frontiers in Marine Science

PERSPECTIVE
published: 29 July 2021
doi: 10.3389/fmars.2021.706161

Challenging the Need for Deep Seabed Mining From the Perspective of Metal Demand, Biodiversity, Ecosystems Services, and Benefit Sharing

K. A. Miller[1], *K. Brigden*[1], *D. Santillo*[1], *D. Currie*[2], *P. Johnston*[1] *and K. F. Thompson*[1,3]*

[1] Greenpeace Research Laboratories, University of Exeter, Exeter, United Kingdom, [2] Globelaw, Christchurch, New Zealand, [3] School of Biosciences, University of Exeter, Exeter, United Kingdom

OPEN ACCESS

Edited by:
Michelle Scobie,
The University of the West Indies St. Augustine, Trinidad and Tobago

Reviewed by:
Catherine Iorns,
Victoria University of Wellington, New Zealand
Wan Izatul Asma Wan Talaat,
University of Malaysia Terengganu, Malaysia

***Correspondence:**
K. F. Thompson
k.f.thompson@exeter.ac.uk

Specialty section:
This article was submitted to Marine Ecosystem Ecology, a section of the journal Frontiers in Marine Science

Received: *06 May 2021*
Accepted: *09 July 2021*
Published: *29 July 2021*

Citation:
Miller KA, Brigden K, Santillo D, Currie D, Johnston P and Thompson KF (2021) Challenging the Need for Deep Seabed Mining From the Perspective of Metal Demand, Biodiversity, Ecosystems Services, and Benefit Sharing. Front. Mar. Sci. 8:706161. doi: 10.3389/fmars.2021.706161

The extraction of minerals from the seabed of the deep oceans is of increasing interest to investors, mining companies and some coastal states. To date, no commercial-scale deep seabed mining has taken place but there is considerable pressure for minerals mining to become an economic reality, including to supply the projected demand for metals to support a global transition to renewable energy. At the same time, the full environmental impacts of deep seabed mining are difficult to predict but are expected to be highly damaging, both within, and perhaps well beyond, the areas mined. Here, we reflect on the considerable uncertainties that exist in relation to deep seabed mining. In particular, we provide a perspective on: (1) arguments that deep seabed mining is needed to supply minerals for the green energy revolution, using the electric vehicle battery industry as an illustration; (2) risks to biodiversity, ecosystem function and related ecosystem services; and (3) the lack of equitable benefit sharing to the global community now and for future generations. We explore the justification for a global moratorium on deep seabed mining to ensure protection of marine ecosystems, the need to focus on baseline research, and how improved governance of targeted marine regions could be key to the preservation and conservation of the ocean biome.

Keywords: marine minerals, deep sea, biodiversity, battery technology, ocean governance, critical metals

INTRODUCTION

Interest in mining deep-sea minerals is growing because of a perceived or predicted need to meet increased demand for minerals, including in support of a "green transition," and the financial rewards that could flow from exploitation of metal-rich deposits. The International Seabed Authority (ISA), has, as of May 2021, issued 31 exploration contracts, many of which are with private companies headquartered in the global north. Exploitation regulations are being drafted by the ISA. To date, no exploitation contracts have been awarded by the ISA for mining in the area beyond national jurisdiction (ABNJ), and no commercial deep-sea mining has taken place on continental shelves.

In spite of the irreversibility of environmental impacts, and huge uncertainties over their scale and severity, the deep-sea mining industry is gaining prominence, supported by carefully crafted narratives that aim to position proposed operations as a viable option to supply virgin mineral resources (Childs, 2019). In some cases, seabed mining is presented as an unavoidable consequence of ever-growing demand, in others as the "lesser of two evils" in comparison to land-based mining. Reasons cited by deep-sea mining proponents to exploit ocean mineral reserves include a decline in terrestrial ore quantity and quality (Ali et al., 2017; Hein et al., 2020), the potential for social conflict in regions from where natural resources are extracted (Ali et al., 2017) and the potential impact from terrestrial mining, including on the climate (Paulikas et al., 2020a). Civil society groups are becoming increasingly vocal in their opposition to deep sea mining, and there are calls for industry to take into account the profound cultural and spiritual ties that many remote island nations have with the sea.

Mining the deep sea will cause extensive damage to, and will have long-lasting impacts on, the ocean biome (Miller et al., 2018; Vonnahme et al., 2020). Marine ecosystems are already experiencing an unprecedented combination of pressures, including climate change, acidification, deoxygenation, pollution and the over-exploitation of living marine resources (Danovaro et al., 2020). Targets have been set for global ocean protection, mechanisms implemented and conservation programmes initiated, but these are overshadowed by the overarching lack of a coherent strategy. For example, UN Sustainable Development Goal 14 ("to protect the health of the ocean") is not fully on track to achieve all ten targets by 2030 (Johansen and Vestvik, 2020) and none of the Aichi targets have been achieved within the past UN Decade on Biodiversity (Secretariat of the Convention on Biological Diversity, 2020). Progress continues this year (2021) to develop a legally binding instrument for conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. Opening the deep seabed to mining on an industrial scale would be fundamentally at odds with such commitments.

THE PERCEIVED BENEFITS AND RISKS OF DEEP-SEA MINING

The Argued Need for Deep Seabed Mining to Supply Minerals for the Green Revolution

The move towards a low-carbon economy is projected to lead to increased demand for minerals including cobalt, lithium, nickel, copper, vanadium and indium for use in electric vehicles (EVs), green energy technologies and storage batteries, with large increases in demand predicted for cobalt, nickel and lithium (Teske, 2019; World Economic Forum, 2019; Hund et al., 2020). Interest in mining virgin resources from the deep sea has, in part, been driven by such projections, alongside desires to maintain a diversity of supply and concerns about environmental and human rights impacts associated with terrestrial mining (Church and Crawford, 2020; Lèbre et al., 2020; Paulikas et al., 2020b).

Despite detailed estimates for the quantities of minerals and metals needed to realise the transition to green technologies, the extent of future demand remains highly uncertain. Assumptions on which projections are based are subject to considerable uncertainties and are likely to evolve substantially over the coming decades. Two key factors that influence modelled demand are the future availability of energy-related technologies (especially for batteries) and what those imply in terms of metal demand and the rate and scale of manufacturing of those technologies. Månberger and Stenqvist (2018) report that terrestrial mineral reserves are sufficient to support a transition to renewable technologies given potential future innovations, with the possible exception of lithium-containing batteries (planned exploitation of deep-sea reserves generally does not target lithium).

Batteries have been highlighted as posing a dominant future demand for certain metals that are also associated with deep seabed resources and provide a useful example (**Figure 1**). Many projections assume ongoing use of current lithium-ion battery technology (incorporating cobalt and nickel) for both EV and stationary storage uses (Hund et al., 2020), despite available and in-development alternatives such as the cobalt-free lithium-ion car battery from Svolt (2019), and Tesla's use of lithium-ion phosphate batteries in certain vehicles, which require neither cobalt nor nickel (Tesla, 2020). Projected future demand for EV batteries depends on the assumed transport model and the relative scale of different transport modes. Projections are based on models that range from a business-as-usual approach to sustainable transport models that are less dependent on personal vehicles. More integrated transport systems could enable even fewer vehicles and batteries. Improved technological design, such as elimination of built-in obsolescence, could also have a major influence on future demands for raw materials and finished goods (Thompson et al., 2018).

The European Commission (EC) proposal concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020 (EC, 2020), includes measures to ensure large increases in recycling rates and greater use of recycled content, as well as ensuring due diligence in sourcing raw materials for batteries. The EC proposal does not make direct reference to seabed mining but emphasises the need for the development of sustainable battery technology and carbon-neutral energy storage. It will be vital that, alongside pursuit of a circular economy-based approach, the sustainability and ethical issues arising from existing and future terrestrial mining are also addressed.

Paulikas et al. (2020b, p.8) argue that deep seabed mining is necessary because "Economic impact outcomes are expected to be overall better when producing metals from nodules." The impact of lower prices on those currently reliant on terrestrial mining aside, in reality, it is unlikely that terrestrial mining would be displaced significantly if deep-sea mining were to commence; the sectors would become competitors in a larger minerals market without a transformational economy that reduces demand. Paulikas et al. (2020b) express some confidence in the financial

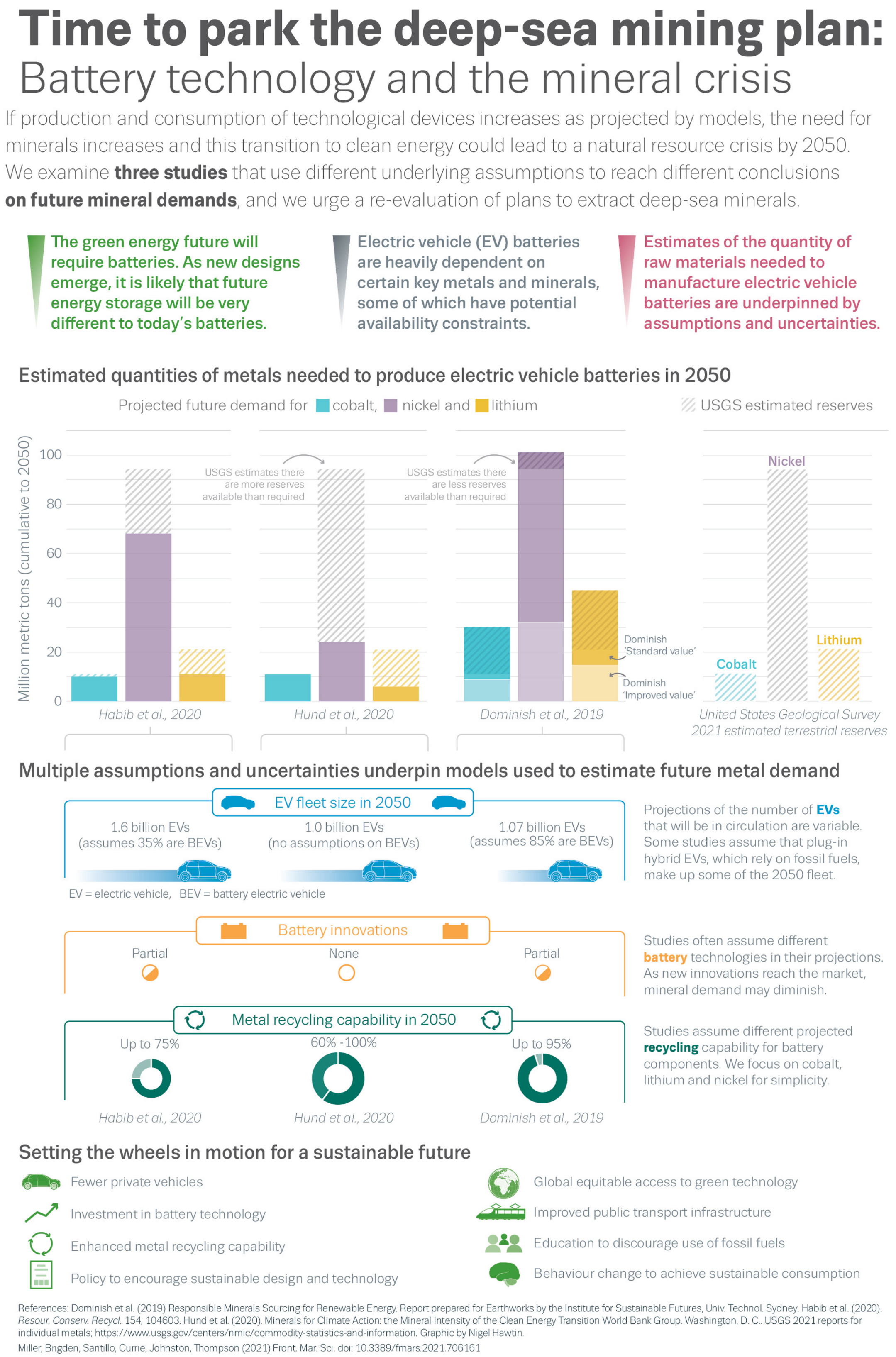

FIGURE 1 | Electric vehicle (EV) battery technology provides a useful case study to illustrate the uncertainties in projected demand and need for deep sea minerals. Our focused analysis suggests that demand for the minerals used to manufacture EV batteries could vary significantly – complex underlying reasons involve an interplay of factors such as human behaviour, investment in public transport infrastructure and technological advances.

outcome of their proposed nodule collection, but their analysis fails to take proper account of the risks for current and future generations of ignoring or undervaluing the functional ecology of the oceans and the ecosystem services they provide.

The Risks to Biodiversity and Ecosystem Services Should Deep Seabed Mining Proceed

Seabed mining will cause unavoidable, irreversible harm to deep-sea ecosystems and puts the health of the wider ocean at risk, adding to other stressors including various forms of pollution (litter, noise, and chemical), poor fisheries management and climate change. Mining impacts include light and noise pollution, sediment plumes and biodiversity loss resulting from widespread habitat fragmentation (Van Dover et al., 2017; Miller et al., 2018; Jones et al., 2020; Duarte et al., 2021). Deep-sea mining poses significant risks to midwater ecosystems, which represent more than 90% of the biosphere, contain fish biomass 100 times greater than the global annual fish catch, connect shallow and deep-sea ecosystems, and play key roles in carbon export and nutrient regeneration. Deep and midwater ecosystem services could be negatively affected by the return sediment plume, projected to be discharged at around 1,200 m, which may persist for hundreds of kilometres and, among other effects, clog respiratory and olfactory surfaces (Drazen, 2020).

Mitigating the impacts of deep-sea mining – or restoring ecosystems in a post-mining scenario – will be extremely difficult and can never be fully achieved (Niner et al., 2018). Even gaining an understanding of the potential biodiversity loss that could be caused by deep-sea mining will require far greater baseline knowledge than exists at present as well as knowledge of the technology that would be used and its direct and indirect effects (Clark et al., 2020; Levin et al., 2020a). Fundamental knowledge gaps remain in our understanding of the oceans, particularly of vulnerable deep-sea species such as cold water corals, crabs and shrimps (Van Dover, 2014; Thompson et al., 2018; Wagner et al., 2020). Connectivity between deep seabed habitats and broader ecosystem functioning are poorly understood. Research suggests that polymetallic nodules play an important part in food-web integrity in benthic ecosystems (Stratmann et al., 2021), and that *in situ* carbon fixation on abyssal plains and hydrothermal vents and their contribution to surface productivity is greater than previously expected (Levin et al., 2020b). Climate change is already having a profound impact on ocean chemistry and temperature, even in the deepest parts of our oceans, and may be contributing to changes to the distribution or migration of species, loss of habitat and food availability (Levin et al., 2020b). There remains a vital need for further primary research to inform decisions and programmes aimed at ensuring protection of the marine environment in the face of multiple existing stressors (Levin et al., 2020b) rather than a focus on "proof of concept" testing of exploitation techniques that will increase those pressures.

Predicting the scale of impacts of deep seabed mining is made more difficult by governance and regulatory uncertainties. For areas of the Pacific earmarked for mining (such as the Clarion-Clipperton Zone), there is no clear vision of how many commercial operations might proceed in parallel within an area, to what extent mining will impact biodiversity cumulatively over broader spatial scales, or how regulations might be enforced and by whom. Ecosystem services framework approaches are increasingly being used to evaluate situations where terrestrial or shallow-water ecosystems – for example forests or wetlands – could be impacted by human activities. It is hard to see how such approaches could be applied within the deep sea given the extent of uncertainties regarding ecosystem processes and their interconnectivities across space and depth. Some have argued that there is an opportunity for the ISA to take on such a framework, given that no commercial-scale mining has yet taken place (Le et al., 2017; Levin et al., 2020b).

Ecosystems services – which can be subdivided into provisioning, regulating and cultural services (Millennium Ecosystem Assessment, 2005) – have direct relevance to the habitats that fall under proposed deep seabed mining areas. Le et al. (2017) provide examples of provisioning services, such as spawning and nursery habitats supported by seamount ecosystems. Potentially vast provisioning resources are provided by deep sea habitats in relation to marine genetic resources and biomaterials, many of which have important applications in human health (Ehrlich et al., 2006; Arrieta et al., 2010; Blasiak et al., 2020). Regulating services include long-term methane and carbon sequestration, both of which are highly important for climate change mitigation. Microbial communities of vent and nodule systems are diverse and, in many cases, still poorly described, but may play an important regulatory part in the global cycling of carbon, sulphur and heavy metals (Meyer-Lombard et al., 2013; German et al., 2015; Sweetman et al., 2019). Experiments indicate that the regulatory function is significantly affected by physical disturbance, with changes persisting over long timescales, such that deep seabed mining may be directly at odds with current climate goals if such regulatory services are degraded (Nath et al., 2012).

The cultural services provided by undisturbed ecosystems are diverse and may pose still greater challenges for inclusive and quantitative assessment. Many societies hold the oceans and marine life as sacred within their traditions and histories. Such services include those that relate to educational and aesthetic resources provided by the deep sea. Local community organisations and Indigenous groups such as The Alliance of Solwara Warriors are, alongside civil society organisations such as the Deep Sea Conservation Coalition, questioning the need for, and implications of, deep-sea mining. These groups are challenging the lack of transparency within the processes under the ISA by which applications are considered and exploration contracts issued with little public scrutiny and with no clear regard for cultural values (Levin et al., 2020a).

The Lack of Equitable Benefit Sharing With the Global Community

To date, considerations of equitability in relation to deep-sea mining have focused largely on the proposed mechanisms for financial benefit sharing. Article 140 of the United Nations Convention on the Law of the Sea (UNCLOS), under which mandate the ISA operates, requires that revenue generated from seabed mining needs to be equitably shared between nations, with a particular consideration taken of developing States. The ISA is in the process of negotiating benefit sharing, with some suggestions that initial royalties to be shared among nations will total 2%, rising to 6% at a future date (Levin et al., 2020a). This model would mean that mining companies would benefit from around 70% of the total project profits, the ISA around 6%, including the amounts to be distributed, with the remainder to go to the sponsoring state (The African Group, 2018). Negotiations of such a benefit system had already been opposed by 47 African member states, who calculated a potential financial return of less than US$100,000 per annum per country (The African Group, 2019).

Beyond the detail of financial benefit sharing, however, an emerging approach that seeks to grant locations, habitats and ecosystems "Rights of Nature" could bring a fundamentally different perspective to debates on deep-sea mining by enabling re-evaluation of the relationship between humanity and the natural world. Although the concept of giving rights to nature might seem new to many in the industrialised West, the concept is not unusual to some Indigenous communities. In 2008, Ecuador became the first nation to include Rights of Nature in its constitution (Republic of Ecuador, 2008). Other examples of such an approach are few but are gradually increasing in number. In New Zealand, for example, the Te Urewera Forest and the Whanganui River or Te Awa Tupua are defined as legal entities with "all the rights, powers, duties, and liabilities of a legal person" (Te Urewera Act, 2014; Te Awa Tupua, 2017). A Rights of Nature approach could be applied to the oceans (David, 2017; Harden-Davies et al., 2020) alongside the precautionary principle and sustainable development concepts. A legal instrument that grants rights to an ocean is years away from being formulated and implemented, but the concept behind it is one of holistic and coherent rather than fragmented protection. If applied to the deep sea in the ABNJ, a Rights of Nature framework would recognise the ocean as a rights-bearing subject, rather than an object to be owned, controlled and exploited (Borras, 2016).

DISCUSSION

The multifarious issues surrounding deep seabed mining have no doubt contributed to the many different opinions between – and within – groups of stakeholders that include scientists, industry contractors, civil society, governments, investors and regulators. Reconciling the perspectives of such diverse groups will be extremely challenging and some may be unhappy with the outcome. What is certain, however, is that to prevent biodiversity loss and minimise stressors that impede marine ecosystem functioning and the ecosystem services that benefit humanity, ocean protection must be prioritised. Doubts that UN SDG14 may not be met fully by 2030 are of great concern – one estimate is that US$174.52 billion per year will be needed to be spent on, for example, conservation and research to achieve this one goal (Johansen and Vestvik, 2020).

But the future contains hope. Proposals from within the academic community to enhance regulations and protection measures are encouraging and include: establishing a coherent deep ocean observation system (Levin et al., 2019, 2020a; Jones et al., 2020); evaluating the part played by the ISA in regulatory actions and enforcing EIAs (Clark et al., 2020; Jones et al., 2020; Levin et al., 2020a); establishing legally binding MPA networks in the ABNJ (O'Leary et al., 2020); and questioning whether corporations are meeting human rights obligations under UNCLOS (Bernaz and Pietropaoli, 2020). A United Nations Intergovernmental Conference is negotiating an international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (United Nations, 2017) which is expected to provide *inter alia* a mechanism for establishing a representative network of MPAs in the ABNJ.

In its Pathways to the 2050 Vision for Biodiversity, The Convention of Biological Diversity sets out Eight Transitions to Living in Harmony with Nature, including the target that, "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people" (Secretariat of the Convention on Biological Diversity, 2020).

We have an opportunity to refocus our approach towards nature. A true transition from ownership to guardianship of the natural world could include a Rights of Nature approach to the ocean, rather than only considering the benefits that it may deliver to a small percentage of the global population. As currently projected, any profits from deep-sea mining will predominantly benefit a handful of corporations in the world's richest countries, rather than less well-developed States.

SDG 12 aims to ensure sustainable consumption and production patterns, which is essential if the world is to achieve the other UN SDGs (Bengtsson, 2018). In the context of deep-sea mining, we suggest as a practical first step a conversation between all stakeholders to assess future demand for minerals required to transition to a low-carbon economy. A full appreciation of the many uncertainties and indeterminacies attached to projected demand for relevant metals could help to inform conversations between stakeholders. Realigning and refocusing research on product design to enhance the sustainability and lifespan of future technologies may enable a richer suite of options in the future. Policy mechanisms, such as those related to urban design in the sphere of public transport (including vehicle sharing), together with incentives to promote consumer awareness and behaviour change will be important to achieve a sustainable transition.

Once started, deep-sea mining is likely to be impossible to stop. Once lost, biodiversity will be impossible to restore. In writing this Perspective we have outlined the need to avoid mining the deep sea to prevent biodiversity loss and associated ecosystem services. Our case study focuses specifically on uncertainties related to future EV battery technologies and transport infrastructure and challenges the perceived demand for deep sea minerals. More broadly, however, recognising and adopting a Rights of Nature approach could help ensure a thriving natural world for generations and a more sustainable future for humanity in protecting those rights. The ongoing COVID-19 pandemic has highlighted how declining ecosystem integrity has contributed to human health and economic risk on a global scale. The pandemic may also have contributed to a reassessment of social values, promoting an awareness and willingness to fundamentally change behaviour towards the protection of natural systems. We have an opportunity to refocus our approach to managing and living sustainably within natural ecosystems and by replacing a sense of ownership and dominance to one of harmony and belonging.

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

KT and KM conceived the perspective. KM, KT, KB, and DS wrote the manuscript. DS, PJ, and DC critically reviewed the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

The preparation of this manuscript was funded by Umweltstiftung Greenpeace to provide independent scientific advice and analytic services to that non-governmental organisation.

ACKNOWLEDGMENTS

We thank Victor David, Research Institute Pour Le Développement France, for insights into the Rights of Nature approach and how this might be applied to the Pacific Ocean. Thanks also to Nigel Hawtin for design of **Figure 1**. In addition, we thank two reviewers for their helpful comments that improved the manuscript.

REFERENCES

Ali, S. H., Giurco, D., Arndt, N., Nickless, E., Brown, G., Demetriades, D., et al. (2017). Mineral supply for sustainable development requires resource governance. *Nature* 543, 367–372. doi: 10.1038/nature21359

Arrieta, J., Arnaud-Haond, S., and Duarte, C. (2010). What lies underneath: Conserving the oceans' genetic resources. *Proc. Natl. Acad. Sci. U S A.* 107, 18318–18324. doi: 10.1073/pnas.0911897107

Bengtsson, M. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. *Sustain. Sci.* 13, 1533–1547. doi: 10.1007/s11625-018-0582-1

Bernaz, N., and Pietropaoli, I. (2020). Developing a business and human rights treaty: Lessons from the deep seabed mining regime under the United Nations Convention on the Law of the Sea. *Bus. Hum. Rights J.* 5, 200–220. doi: 10.1017/bhj.2020.7

Blasiak, R., Wynberg, R., Grorud-Colvert, K., and Thambisetty, S. (2020). *The Ocean Genome: Conservation and the Fair, Equitable and Sustainable Use of Marine Genetic Resources*. Washington, DC: World Resources Institute.

Borras, S. (2016). New transitions from human rights to the environment to the rights of nature. *Transnatl. Environ. Law* 5, 113–143. doi: 10.1017/S204710251500028X

Childs, J. (2019). Greening the blue? Corporate strategies for legitimising deep sea mining. *Political Geogr.* 74:102060. doi: 10.1016/j.polgeo.2019.102060

Church, C., and Crawford, A. (2020). "Minerals and the Metals for the Energy Transition: Exploring the Conflict Implications for Mineral-Rich, Fragile States," in *The Geopolitics of the Global Energy Transition. Lecture Notes in Energy*, eds M. Hafner and S. Tagliapietra (Cham: Springer), 73. doi: 10.1007/978-3-030-39066-2_12

Clark, M. R., Durden, J. M., and Christiansen, S. (2020). Environmental Impact Assessments for deep-sea mining: Can we improve their future effectiveness? *Mar. Policy* 114:026. doi: 10.1016/j.marpol.2018.11.026

Danovaro, R., Fanelli, E., Aguzzi, J., Billett, D., Carugati, L., and Corinaldesi, C. (2020). Ecological variables for developing a global deep-ocean monitoring and conservation strategy. *Nat. Ecol. Evol.* 4, 181–192. doi: 10.1038/s41559-019-1091-z

David, V. (2017). La nouvelle vague des droits de la nature. La personnalité juridique reconnue aux fleuves Whanganui, Gange et Yamuna. *Revue Juridique L'environnement* 42, 409–424.

Drazen, G. (2020). Opinion: Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. *PNAS* 8:2011914117. doi: 10.1073/pnas.2011914117

Duarte, C. M., Chapuis, L., Collin, S. P., Costa, D. P., Devassy, R. P., Eguiluz, V. M., et al. (2021). The soundscape of the Anthropocene ocean. *Science* 371:eaba4658. doi: 10.1126/science.aba4658

EC (2020). *European Commission Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020*. Luxembourg City: EC.

Ehrlich, H., Etnoyer, P., Litvinov, S. D., Olennikova, M. M., Domaschke, H., Hanke, T., et al. (2006). Biomaterial structure in deep-sea bamboo coral (Anthozoa: Gorgonacea: Isididae): Perspectives for the development of bone implants and templates for tissue engineering. *Mater. Sci. Eng. Technol.* 37, 552–557. doi: 10.1002/mawe.200600036

German, C., Legendre, L., Sander, S., Niquil, N., Luther, G. III, Bharati, L., et al. (2015). Hydrothermal Fe cycling and deep ocean organic carbon scavenging: model-based evidence for significant POC supply to seafloor sediments. *Earth Planet. Sci. Lett.* 419, 143–153. doi: 10.1016/j.epsl.2015.03.012

Harden-Davies, H., Humphries, F., Glen Wright, Gjerde, K., and Vierras, M. (2020). Rights of Nature: Perspectives for Global Ocean Stewardship. *Mar. Policy* 122:104059. doi: 10.1016/j.marpol.2020.104059

Hein, J. R., Koschinsky, A., and Kuhn, T. (2020). Deep-ocean polymetallic nodules as a resource for critical materials. *Nat. Rev. Earth Environ.* 1, 158–169. doi: 10.1038/s43017-020-0027-0

Hund, K., La Porta, D., Fabregas, T. P., Laing, T., and Drexhage, J. (2020). *Minerals for Climate Action: the Mineral Intensity of the Clean Energy Transition World Bank Group*. Washington, D. C: World Bank.

Johansen, D. F., and Vestvik, R. A. (2020). The cost of saving our ocean - estimating the funding gap of sustainable development goal 14. *Mar. Policy* 112:103783. doi: 10.1016/j.marpol.2019.103783

Jones, D. O. B., Ardron, J. A., Colaço, A., and Durden, J. M. (2020). Environmental considerations for impact and preservation reference zones for deep-sea polymetallic nodule mining. *Mar. Policy* 118:103312. doi: 10.1016/j.marpol.2018.10.025

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 2 II Top. Stud. Oceanogr.* 137, 486–503. doi: 10.1016/j.dsr2.2016.08.007

Lèbre, É, Stringer, M., Svobodova, K., Owen, J. R., Kemp, D., Côte, C., et al. (2020). The social and environmental complexities of extracting energy transition metals. *Nat. Commun.* 11:4823. doi: 10.1038/s41467-020-18661-9

Levin, L. A., Bett, B. J., Gates, A. R., Heimbach, P., Howe, B. M., Janssen, F., et al. (2019). Global observing needs in the deep ocean. *Front. Mar. Sci.* 6:241. doi: 10.3389/fmars.2019.00241

Levin, L. A., Amon, D. J., and Lily, H. (2020a). Challenges to the sustainability of deep-seabed mining. *Nat. Sustain.* 3, 784–794. doi: 10.1038/s41893-020-0558-x

Levin, L. A., Wei, C.-L., Dunn, D. C., Amon, D. J., Ashford, O. S., Cheung, W. W. L., et al. (2020b). Climate change considerations are fundamental to management of deep-sea resource extraction. *Glob. Ch. Biol.* 26, 4664–4678. doi: 10.1111/gcb.15223

Månberger, A., and Stenqvist, B. (2018). Global metal flows in the renewable energy transition: Exploring the effects of substitutes, technological mix and development. *Energy Policy* 119, 226–241. doi: 10.1016/j.enpol.2018.04.056

Meyer-Lombard, D. R., Amend, J. P., and Osburn, M. R. (2013). Microbial diversity and potential for arsenic and iron biogeochemical cycling at an arsenic rich, shallow-sea hydrothermal vent (Tutum Bay, Papua New Guinea). *Chem. Geol.* 348, 37–47. doi: 10.1016/j.chemgeo.2012.02.024

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Washington DC: Island Press.

Miller, K. A., Thompson, K. F., Johnston, P., and Santillo, D. (2018). An overview of seabed mining including the current state of development, environmental impacts and knowledge gaps. *Front. Mar. Sci.* 4:418. doi: 10.3389/fmars.2017.00418

Nath, B. N., Khadge, N. H., Nabar, S., RaghuKumar, C., Ingole, B. S., Valsangkar, A. B., et al. (2012). Monitoring the sedimentary carbon in an artificially disturbed deep-sea sedimentary environment. *Environ. Monit. Assess.* 184:2829. doi: 10.1007/s10661-011-2154-z

Niner, H. J., Ardron, J. A., Escobar, E. G., Gianni, M., Jaeckel, A., Jones, D. O. B., et al. (2018). Deep-sea mining with no net loss of biodiversity – an impossible aim. *Front. Mar. Sci.* 5:53. doi: 10.3389/fmars.2018.00053

O'Leary, B. C., Hoppit, G., Townley, A., Allen, H. L., McIntyre, C. J., and Roberts, C. M. (2020). Options for managing human threats to high seas biodiversity. *Ocean Coast. Manag.* 187:105110. doi: 10.1016/j.ocecoaman.2020.105110

Paulikas, D., Katona, S., Ilves, E., and Ali, S. H. (2020a). Life cycle climate change impacts of producing battery metals from land ores versus deep-sea polymetallic nodules. *J. Cleaner Prod.* 275:123822. doi: 10.1016/j.jclepro.2020.123822

Paulikas, D., Katona, S., Ilves, E., Stone, G., and O'Sullivan, A. (2020b). *Where should metals for the green transition come from?*. Vancouver: DeepGreen Metals Inc.

Republic of Ecuador (2008). *Constitution of the Republic of Ecuador, October 20, 2008*. Available online at: http://pdba.georgetown.edu/Constitutions/Ecuador/english08.html (accessed January 15, 2021)

Secretariat of the Convention on Biological Diversity (2020). *Global Biodiversity Outlook 5*. Montreal: Secretariat of the Convention on Biological Diversity.

Stratmann, T., Soetaert, K., Kersken, D., and van Oevelen, D. (2021). Polymetallic nodules are essential for food-web integrity of a prospective deep-seabed mining area in Pacific abyssal plains. *bioRxiv* 430718 [preprint]. doi: 10.1101/2021.02.11.430718

Svolt (2019). *Press release July 9, 2019: 'SVOLT celebrates the world's first NCMA and NMx cells and starts plans to build factory in Europe'*. Available online at: https://en.svolt.cn/news/info/40 (accessed December 18, 2020).

Sweetman, A. K., Smith, C. R., Shulse, C. N., Maillot, B., Lindh, M., Church, M. J., et al. (2019). Key role of bacteria in the short-term cycling of carbon at the abyssal seafloor in a low particulate organic carbon flux region of the eastern Pacific Ocean. *Limnol. Oceanogr.* 64, 694–713. doi: 10.1002/lno.11069

Te Awa Tupua (2017). *Te Awa Tupua Act 2017*. Available online at: https://www.legislation.govt.nz/act/public/2017/0007/latest/whole.html (accessed January 15, 2021).

Te Urewera Act (2014). *Te Urewera Act 2014*. 2014. Available online at: https://www.legislation.govt.nz/act/public/2014/0051/latest/whole.html (accessed January 15, 2021)

Teske, S. (2019). *Achieving the Paris Climate Agreement Goals, Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C*. Cham: Springer.

Tesla (2020). *Presentation for the 2020 Annual Meeting of Stockholders and Battery Day*. Palo Alto: Tesla.

The African Group (2018). *Statement by Algeria on Behalf of the African Group to the International Seabed Authority 9 July 2018*. Washington DC: The African Group.

The African Group (2019). *Statement by Algeria on Behalf of the African Group to the International Seabed Authority 25 February 2019*. Washington DC: The African Group.

Thompson, K. F., Miller, K. A., Currie, D., Johnston, P., and Santillo, D. (2018). Approaches to governance of the deep seabed. *Front. Mar. Sci.* 5:480. doi: 10.3389/fmars.2018.00480

United Nations (2017). *General Assembly resolution 72/249: 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*. New York, NY: United Nations.

Van Dover, C. L. (2014). Impacts of anthropogenic disturbances at deep-sea hydrothermal vent ecosystems: A review. *Mar. Environ. Res.* 102, 59–72. doi: 10.1016/j.marenvres.2014.03.008

Van Dover, C. L., Ardron, J. A., Escobar, E., Gianni, M., Gjerde, K. M., Jaeckel, A., et al. (2017). Biodiversity loss from deep-sea mining. *Nat. Geosci.* 10, 464–465. doi: 10.1038/ngeo2983

Vonnahme, T. R., Molari, M., Janssen, F., Wenzhöfer, F., Haeckel, M., Titschack, J., et al. (2020). Effects of a deep-sea mining experiment on seafloor microbial communities and functions after 26 years. *Sci. Adv.* 6:eaaz5922. doi: 10.1126/sciadv.aaz5922

Wagner, D., Friedlander, A. M., Pyle, R. L., Brooks, C. M., Gjerde, K. M., and Wilhelm, T. A. (2020). Coral reefs of the high seas: Hidden biodiversity hotspots in need of protection. *Front. Mar. Sci.* 7:567428. doi: 10.3389/fmars.2020.567428

World Economic Forum (2019). *A vision for a sustainable battery value chain in 2030 unlocking the full potential to power sustainable development and climate change mitigation*. Geneva: World Economic Forum.

Conflict of Interest: DC was employed by Globelaw, Christchurch, New Zealand.

The remaining 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.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.