Commentary

Heading to the deep end without knowing how to swim: Do we need deep-seabed mining?

Diva J. Amon,[1,2,*] Lisa A. Levin,[3] Anna Metaxas,[4] Gavin M. Mudd,[5] and Craig R. Smith[6]
[1]SpeSeas, D'Abadie, Trinidad and Tobago
[2]Marine Science Institute, University of California, Santa Barbara, Santa Barbara, CA, USA
[3]Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, USA
[4]Department of Oceanography, Dalhousie University, Halifax, NS, Canada
[5]Environmental Engineering, School of Engineering, RMIT University, Melbourne, VIC, Australia
[6]Department of Oceanography, University of Hawai'i at Manoa, Honolulu, HI, USA
*Correspondence: divaamon@gmail.com
https://doi.org/10.1016/j.oneear.2022.02.013

The deep seafloor is regarded as a potentially large source of the minerals needed for producing batteries to fuel the transition to a low-carbon energy system, but rapid, unrestrained mining would have severe impacts on deep-ocean ecosystems and should be avoided. We propose alternative pathways forward.

In this warming world, humankind must curb carbon emissions and meet net-zero goals by 2050.[1] This requires transformation of our energy and transport systems to low-carbon technologies (renewable energy and electric vehicles), which in turn requires the use of batteries to store energy given the intermittency of solar and wind energy. At present, battery designs typically use lithium (Li), nickel (Ni), and cobalt (Co). By 2015, battery production required about 31,500 tons of Li, 2,280,000 tons of Ni, and 126,000 tons of Co.[2] Estimates of global demand for Li, Ni, and Co by 2050 vary by technology choice, scenario target (e.g., 2050 net zero), and battery chemistry, but they commonly range up to or more than ten times 2015 levels (e.g., World Bank Group[2]). However, there is little consensus on where these minerals will come from, especially considering the desire for responsible mining to meet sustainability needs, but the deep ocean is being portrayed as one major potential source.[3,4]

Deep-seabed mining (DSM) could cause significant damage to near-pristine and important ecosystems on enormous scales. This could potentially be permitted within 2 years in areas beyond national jurisdiction (ABNJ). Here, we argue that this rapid, unrestrained expansion of mining into the deep ocean might not align with sustainable development objectives given the scope and scale of potential impacts. We ask whether humankind needs to dive into the deep ocean for minerals at all and propose alternative pathways forward.

Jeopardizing the depths

Mining of the seabed for minerals required for batteries is being explored in polymetallic nodules on the abyssal seafloor (Ni, Li, and Co), in polymetallic sulfides at active and inactive hydrothermal vents (copper, zinc, silver, and gold, although not "primary" in battery chemical design, are used in renewable energy and battery technology), and in ferromanganese crusts on seamounts (Ni, Li, and Co) within exclusive economic zones and in ABNJ globally.[3] To date, 31 exploration contracts covering more than 1.3 million km^2 of deep seafloor globally have been granted in ABNJ by the International Seabed Authority (ISA) (https://www.isa.org.jm/exploration-contracts). However, many scientists, environmental non-governmental organizations (NGOs), businesses such as battery producers and consumers, local communities, and Indigenous Peoples are concerned that the emerging DSM industry does not promote equitable net-zero transition and socio-ecological sustainability.[3]

The projected intensities and methodologies, as well as spatial scales, of DSM would cause significant environmental impacts,[4–6] such as direct removal and destruction of seafloor habitats along with their unique fauna. Sediment plumes created from seafloor disturbance and the return of sediment-laden wastewater will extend the impacts of DSM horizontally and vertically for tens to hundreds of kilometers.[5] Additionally, there will be contaminant release, changes to water properties, and increases in noise and light.

DSM is predicted to cause intense damage to some of the planet's most pristine habitats, many of which are also biodiversity hotspots, vulnerable marine ecosystems, and/or ecologically and biologically significant areas. For example, all 11 known active vent fields on the northern Mid-Atlantic Ridge are in exploration contract areas despite meeting multiple criteria for protection, including uniqueness or rarity, critical habitat, and importance for threatened, endangered, or declining species and/or habitats.[7] Seamounts often support productive benthic and pelagic assemblages designated as biodiversity hotspots.[4] The Clarion-Clipperton Zone (CCZ), which has the most mining interest for battery minerals currently, also shows extraordinary diversity (most of the many thousands of species are still undescribed[8])—a clear demonstration that not only do we have little knowledge, but also what we do know is concerning.

Mining impacts through ecosystem degradation have the potential to damage ecosystem services such as climate regulation, fisheries, elemental cycling, the provision of marine genetic resources, and the culture and well-being of local communities.[9] For example, because northern Mid-Atlantic Ridge mining exploration claims substantially overlap areas managed by the North East Atlantic Fisheries Commission, mining could displace or spatially concentrate fishing efforts, yielding reduced catch or local fishery depletion.[10]

These DSM impacts might be considered inconsequential on small scales of tens to hundreds of kilometers, but the scales of potential disturbance are enormous. In the CCZ alone, some industry projections are to directly mine seafloor habitats over a total area of ~500,000 km^2.[11] Plume disturbances and noise pollution will at least triple this areal impact to 1,500,000 km^2,[4,5] yielding a footprint the size of Spain, Portugal, France, Belgium, and Germany combined and 300 times the area of the Grand Canyon (Figure 1). In addition, these disturbances will be three dimensional, potentially extending throughout the ~4,500-m-high water column to disrupt 6,000,000 km^3 of ocean, a volume 1,000 times that of the Grand Canyon and three times larger than the entire Himalayan Mountain Range (Figure 1).[4] This DSM footprint increases when we consider the remaining 13 exploration contract areas covering ~85,000 km^2 in the West Pacific Ocean, West and Central Indian Ocean, and North and South Atlantic. Importantly, impacts will also extend beyond the depths given the connected nature of the ocean and onto the land where processing will occur.

A management and mitigation abyss

Managing and mitigating the impacts of DSM present some daunting challenges. A comprehensive understanding of the structures and functions of deep-sea ecosystems is necessary for assessing whether DSM can avoid causing "serious harm" to the marine environment.[12] Publicly available scientific knowledge is far too limited to enable evidence-based decision-making on DSM in targeted regions.[13] The lack of a strong regulatory framework, combined with nascent mining technology and monitoring approaches, as well as undefined enforcement of protocols, is of grave concern and should prompt a precautionary approach.

Not only are deep-sea ecosystems highly vulnerable to disturbance and extremely slow to recover, but habitat restoration also appears inconceivable. These characteristics leave little room for error. Recovery of ecosystems depends on population replenishment, which will not be successful if source populations are destroyed or too distant. For instance, the high biodiversity associated with the large heterogeneity of habitats in the CCZ is unlikely to be represented in potential recruits because not all species are able to move across its vast area.[14] Also, the recipient habitats will have been profoundly altered across huge scales and might no longer be suitable. The large distances and new physical barriers to dispersal (e.g., by plumes) will make natural recovery on ecological timescales nearly impossible.

The targeted polymetallic sulfides were formed over millennia, and associated ecosystem dynamics could have evolved on similarly lengthy timescales.[4] For seamounts and nodule biotas, recovery is expected to be essentially nonexistent because nodules and crusts regrow very slowly (1–250 mm/My).[3,4] Additionally, DSM will interact with other anthropogenic stressors on deep-sea ecosystems, including climate change, bottom trawling, and pollution, most likely further reducing the probability of recovery.[10]

Because mined deep-sea habitats are unlikely to recover naturally, habitat restoration might seem desirable. However, if we assume very conservative restoration costs of abyssal seafloor habitats similar to those of coastal ecosystems,[15] restoration of just 10% of 500,000 km^2 of abyssal seafloor would cost US$50 billion and would probably still be inadequate to prevent substantial species extinctions. Furthermore, because abyssal communities recolonize very slowly, it would take decades to determine whether a particular restoration approach was truly effective.[6]

Securing battery minerals from the deep seafloor to achieve net-zero emissions poses a sustainability conundrum given the significant and wide-ranging impacts that will occur on spatial and temporal scales not yet seen in the ocean. This, combined with the inadequate knowledge to inform management and the lack of technology for effective environmental monitoring, casts serious doubts on the wisdom of proceeding with DSM at the current pace (i.e., within the next few years) and urges us to explore alternative approaches for the development of renewable energy resources.

Is exploitation of the depths needed?

As it stands, the expected environmental impacts of DSM are not aligned with many intergovernmental and national policy agendas worldwide, which seek to halt biodiversity loss. The goals of the post-2020 Global Biodiversity Framework include no net loss by 2030; maintaining the integrity of freshwater, marine, and terrestrial ecosystems; and placing biodiversity on a trend to recovery by mid-century. UN Sustainable Development Goal (SDG) 14, which aims "to conserve and sustainably use the oceans, seas and marine resources," includes targets on reducing pollution and increasing scientific knowledge and development of research capacity to improve ocean health (https://sdgs.un.org/goals). DSM even seems at odds with some of the ISA's own guiding principles, e.g., Article 145 of the UN Convention on the Law of the Sea, which calls to ensure effective protection for the marine environment from harmful effects that could arise from activities in ABNJ. Yet, and despite its irreparable environmental impacts, plans for DSM are forging ahead.

Often DSM is justified by the assumption that land-based metal reserves are being depleted rapidly. Yet, extensive research shows that the opposite is true. In mining, reserves refer to the components of a mineral deposit that can be mined in one to two decades at a reasonable profit, whereas resources refer to those that are less certain economically, environmentally, or socially, and they are always far greater than reserves. In 2018, when global extraction of Ni was about 2.4 Mt/year, the US Geological Survey estimated global Ni reserves at 89 Mt,[16] but global resources were at least 335.3 Mt Ni (excluding reported nodule resource estimates).[17] Similarly for Co, when global production was 0.15 Mt/year, global terrestrial reserves were estimated at 6.9 Mt,[16] and global resources were at 33.6 Mt. Resources of Ni and Co

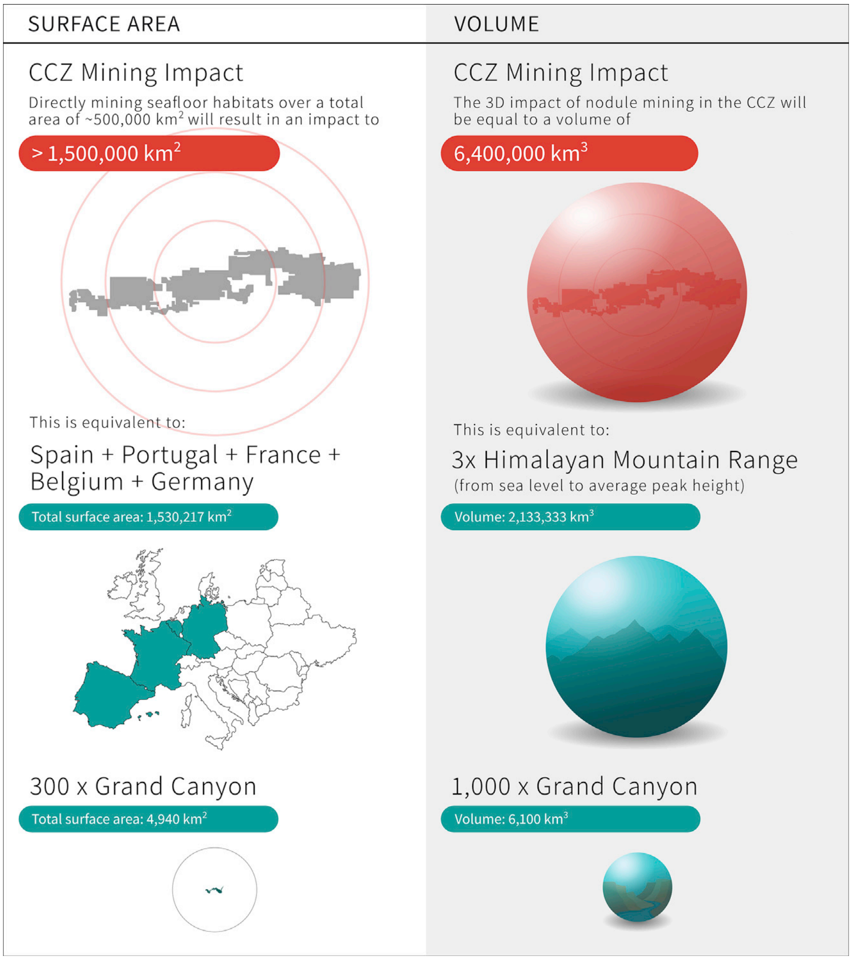

Figure 1. Comparison of the spatial scale of impacts from deep-seabed mining in the Clarion-Clipperton Zone (CCZ) with well-known terrestrial features

already identified on land could therefore meet global demand for many decades to come.[17] Additionally, known reserves and resources invariably expand with further exploration, improvements in technology, discoveries of new deposits, and rising market prices supporting the costs of mining. Moving forward, the path for extracting the resources needed should be done in the most sustainable manner possible—and the deep ocean does not meet this goal.

An obvious way to avoid the expansion of mining into the deep ocean is embracing a circular economy of those minerals and reusing, repurposing, reforming, remanufacturing, and recycling them to the greatest extent possible. Recycling needs much less energy, water, and chemicals; leaves considerably less waste than mining; and provides greater security over the resources needed for modern technology and infrastructure. The trajectory to achieve high recycling rates for minerals is complex because many parts of the world still need to build stocks in their urban and industrial systems to facilitate metal flows for recycling (e.g., rare earths, Li, and Co). However, there is widespread agreement on the overall need to move to a circular economy framework, as evidenced by such numerous government policies globally and, increasingly, the corporate sector. A shift to such a circular system would be the best way to satisfy the needed metal resources for batteries in our path to net-zero emissions while protecting ecosystems to reach conservation targets.

DSM will most likely be impossible to stop once it commences, as has been seen with other resource industries, even if it proves to be environmentally damaging. Societal dependence is partially responsible, but the demands for returns on major investment of capital is another. For example, there is every reason to halt deep-ocean oil and gas exploration and extraction; they do not represent a large part of global energy reserves and are wreaking havoc on the climate (especially suspected methane leaks, which are a plausible explanation of rapidly growing atmospheric methane levels). Yet this continues with new activity around the world. DSM, which might require start-up capital expenditures of nearly US$2 billion for a single venture, is also unlikely to stop easily once started, even if battery innovations reduce demand for Co and Ni, ecosystem damage is substantial, and unforeseen problems emerge (e.g., Deepwater Horizon). Also, given the constant evolution in battery design and improvements in performance for different uses, it can be expected that battery chemistry will continue to change in response to market drivers, supply issues, costs, and environmental and human-rights concerns. Thus, it would be unwise to justify a new industry, such as DSM, solely on the basis of the short-term need for currently used battery minerals.

There are opportunities to alter the current trajectory of this nascent industry. Elevating the role of science and placing trust in scientists is an integral component of evidence-based decision-making. Scientists have requested that they be given time to generate the evidence required for effectively preserving and sustaining ocean ecosystems. Amon et al.[13] project that completing adequate research for all DSM resources in all regions is likely to take several decades, indicating that a push to begin DSM within 2 years is scientifically unwise. And hundreds of scientists have joined environmental NGOs in calling for a delay to the initiation of DSM (https://www.seabedminingsciencestatement.org/).

A more specific opportunity is for the ISA itself to become a champion of deep-sea science and conservation given that precedent has already been set for this among other resource-oriented UN bodies. The International Whaling Commission, established to manage international whaling, declared a moratorium on whaling 36 years after its formation and has since refocused its efforts on the science and preservation of whale stocks. Although not without controversy, these events were driven by the scientific reality of the unsustainability of whaling. Given the ISA's core missions, especially related to marine research, capacity development, and the protection of the marine environment, a similar pivot in its primary focus as led by the 167 Member States would be feasible. Coincidentally, 36 years after the formation of the ISA would be 2030; a new ISA emphasis would be a fitting goal for the UN Decade for Ocean Science for Sustainable Development.

The role of batteries in transitioning toward a low-carbon energy system is undebatable, but we caution against the rapid, unrestrained expansion of mining into the deep ocean to obtain the required materials because it will not support the targeted sustainable use of natural resources and ecosystems. We call on the global community to consider the proposed alternatives while enough scientific evidence is gathered and a strong regulatory framework is established.

DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Intergovernmental Panel on Climate Change (2018). Global warming of 1.5°C. https://www.ipcc.ch/sr15/.
2. World Bank Group (2017). The growing role of minerals and metals for a low carbon future. https://openknowledge.worldbank.org/handle/10986/28312.
3. Levin, L.A., Amon, D.J., and Lily, H. (2020). Challenges to the sustainability of deep-seabed mining. Nat. Sustain. *3*, 784–794. https://doi.org/10.1038/s41893-020-0558-x.
4. Smith, C.R., Tunnicliffe, V., Colaço, A., Drazen, J.C., Gollner, S., Levin, L.A., Mestre, N.C., Metaxas, A., Molodtsova, T.N., Morato, T., et al. (2020). Deep-sea misconceptions cause underestimation of seabed-mining impacts. Trends Ecol. Evol. *35*, 853–857. https://doi.org/10.1016/j.tree.2020.07.002.
5. Drazen, J.C., Smith, C.R., Gjerde, K.M., Haddock, S.H.D., Carter, G.S., Choy, C.A., Clark, M.R., Dutrieux, P., Goetze, E., Hauton, C., et al. (2020). Opinion: Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. Proc. Natl. Acad. Sci. USA *117*, 17455–17460. https://doi.org/10.1073/pnas.2011914117.
6. Vonnahme, T.R., Molari, M., Janssen, F., Wenzhöfer, F., Haeckel, M., Titschack, J., and Boetius, A. (2020). Effects of a deep-sea mining experiment on seafloor microbial communities and functions after 26 years. Sci. Adv. *6*, eaaz5922. https://doi.org/10.1126/sciadv.aaz5922.
7. Gollner, S., Colaço, A., Gebruk, A., Halpin, P.N., Higgs, N., Menini, E., Mestre, N.C., Qian, P.Y., Sarrazin, J., Szafranski, K., and Van Dover, C.L. (2021). Application of scientific criteria for identifying hydrothermal ecosystems in need of protection. Mar. Policy *132*, 104641. https://doi.org/10.1016/j.marpol.2021.104641.
8. Smith, C.R., Clark, M.R., Goetze, E., Glover, A.G., and Howell, K.L. (2021). The research topic biodiversity, connectivity and ecosystem function across the Clarion-Clipperton Zone: A regional synthesis for an area targeted for nodule mining. Front. Mar. Sci. https://doi.org/10.3389/fmars.2021.797516.
9. Le, J.T., Levin, L.A., and Carson, R.T. (2017). Incorporating ecosystem services into environmental management of deep-seabed mining. Deep Sea Res. Part II Top. Stud. Oceanogr. *137*, 486–503.
10. Levin, L.A., Wei, C.-L., Dunn, D.C., Amon, D.J., Ashford, O.S., Cheung, W.W.L., Colaço, A., Dominguez-Carrió, C., Escobar, E.G., Harden-Davies, H.R., et al. (2020). Climate change considerations are fundamental to management of deep-sea resource extraction. Glob. Change Biol. *26*, 4664–4678. https://doi.org/10.1111/gcb.15223.
11. Paulikas, D., Katona, S., Ilves, E., and Ali, S.H. (2022). Deep-sea nodules versus land ores: A comparative systems analysis of mining and processing wastes for battery-metal supply chains. J. Ind. Ecol. https://doi.org/10.1111/jiec.13225.
12. United Nations Convention on the Law of the Sea. Montego Bay, December 10, 1982. https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_en.
13. Amon, D.J., Gollner, S., Morato, T., Smith, C.R., Chen, C., Christensen, S., Currie, B., Drazen, J.C., T F, Gianni, M., et al. (2022). Assessment of scientific gaps related to the effective environmental management of deep-seabed mining. Mar. Policy. https://doi.org/10.1016/j.marpol.2022.105006.
14. Washburn, T.W., Jones, D.O.B., Wei, C.-L., and Smith, C.R. (2021). Environmental heterogeneity throughout the Clarion-Clipperton Zone and the potential representativity of the APEI network. Front. Mar. Sci. *8*. https://doi.org/10.3389/fmars.2021.661685.
15. Cooper, K., Burdon, D., Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, K., Ware, S., and Vivian, C. (2013). Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. Mar. Pollut. Bull. *75*, 33–45. https://doi.org/10.1016/j.marpolbul.2013.08.009.
16. US Geological Survey (2019). Mineral commodity summaries 2019. https://doi.org/10.3133/70202434.
17. Mudd, G.M., and Jowitt, S.M. (2022). The new century for nickel resources, reserves and mining: Reassessing the sustainability of the devil's metal. Econ. Geol. https://doi.org/10.5382/econgeo.4950.