Should we mine the deep seafloor?

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Key Points:
- Momentum is growing toward the emergence of a deep-sea mining industry
- There is continuing debate about sustainable exploitation of seabed resources, and whether their development is worth the ecological risk
- Many aspects of resource extraction and environmental regulation remain too uncertain to optimally aid decision-making

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Abstract As land-based mineral resources become increasingly difficult and expensive to acquire, the potential for mining resources from the deep seafloor has become widely discussed and debated. Exploration leases are being granted, and technologies are under development. However, the quantity and quality of the resources are uncertain, and many worry about risks to vulnerable deep-sea ecosystems. Deep-sea mining has become part of the discussion of the United Nations Sustainable Development Goals. In this article we provide a summary of benefits, costs, and uncertainties that surround this potentially attractive but contentious topic.

1. Introduction

Resources such as sand, gravel, diamonds, tin, and gold already are extracted from the shallow seabed [*Hannington et al.*, 2017], and the oil and gas industry recently has moved into water depths approaching 3000 m. However, there has been no deep-sea mining thus far. With growing concerns about the scarcity of metals (e.g., *European Commission* [2014]), due in part to increased demand for a diversity of metals in today's products, declining grades of resources on land [*Calvo et al.*, 2016], and concerns about security of supply [*Northey et al.*, 2014], we are now faced with the question — *Should we mine the deep seafloor?* A number of different countries and some commercial companies certainly are moving in that direction. The world's first deep-sea mining lease within an Exclusive Economic Zone was granted in 2011 by the government of Papua New Guinea, and as of 2017, 27 exploration contracts for "the Area" beyond national jurisdiction had been issued by the International Seabed Authority (ISA). Draft Exploitation Regulations for the Area were released by the ISA for public comment in November 2016, and in March 2017 the ISA convened an expert group of scientists to discuss the first working draft Environmental Regulations.

Mineral resources on the deep seafloor are poised to contribute to the supply of some metals, if numerous conditions are met: namely, that the resources have been evaluated adequately, that marine ecosystem impacts can be assessed and mitigated, and that adequate legal structures are promulgated to assure clear title and responsible approaches to exploitation. The question — Should we mine the deep seafloor? — is being closely examined by natural and social scientists around the globe. For some people who wish to see an end to land-based mining the answer is "yes"; for others who say that we cannot risk negative impacts on a vast understudied part of our planet, the response is a resounding "no." There are huge uncertainties on all aspects of the debate — including land-based supplies, the scope of future demand, seafloor resource potential, and impacts on ecosystems and their services that contribute to human well-being.

We (the authors of this Commentary) posed this question at a recent session of the American Association for the Advancement of Science [*Graedel et al.*, 2017]. As natural scientists with expertise in critical metals, seafloor geology, and deep-sea ecosystems, we wanted to explore the best available, objective, scientific evidence to inform the question — Should we mine the deep seafloor? Our goal was to provide a dispassionate review of what is motivating different responses to the question.

2. Uncertainties

The uncertainties have been difficult to address objectively, and the situation analysis for the technical, economic, and environmental feasibility of the proposed industry remains incomplete. Are there enough
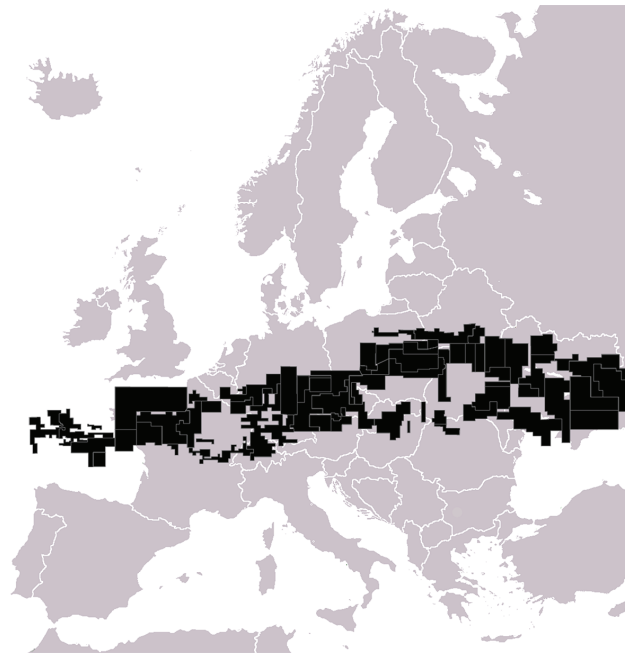
Figure 1. Total area of exploration licenses for manganese nodules in the Clarion-Clipperton Zone (CCZ; ~1.1 million km^2) compared to the area of Europe. Image credit: GEOMAR Helmholtz Center for Ocean Research Kiel.

resources to make a difference? Are they the resources that we need? Do we fully understand the risks to the marine environment? Some consider that the resources are nearly boundless, especially manganese nodules in places such as the Clarion Clipperton Zone (CCZ) in the Pacific (Figure 1). Machines have been built to recover nodules and to mine massive sulfides, although complete mining systems have not yet been fully tested. Challenges of working in the deep sea have been largely overcome by the oil and gas industries. So, what is holding back the emergence of the industry? The return on investment remains a major question. Can the minerals be exploited at a cost that is competitive with land-based mining? Nobody knows, because there are no deep-sea mining operations yet that could serve as economic benchmarks. Also, it remains unclear to what extent a precautionary approach to the protection of the marine ecosystems would be applied [*Mengerink et al.*, 2014].

Under some scenarios, traditional land-based supplies of resources may be challenged to meet future demand [*Ali et al.*, 2017]. For example, a number of different scenarios for copper demand suggest that by mid-century significant new resources will be needed to enable a better quality of life for people in developing countries [*Elshkaki et al.*, 2016]. The developed world will require mineral resources for widespread implementation of "green" technologies. Estimates of the abundance of manganese nodules in the CCZ suggest that, if recoverable, they could satisfy current demand for manganese, nickel, cobalt, and copper for decades. Seafloor massive sulfide deposits represent a smaller resource but are characterized by much higher grades of metals, including copper, zinc, silver, and gold [*Petersen et al.*, 2016]. It remains unclear, however, whether the sizes and quality of deep-sea deposits would be sufficient to support a new mining industry [*Petersen et al.*, 2016; *Hannington et al.*, 2017].

With a better understanding of the structure and dynamics of deep-sea ecosystems, it is thought that we could design monitoring and protected area networks to reduce impacts [*Wedding et al.*, 2015; *Danovaro et al.*, 2017]. An international survey recently gathered expert opinion to better predict risks from the direct and indirect effects of seabed mining [*MIDAS Consortium*, 2016]. Concerns remain about sustainable approaches to exploiting the known seabed resources, and whether their development is worth the ecological risk. Environmental impacts in many of the targeted habitats are likely to be long-lasting [*MIDAS Consortium*, 2016], especially for the ecosystems of relatively quiescent abyssal plains where manganese nodules occur [*Jones et al.*, 2017] and on ferromanganese-encrusted seamounts (some of which are already protected; Figure 2). Catastrophic natural disturbances have been observed at a few hydrothermal vent
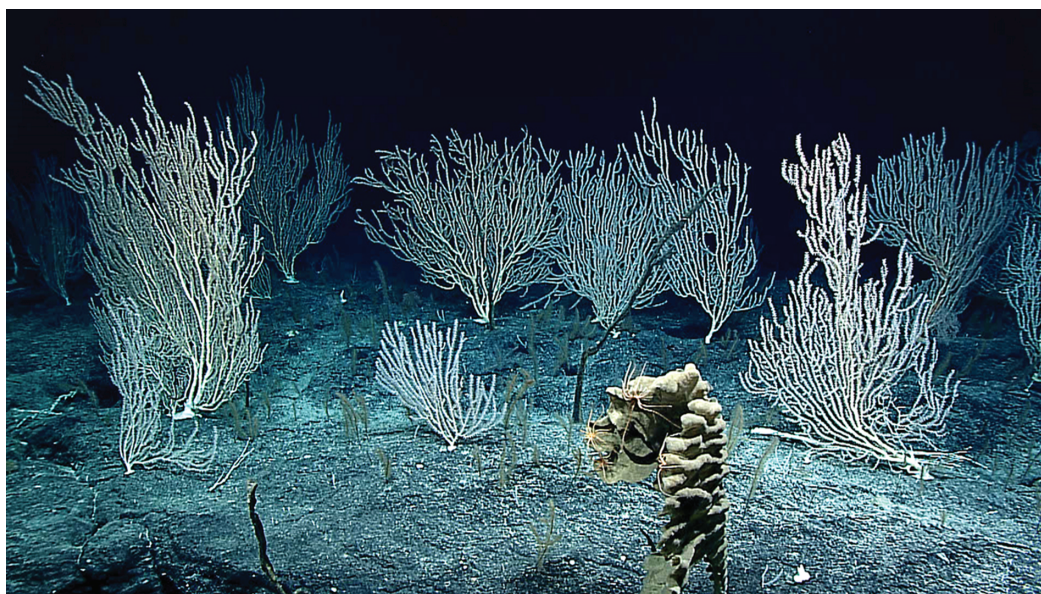
Figure 2. Deep-sea corals at a ferromanganese-encrusted seamount in the Pacific Remote Islands Marine National Monument (PRIMNM). Expanded in 2014, PRIMNM is one of the largest marine protected areas in the world (~1.3 million km^2). Image credit: NOAA Office of Ocean Exploration and Research, Deepwater Wonders of Wake.

fields (e.g., *Mullineaux et al*., [2010]), but the vulnerability and resilience of these ecosystems at active sulfide deposits remain poorly known in a broad range of tectonic and geologic settings. Also, we know very little about ecosystem structure and dynamics at inactive massive sulfide deposits where impacts might be more severe [*Van Dover*, 2011]. In addition to environmental impacts, there are potential costs to society of lost or degraded ecosystem services. Recent research is identifying the array of services from deep-sea ecosystems [*Le et al*., 2017], that may have value through direct or indirect use or through conservation (nonuse).

3. Looking Ahead

In only 3 years since scientists called for deep-ocean stewardship [*Mengerink et al*., 2014], the number of exploration contracts granted by the ISA has more than doubled. Both short- and long-term prospects for deep-sea mining continue to be explored. Yet, the tipping point in terms of economic, scientific, techno-logical, and regulatory advances has not been reached. Although seabed mining off Papua New Guinea is proposed within a couple years [*Nautilus Minerals*, 2016], there may be time to address some of the uncer-tainties before any large-scale mining begins. Among the challenges is to establish the resource potential of the deep sea with much greater confidence before the demand for those resources becomes immediate. Even if all of the license areas currently being explored were completely mapped, the cumulative surveys would represent less than 0.5% of the global ocean area. Making informed decisions about how to manage resources in the remaining 99.5% cannot be made without enhanced and continuing exploration of the deep sea.

Whether one answers "yes" or "no" today to mining of the deep seafloor, it is clear that many aspects of resource extraction and environmental regulation are simply inadequately informed to make decisions if doing so becomes a necessity in the future. If we need to acquire new resources, then we need to know where (and when) that exploitation might occur. Pilot tests for mining operations should not be solely for the development of technologies and capacity building, but they also should be designed to better under-stand responses of ecosystems to disturbances and to inform environmental monitoring and the design of networks of protected areas [*Danovaro et al*., 2017; *Jones et al*., 2017]. Environmental regulations are being developed with great uncertainties about resource potential and ecosystem structure, dynamics, and ser-vices. Regulations need to be flexible enough to accommodate new knowledge from scientific research that may dramatically change our view of the global ocean resource potential. For example, mineral resources beyond the mid-ocean ridges and on continental margins [*Petersen et al*., 2016; *Hannington et al*., 2017], or

other potential benefits that humans may receive from the deep ocean such as discoveries that lead to new medicines, may be important considerations for the future. Biological resource potential is being considered in the development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, in particular marine genetic resources [*United Nations* 2015a]. Natural and social scientists will need to work together to evaluate deep-sea ecosystem services, and this should be part of the cost–benefit analysis for mining projects.

An important related topic is that challenges and opportunities for deep-sea mining straddle several of the United Nations Sustainable Development Goals, including Goal 9 to build infrastructure "with a focus on affordable and equitable access for all;" Goal 10 to reduce inequality; and Goal 14 to conserve and sustainably use the ocean and its resources [*United Nations*, 2015b]. As noted by *Ali et al*. [2017], attaining these goals will inevitably "require minerals for infrastructure, but scant attention has been paid to the science and policy needed to meet these targets." A more equitable world appears to require large and continuing supplies of mineral resources (e.g., *Elshkaki et al*. [2016]), but sustainable development may require a move away from resource-intensive life styles and thus from the high and growing levels of per capita demand. The answer to the question—*Should we mine the deep seafloor?* —will depend on the interpretation of all of these goals and the steps taken to achieve them.

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