic plans, like the strategic plan for the period 2024–2028(ISBA/28/A/7). Moreover, UNCLOS obliges the ISA to take measures to ensure that the marine environment is protected from harmful effects that may arise from activities in the "Area". The provisions of the existing REMP, one of the ISA's unique environmental policies, are inadequate, especially in finding a balance between environmental protection and the exploitation of the mineral resources in the "Area".

There is a dispute among the parties to the Implementing Agreement as to whether the Mining Code currently being negotiated by the ISA should regulate REMPs (ISA, 2019). In July 2019, representatives of the United Kingdom, Germany, the Netherlands, and a number of African countries argued that REMPs should be a prerequisite for mining activities, while another voice, represented by China, emphasized that REMPs should not be a stumbling block to commercial development (ISA, 2019). REMPs are currently not explicitly regulated in the latest draft of the revised Mining Code. It is only mentioned in Fundamental Policies and Principles in Mining Code as well as the Environmental Impact Statement Regulations. However, in terms of the REMP, the criteria, guidelines, its relationship with the Mining Code, the review mechanism, and the roster of independent reviewers are also controversial among countries. No legal document has been issued on the general norms, and the draft recommendation on the standardized methodology of the REMP (ISA, 2022), which was submitted by the Legal and Technical Commission (LTC) to the Council of the ISA in 2022, is still in the review stage (Zeng and Gao, 2020). These deficiencies make it difficult to prove that REMP neither infringes upon the legitimate rights of countries to explore and exploit the mineral resources in the "Area" in accordance with the UNCLOS principle of "common heritage of mankind", nor overprotects the environment of the "Area".

The formulation of environmental rules for the "Area" and the negotiation and formulation of draft Mining Code are mutually constraining. As seen from the latest draft of the Mining Code, the environmental rules still need to be improved. The environmental management of the ISA is weak, because it only provides a more general framework for the procedures related to environmental protection, and fails to formulate relevant and effective measures and normative standards in accordance with the provisions of Article 145 of UNCLOS. It can be seen that the ISA's 2024–2028 strategy only reflects the principles for the establishment of the REMP, but the overall objectives and specific content regarding the REMP remain unclear. In a word, it is the insufficiency of REMP participation in practice and indeterminacy of the specific rights and obligations of REMP's governing organs and stakeholders that result in a slow process of REMP development.

4 Suggestions for challenges faced by REMPs

4.1 Promote national engagement in REMPs by developing and improving the mining code

Focusing on the arguments about the legal force of REMPs, the first suggestion we propose is that the ISA should add encouragement clauses to the Mining Code to encourage states parties, sponsoring states, and contractors to actively participate in the construction of REMPs.

As mentioned in Section 3.1, neither the UNCLOS Implementing Agreement nor the three Exploration Regulations contain specific provisions for the REMP. It was not until 2012 that the REMP for the CCZ was officially issued and implemented, a decade after the Kaplan project in 2002. The fact that REMPs, as an environmental protection policy, are not legally binding is one of the main challenges faced in their implementation, which was also prominent in the discussions on the establishment of the REMP for the NWP. Therefore, when it comes to the exploitation of deep seabed mineral resources, the implementation of the REMP needs to be more efficient. The Secretariat of the ISA has suggested that, as an environmental policy, the Council could decide that no contracts should be awarded in the relevant area until the REMP is established.

At present, the Mining Code is about to be introduced, and the REMPs for priority regions such as the NWP will also conduct new workshop to form the text of relevant motions. If the Mining Code includes provisions encouraging states parties, sponsoring states, and contractors to actively participate in the construction of REMPs, it can not only increase the degree of national participation and the recognition of REMPs through the expansion of national practices (Ardito and Rovere, 2022), but also provide a relatively binding legal basis for the implementation of REMPs by the States Parties and contractors, thereby solving the problem of the development procedure and legal binding force of emerging programs such as the REMP for the NWP.

4.2 Coordinate the application between REMPs and BBNJ agreement through ISA

As for the conflicts between REMPs and the BBNJ Agreement, we suggest that the ISA should play a leading role in coordinating the application between REMPs and BBNJ Agreement.

The rules formulated by ISA and the BBNJ Agreement were originally two sets of rules regimes developed in parallel under the UNCLOS system. However, conflicts have arisen between the application of the two sets of rules in the "Area", especially in the application of the ABMTs. Firstly, a fact should be recognized that there is no conflict of purpose between the REMP and the BBNJ Agreement, both of which are aimed at the protection of the deep-sea environment. On that basis, there should be a inter-institutional coordinating organ to facilitate communication and data-sharing between the REMP and BBNJ Agreements. Up to now, the BBNJ agreement has been finalized, while many of ISA's rules are still in the process of being formulated. Given that ISA has accumulated a wealth of management experience in "Area" issues, it can be considered to be responsible for issues such as communication and data sharing with the BBNJ Agreement.

Secondly, the framework and content design of the REMP should be improved based on the BBNJ Agreement. ISA can set up a supervisory mechanism to regularly check the implementation and monitoring of the management and protection measures of the REMP, as well as cooperate and share information and data with the competent agencies of the BBNJ Agreement. At present, several APEIs have been delineated in the REMP for NWP, and the BBNJ Agreement implements ABMTs aimed at conserving biodiversity in the "Area". Based on that basis, besides prohibiting mining in APEIs, attention should also be paid to collecting relevant scientific data on biodiversity in APEIs and analyzing the influence of mining activities out of the APEIs on biodiversity in APEIs. Meanwhile, ISA should play a leading role in coordinating the REMP for NWP with the BBNJ Agreement to achieve the objectives of protecting the environment, implementing and monitoring of the ABMTs and the EIA, and making timely adjustments in accordance with the BBNJ Agreement.

4.3 Improve the regulations of REMPs with the principle of scientific evidence

To solve the problem of lacking regulations for balancing exploitation and conservation, we recommend that it is necessary to improve the regulations of REMPs with the principle of scientific evidence.

The purpose of REMP is not to prohibit deep-sea mining, but rather to protect the deep-sea environment in the face of uncertainty impacts of deep-sea mining. At a deeper level, the protection of the deep-sea environment by REMP is, in a sense, aimed at better formulating exploitation regulations and promoting sustainable development for the common interests of mankind. The principle of scientific evidence, which is generally found in international treaties in the field of environment, ecology, and health, is an important basis for action and decision-making by relevant subjects of international law in risk areas. Scientific data needs to be translated into information, and finally knowledge, that is practical and communicated to fit into existing or planned processes and procedures. A disconnect between scientists and seabed-mining policymakers may result in interactions related to science being abstract, jargon-filled (e.g., ecosystem approach), and unspecific, which can sometimes lead to miscommunication and planning error (Amon, D. J. et al., 2022).

According to the experience of the REMP for the NWP, the establishment of any new REMP requires a large amount of scientific data support. Therefore, it is of crucial importance to construct a sound environmental data collection and verification mechanisms for REMPs. In the discussion of the REMP for the NWP, it can be found that the environmental baseline data collected by contractors play an important role. However, the fact that the quality and quantity of data submitted by contractors is uneven, necessitates the establishment of a comprehensive set of criteria for the collection and certification of data in order to ensure the availability of data. Besides, the obligation of contractors to submit environmental baseline data is still limited to the scope of the contract, because contractors are not obliged to collect environmental data outside the contract area. For environmental baseline data beyond contractual obligations, the ISA needs to establish an incentive mechanism aimed at motivating contractors, sponsoring states, state parties, and other scientific institutions to actively participate in the collection of environmental data (Ginzky et al., 2020). For example, the ISA currently has a centralized database (deep data) of public and private information data on marine mineral resources obtained from various institutions around the globe. Through the incentive mechanism,

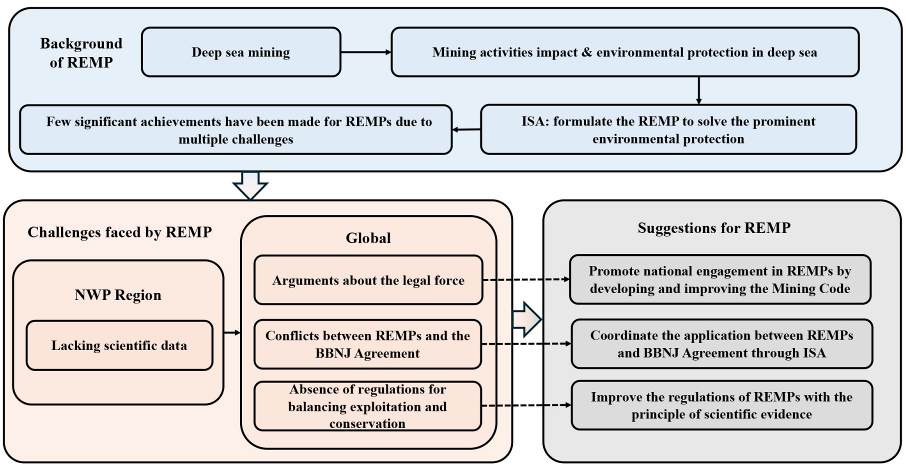

FIGURE 1
Flow chart showing all sections and new insights.

it is practicable to attract various entities to participate in the construction of the deep sea database under unified data standards, which is vital for the development of the establishments of REMPs from NWP to global.

5 Conclusion

In summary, we have systematically investigated the challenges faced by REMPs under the background of deep-sea mining. We firstly review the historical evolution of REMP. By analyzing the status of REMPs for NWP region, we find that the main difficulty for NWP REMP is the lack of deep-sea scientific data. Further, we discuss and point out three challenges faced by REMPs in global, which are arguments about the legal force of REMP, conflicts between REMPs and the BBNJ Agreement and absence of regulations for balancing exploitation and conservation. Focusing on the difficulties and challenges faced by REMPs from NWP to global, we propose three suggestions that promote national engagement to strengthen the legal force of REMPs by developing and improving the Mining Code, coordinate the application to solve the conflicts between REMPs and BBNJ Agreement through ISA and improve the regulations of REMPs with the principle of scientific evidence to balance conservation and exploitation. From a new perspective (Figure 1), we believe this work is of great value for the development of REMPs from NWP to global under the background of deep-sea mining.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

WZ: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. TL: Data curation, Investigation, Methodology, Writing – review & editing. XQ: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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