June 2020

Ocean and Climate Discussion Series

Considering the Deep Sea as a Source of Minerals and Rare Elements

This brief reviews the climate-related implications of deep-sea mining, including associated environmental risks. It identifies multiple knowledge and governance gaps that must be closed to fully evaluate whether deep-sea mining offers an acceptable way to obtain critical minerals, and concludes that deep-sea mining should not be allowed unless and until these uncertainties are resolved. It is part of Ocean Conservancy's "Ocean and Climate Discussion Series," which provides science-based analysis to inform the global dialogue on integrating ocean issues into climate policy.

Introduction

A global shift to renewable energy is central to solving the climate challenge. The batteries and digital technologies needed to support this shift require critical minerals including the chemical elements copper, silver, gold, zinc, manganese, cobalt, nickel, tin, and rare earth elements (REEs). Terrestrial mining currently satisfies the demand for cobalt, lithium, and REEs, but demand and supply chain risks are growing, increasing the interest in securing these materials elsewhere. Abundant stores of these elements have been discovered in specific seafloor environments. However, the full implications of deep-sea mining (DSM) for climate mitigation and adaptation, as well as its environmental costs, are insufficiently researched and highly uncertain.

This brief provides policymakers with an overview of the climate-related implications of DSM, including associated environmental risks. It reviews the state of knowledge concerning the mitigation and adaptation implications of mining in deep-sea environments, and highlights the current state of DSM governance and activity. Many uncertainties remain about the full consequences of DSM for ocean carbon storage and biodiversity, and about whether DSM offers an acceptable alternative to land-sourced or recycled materials. Industrial DSM should not be allowed unless and until these and other uncertainties are resolved.

Current State of Knowledge

Deep sea systems provide a wide array of critical benefits to life on Earth, including fisheries, carbon cycling and storage, drug precursors, element processing, and even cultural and educational significance. These benefits are highly interconnected because they involve similar mechanisms, environmental features, or species (1). 40% of fish are now caught below 200m (2) and these naturally slow-growing species are increasingly overfished (3). The deep ocean is minimally studied – only 2% of deep ocean observations come from depths below 500m. Nevertheless, two centuries of limited samples and recent excursions of manned and unmanned devices have uncovered more than 400,000 named species, a small fraction of the millions thought to be present in the deep ocean (4).

Deep sea habitats where critical elements are found, like seamounts (underwater mountains), hydrothermal vents, cobalt rich crusts, and metallic nodules, host unique species that can only live in the extreme conditions found around those locations (5). For instance, microbes hosted by tubeworms or crabs living near hydrothermal vents or growing in mats on mineral substrates are primary producers that depend on hydrothermal vent fluids for energy (6), and they sustain a wide variety of predatory deep-sea species. Polymetallic/ferromanganese nodules provide important habitats for microbes that generate food from chemical sources and provide a major food source for other seafloor species (7). Other bottom-dwelling organisms attach to the hard substrate provided by nodules. Richly diverse deep sea ecosystems arise from these improbable starting conditions, yet these ecosystems are still not well understood.

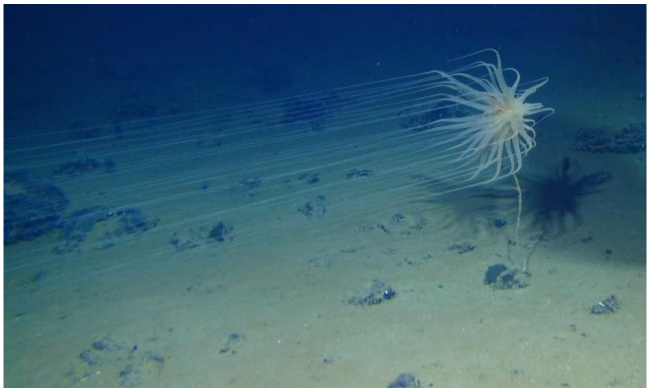

Image 1. A cnidarian that lives on sponge stalks attached to polymetallic nodules, collected at 4,100m in the Clarion-Clipperton Fracture Zone (CCZ). Image: NOAA.

Authors: Sarah R. Cooley, Chris Robbins, Kalina Browne

Recovery of deep sea ecosystems from physical disturbances – including displacement, noise pollution, sediment plume spreading and settling, or crushing associated with mining activities – varies widely and relates to depth, bottom type, species present, extent and type of disturbance, and local patterns of natural disturbance (8–10). Animals in slowly changing environments like the deep seafloor are unaccustomed to physical disturbances. Recovery times of deep seafloor environments are very likely to last from decades to millennia (5,11–13), given the long lifetimes of many deep sea species (14,15) and the extremely low replacement rate of sedimentary habitat. In addition, very little is known about the interaction of disturbances from mining and other global changes. Climate-driven stressors such as ocean acidification, warming, and oxygen depletion are likely to have additive and synergistic effects on a biological community's ability to recover from deep-sea mining impacts (16).

Analysis

Mitigation

Deep-sea mining (DSM) is proposed as a way to advance climate mitigation by supporting renewable energy growth, but the global carbon cycle implications of DSM are not known. Mining activities may affect the natural sequestration of carbon in the seabed or the ocean's carbon cycle. The full carbon cycle impacts, including emissions, of DSM have not been evaluated yet.

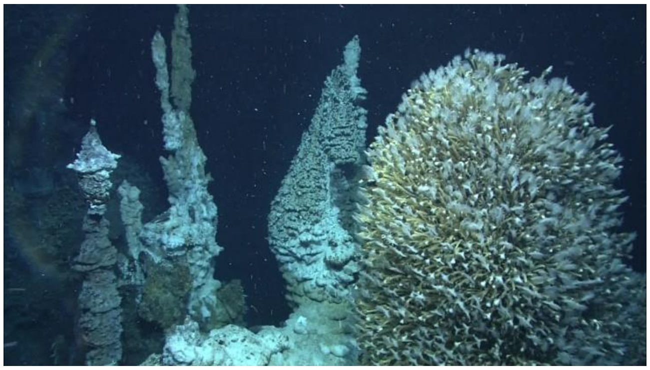

Image 2. A low-temperature sulfide chimney colonized by vent barnacles (right). Image: NOAA.

Ocean sediments contain a small proportion of the carbon naturally captured by biological activities in the upper ocean. By the time this material sinks to the sea floor, it has been recycled by marine animals and microbes many times, each time releasing carbon dioxide into the water column. In the center of major ocean basins, sedimentary materials have been so thoroughly reworked that microbial respiration cannot release much more carbon dioxide (5). Owing to their large spatial area, deep ocean areas sequester about 75% of global sedimentary carbon while continental shelf and slope sediments (although richer in carbon due to more fertilization from land-based sources and less time for recycling) sequester about 23% (5,17).

Some scientific researchers have raised concerns that mining in certain locations will agitate sediments and expose buried organic carbon, which could allow microbes to recycle sediments again and release more carbon dioxide into the deep water (5). Given the relatively long time for bottom water to return to the ocean surface (centuries) and the ability of cold, high-pressure deep water to store a great deal of carbon dioxide, any carbon dioxide released from disturbing deep ocean sediments by DSM seems more likely to promote regional ocean acidification than to escape to the atmosphere.

Microbial species support diverse deep sea communities by harnessing energy and carbon from recycling falling organic material or chemosynthesis (capturing energy to live from chemical compounds in seafloor materials or hydrothermal vent fluids). Hydrothermal vent species like tubeworms and crabs host symbiotic chemosynthetic microbes that sustain them; free-living chemosynthetic microbes and microbial mats on mineral substrates also feed a wide variety of predatory species. Microbes living on polymetallic nodules can also supply the local ecosystem with as much organic carbon as that falling from the water column (7).

Initial studies suggest that mining could severely disrupt carbon cycling by deep sea life either through habitat disruption or removal. For instance, microbial populations had not recovered 26 years after simulated polymetallic nodule mining activities in the Peru Basin in the Eastern Pacific (13). Polymetallic nodules form extremely slowly, at the rate of millimeters per thousands of years, or even possibly millimeters to centimeters per million years, suggesting that this habitat is irreplaceable on human-relevant timescales (18,19). In contrast, there are no published data on recovery from disturbance at inactive vent sites (20), but it is likely that fauna inhabiting massive seafloor sulfide deposits at inactive vents may never recover because this habitat will not regenerate.

The carbon cycle externalities of DSM, including sediment plume behavior and life-cycle analyses of carbon emissions, are not well known. DSM techniques proposed to date all involve extremely large remotely operated devices that crawl along the seafloor on continuous tracks to collect minerals and carry them to a pipe string or riser, which raises the minerals to ships on the surface, where the materials are either stored or processed (21). Each type of seafloor collection device further disturbs the benthic environment by using grinding wheels to break up hydrothermal vent structures and crusts or sonicators to separate crust materials. Both the disturbance of the seafloor and the release of waste materials into the upper ocean are expected to have substantial impacts on seafloor and water column ecosystems, which are only beginning to be investigated (22,23). Sediment plumes and released tailings (waste ground mineral materials) in the upper ocean could decrease biological productivity in the water column by physically blocking light penetration, and these plumes could even create transboundary governance challenges by crossing jurisdictional boundaries and altering water column or seafloor biological activity in a neighboring jurisdiction (24). Although DSM techniques are sure to be logistically complex and energy intensive, there is currently no industry-independent life cycle analysis of the greenhouse gas impacts associated with this mining approach (of both emissions of the mining process and any local alterations of ocean carbon storage) to compare with traditional, land-based mining.

Adaptation

DSM may represent a challenge to climate adaptation, as it will add additional non-climate stressors to an ocean system that provides important benefits to life on Earth now, and it may limit opportunities to adapt to climate change in the future. Climate change and other human impacts are already affecting deep sea systems, and exactly how much perturbation these systems can tolerate while continuing to function is not known.

Deep ocean and seafloor habitats provide a wide variety of benefits, or ecosystem services, that help sustain all life on Earth (1). Supporting and regulating functions from the deep sea include water circulation and carbon dioxide storage and exchange; nutrient cycling and carbon storage in deep water and sediments; primary production (biological energy capture via chemosynthesis); and waste absorption and disposal of material from shallower depths. Provisioning services include fisheries; oil, gas and other forms of energy; rare elements; waste and carbon capture and disposal; bioprospecting opportunities (e.g., drug discovery); and space for communications cables and military operations. Cultural services include scientific and educational opportunities, and the economic benefits that follow from those; inspiration for literature and entertainment; and spiritual wealth and well-being. Despite the inaccessibility of deep oceans, they have captured humans' imaginations for centuries and have inspired exploration and engagement with natural systems (1). These benefits are more highly interdependent in the deep sea than in other places on earth (1). DSM disruption of deep sea systems would therefore likely impair far more services and benefits than commonly thought. For example, loss of deep sea species may foreclose future opportunities to discover new medicines, understand the origins of life on Earth, or harness biological processes for waste detoxification.

Human activity and its consequences are already rapidly changing deep ocean and seafloor ecosystems that provide the biodiversity needed to support the services discussed above. Marine litter, oil and gas drilling, and mining are able to reach every depth (25), at the same time as planetary warming and atmospheric carbon dioxide levels are fundamentally altering ocean conditions. Ocean temperatures from 3000-6000m deep could rise by 1 degree Celsius over the next century (26). Ocean oxygen concentrations will decrease by as much as 0.03 mL L^{-1} by 2100, a 3.7% or more decrease (26). In waters 200-3000m deep, atmospheric carbon dioxide uptake will decrease ocean pH by approximately 0.3 units by 2100 (26). All of these changes represent large alterations in the formerly rather stable ocean environment. Together, ocean warming, acidification, and oxygen loss profoundly affect marine species. Already they are causing marine species to move poleward (27). Vertical stratification is increasing, ultimately altering the amount and timing of phytoplankton production and thus fundamentally changing the magnitude and seasonality of food production supporting the ocean food web (27). Biological recycling and export of organic carbon to the deep ocean are expected to change, as will microbial cycling of elements (27). The impacts of climate change on deep sea ecosystems are not well understood, but it is likely that changing temperature, oxygen, or pH will stress deep sea life. The addition of DSM-related disruptions to existing climate stress could be too much for deep sea species to tolerate, but this is currently very poorly understood.

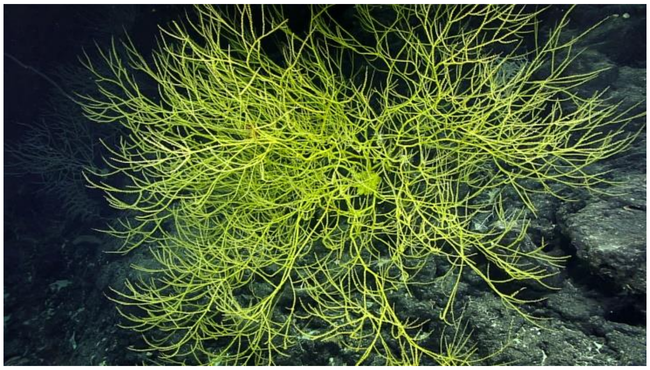

Image 3. A giant bamboo coral nearly as big as a Remote Operated Vehicle on the Kahalewai seamount at close to 1,700m deep. Image: NOAA.

Governance

Seabed activities that occur within national boundaries are subject to a country's own regulations. Currently several known mineral exploration licenses have been issued within EEZs, primarily in Pacific island countries, as well as Japan, New Zealand, Norway, Portugal, and Sudan. Papua New Guinea is the only country that has issued a mining/exploitation license, but seabed mining activities there are currently halted owing to a combination of public resistance, funding difficulties, and legal challenges (28). Other nations have enacted laws either governing deep-sea mining (Cook Islands, Tonga, Portugal, United States) or integrating it with existing policies on offshore petroleum activities (New Zealand, Papua New Guinea) (29).

Deep-seabed activities that occur in the area outside national jurisdiction ("the Area") are controlled by the International Seabed Authority (ISA) (30). The ISA is an independent organization created under the 1982 UN Convention on the Law of the Sea (UNCLOS) to manage seabed resources and to ensure that measures are in place to protect the marine environment from the potentially damaging effects of mining activities within the Area. UNCLOS does not specifically mention climate change, and so does not answer questions arising about DSM and climate mitigation or impacts on deep sea systems from DSM and climate change.

Many key details about regulation of DSM in the Area are unresolved. The ISA/UNCLOS framework requires participants to apply the precautionary approach, to develop strategies dealing with potential environmental impacts, to implement best environmental practices, and to conduct environmental impact assessments. If those obligations are not met, the sponsoring state could be liable under international law (29). The ISA's Mining Code (currently drafted but not yet adopted) lays out draft regulations on exploitation of mineral resources in the Area. The draft includes specific information about practices, monitoring, and contingency plans (29). But other aspects of DSM governance remain unclear, such as how the ISA will abide by foundational UNCLOS concepts of: distributive justice to allocate the benefits from deep sea extraction (29,31); developing a transparent decision-making process where humans' many interests can be recognized and represented (31); and ensuring that no serious injury (and therefore inequity) follows from transboundary sediment plume movement (31). There is no provision for evaluating and permitting DSM in a broader global context that examines the human, economic, and emissions tradeoffs of mining in terrestrial vs. ocean environments; the possibility of securing critical elements through alternative means such as developing new recycling approaches or minimally destructive mining techniques; or the development of new materials that could preclude the need for these elements in the first place.

Foundational information is lacking that would support precautionary management, assessment of environmental impacts, and use of best practices to sustain the deep ocean systems needed especially for climate adaptation. For instance, the tolerance of seafloor environments to disturbance is not well established, and little is known about the substitutability of one seafloor ecosystem for another. Regular follow-up monitoring is difficult. There is concern that DSM places indigenous peoples and their rights at risk; in the South Pacific, DSM-associated vessels were said to have disturbed fish populations, harmed water quality, and disrupted traditional fishing and cultural activities (32). Human communities where onshore processing would occur may also suffer from environmental degradation akin to that associated with terrestrial mining and mineral processing (29,32,33). Questions also remain about whether DSM is even necessary as recovery and recycling of critical minerals improves, as new materials and technologies are developed, and as global markets for these minerals change over time (33). Life-cycle analyses of carbon emissions associated with DSM and other sources of critical minerals are needed to inform the precautionary and environmental management goals of ISA.

Conclusion

It is currently unclear whether DSM would advance climate mitigation, and there are substantial concerns about its effects on climate adaptation and the health of the ocean environment more broadly. Despite the seafloor abundance of chemical elements needed for renewable energy and digital technologies, critical knowledge gaps remain about whether accessing these elements provides a net climate benefit, and what the cumulative environmental and human impacts of DSM would be.

In particular, uncertainty is extremely high about the tolerance of deep-sea ecosystems to additional disturbance on top of the climate-driven changes these systems are already experiencing. It is unknown whether DSM would endanger deep sea ecosystems' continuing ability to provide essential benefits to life on Earth (including carbon storage) now and into the future. The long-term effects of any level of biodiversity loss from DSM are poorly understood. Currently proposed methods of mining seafloor deposits rely on extremely destructive technologies like crawler tractors outfitted to crush and sonically vibrate apart rocks. Understanding is very limited about the behavior of sediment plumes and tailings from ocean mining operations, which could have significant consequences for life in either the water column or seafloor. Industry-independent life cycle analyses showing whether securing elements from the deep sea even offers a net carbon benefit are currently unavailable.

In addition, effective DSM governance is currently lacking, and needs to be further developed. This includes the need to ensure the full implications of DSM – life cycle carbon emissions, ocean biodiversity consequences, economics, and even worldwide ethical implications – are compared with the challenges of improving terrestrial mining or reducing demand for minerals through improving recycling and a circular economy. A multi-sectoral effort is needed to develop a governance framework that is inclusive of all dimensions, considers tradeoffs explicitly, maximizes transparency, and is enforceable.

Accordingly, industrial DSM should not be allowed unless and until its many scientific, economic, and ethical uncertainties are successfully resolved, and a governance and regulatory framework is in place that effectively mitigates and minimizes environmental and human impacts.

About the Authors

Dr. Sarah R. Cooley is Director of Climate Science at Ocean Conservancy. Chris Robbins is Senior Manager of Science Initiatives at Ocean Conservancy. Kalina Browne is a Roger Arliner Young Conservation Fellow at Ocean Conservancy.

Acknowledgements

The authors thank Lisa Levin, Samantha Joye, and an anonymous reviewer for helpful comments on an earlier draft, and Gwynne Taraska, Anne Merwin, Anna Zivian, Amy Trice, and Sandra Whitehouse for comments on this draft.

References

(1) Thurber AR, Sweetman AK, Narayanaswamy BE, Jones DOB, Ingels J, Hansman RL. Ecosystem function and services provided by the deep sea. Biogeosciences. 2014 Jul 29;11(14):3941–63.

(2) Deep Ocean Stewardship Initiative (DOSI). Deep-Sea Fundamentals [Internet]. 2018 Sep [cited 2020 May 11] p. 3. Available from: http://dosi-project.org/wp-content/uploads/2018/05/009-Policy-Brief-3-Deep-sea-Fundamentals-DOSI-V3.pdf

(3) Norse EA, Brooke S, Cheung WWL, Clark MR, Ekeland I, Froese R, et al. Sustainability of deep-sea fisheries. Mar Policy. 2012 Mar 1;36(2):307–20.

(4) Dixon R. How many species are in the deep sea? [Internet]. Deep Sea News. 2019 [cited 2020 Apr 23]. Available from: https://www.deepseanews.com/2019/03/how-many-species-are-in-the-deep-sea/

(5) Orcutt BN, Bradley JA, Brazelton WJ, Estes ER, Goordial JM, Huber JA, et al. Impacts of deep-sea mining on microbial ecosystem services. Limnol Oceanogr. 2020 Jan 13;9999(2020):1–22.

(6) Boschen RE, Rowden AA, Clark MR, Gardner JPA. Mining of deep-sea seafloor massive sulfides: A review of the deposits, their benthic communities, impacts from mining, regulatory frameworks and management strategies. Ocean Coast Manag. 2013 Nov 1;84:54–67.

(7) Sweetman AK, Smith CR, Shulse CN, Maillot B, Lindh M, Church MJ, et al. 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. 2019;64(2):694–713.

(8) Cordes EE, Jones DOB, Schlacher TA, Amon DJ, Bernardino AF, Brooke S, et al. Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. Front Environ Sci [Internet]. 2016 [cited 2020 Apr 24];4. Available from: https://www.frontiersin.org/articles/10.3389/fenvs.2016.00058/full

(9) National Research Council. Effects of Trawling and Dredging on Seafloor Habitat [Internet]. 2002 [cited 2020 May 12]. Available from: https://www.nap.edu/catalog/10323/effects-of-trawling-and-dredging-on-seafloor-habitat

(10) Hixon MA, Tissot BN. Comparison of trawled vs untrawled mud seafloor assemblages of fishes and macroinvertebrates at Coquille Bank, Oregon. J Exp Mar Biol Ecol. 2007 May 31;344(1):23–34.

(11) Williams A, Schlacher TA, Rowden AA, Althaus F, Clark MR, Bowden DA, et al. Seamount megabenthic assemblages fail to recover from trawling impacts. Mar Ecol. 2010;31(s1):183–99.

(12) Vanreusel A, Hilario A, Ribeiro PA, Menot L, Arbizu PM. Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna. Sci Rep. 2016 Jun 1;6(1):1–6.

(13) Vonnahme TR, Molari M, Janssen F, Wenzhöfer F, Haeckel M, Titschack J, et al. Effects of a deep-sea mining experiment on seafloor microbial communities and functions after 26 years. Sci Adv. 2020 May 1;6(18):eaaz5922.

(14) Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I. Global analysis of response and recovery of benthic biota to fishing. Mar Ecol Prog Ser. 2006 Apr 13;311:1–14.

(15) Savage VM, Gilloly JF, Brown JH, Charnov EL. Effects of body size and temperature on population growth. Am Nat. 2004 Mar;163(3):429–41.

(16) Christiansen B, Denda A, Christiansen S. Potential effects of deep seabed mining on pelagic and benthopelagic biota. Mar Policy. 2020 Apr 1;114:103442.

(17) Atwood TB, Witt A, Mayorga J, Hammill E, Sala E. Global Patterns in Marine Sediment Carbon Stocks. Front Mar Sci [Internet]. 2020 [cited 2020 May 12];7. Available from: https://www.frontiersin.org/articles/10.3389/fmars.2020.00165/full

(18) Boltenkov BS. Mechanisms of formation of deep-sea ferromanganese nodules: Mathematical modeling and experimental results. Geochem Int. 2012 Feb 1;50(2):125–32.

(19) Bender ML, Ku T-L, Broecker WS. Manganese Nodules: Their Evolution. Science. 1966 Jan 21;151(3708):325–8.

(20) Gollner S, Govenar B, Martinez Arbizu P, Mullineaux LS, Mills S, Le Bris N, et al. Animal Community Dynamics at Senescent and Active Vents at the 9°N East Pacific Rise After a Volcanic Eruption. Front Mar Sci [Internet]. 2020 [cited 2020 May 12];6. Available from: https://www.frontiersin.org/articles/10.3389/fmars.2019.00832/full

(21) Cuyvers L, Berry W, Gjerde KM, Thiele T, Wilhem C. Deep seabed mining [Internet]. 2018 [cited 2020 Apr 23]. Available from: https://portals.iucn.org/library/node/47761

(22) Gillard B, Purkiani K, Chatzievangelou D, Vink A, Iversen MH, Thomsen L. Physical and hydrodynamic properties of deep sea mining-generated, abyssal sediment plumes in the Clarion Clipperton Fracture Zone (eastern-central Pacific). Elem Sci Anth. 2019 Jan 7;7(1):5.

(23) Spearman J, Taylor J, Crossouard N, Cooper A, Turnbull M, Manning A, et al. Measurement and modelling of deep sea sediment plumes and implications for deep sea mining. Sci Rep. 2020 Mar 19;10(1):1–14.

(24) Thompson KF, Miller KA, Currie D, Johnston P, Santillo D. Seabed Mining and Approaches to Governance of the Deep Seabed. Front Mar Sci [Internet]. 2018 [cited 2020 May 4];5. Available from: https://www.frontiersin.org/articles/10.3389/fmars.2018.00480/full

(25) Levin LA, Bris NL. The deep ocean under climate change. Science. 2015 Nov 13;350(6262):766–8.

(26) Sweetman AK, Thurber AR, Smith CR, Levin LA, Mora C, Wei C-L, et al. Major impacts of climate change on deep-sea benthic ecosystems. Elem Sci Anth. 2017 Feb 23;5(0):4.

(27) IPCC. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [Internet]. Intergovernmental Panel on Climate Change; 2019. Available from: https://www.ipcc.ch/srocc/

(28) Doherty B. Collapse of PNG deep-sea mining venture sparks calls for moratorium. The Guardian [Internet]. 2019 Sep 15 [cited 2020 Apr 23]; Available from: https://www.theguardian.com/world/2019/sep/16/collapse-of-png-deep-sea-mining-venture-sparks-calls-for-moratorium

(29) Koschinsky A, Heinrich L, Boehnke K, Cohrs JC, Markus T, Shani M, et al. Deep-sea mining: Interdisciplinary research on potential environmental, legal, economic, and societal implications. Integr Environ Assess Manag. 2018;14(6):672–91.

(30) Exploration Areas [Internet]. International Seabed Authority. 2019 [cited 2020 Apr 23]. Available from: https://www.isa.org.jm/contractors/exploration-areas

(31) Bourrel M, Thiele T, Currie D. The common of heritage of mankind as a means to assess and advance equity in deep sea mining. Mar Policy. 2018 Sep 1;95:311–6.

(32) Hunter J, Singh P, Aguon J. Broadening Common Heritage: Addressing Gaps in the Deep Sea Mining Regulatory Regime. Harv Environ Law Rev [Internet]. 2018 Apr 16 [cited 2020 May 12]; Available from: https://harvardelr.com/2018/04/16/broadening-common-heritage/

(33) Haugan PM, Levin LA, Amon D, Hemer M, Lily H, Nielsen FG. What Role for Ocean-Based Renewable Energy and Deep Seabed Minerals in a Sustainable Future? [Internet]. World Resources Institute. 2019. Available from: www.oceanpanel.org/blue-papers/ocean-energy-and-mineral-sources

CONTACT US

☎ +1 800-519-1541

✉ memberservices@oceanconservancy.org

💻 oceanconservancy.org

FOLLOW US

☎ *@OceanConservancy*

✉ *@OurOcean*

💻 *@OceanConservancy*

Ocean Conservancy®

Ocean Conservancy is a tax exempt, 501 (c)(3) non-profit organization. Ocean Conservancy is headquartered in Washington, D.C., with regional offices in Alaska, Washington, Oregon, California and Florida.