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HEARING: "DEEP DIVE: EXAMINING THE REGULATORY AND STATUTORY BARRIERS TO DEEP SEA MINING"

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Opening Remarks

Mr. Chairman, Madam Ranking Member, and Members, good afternoon and thank you for inviting me to speak today. My name is Andrew Thaler. I am a deep sea ecologist with more than 15 years of experience researching the environmental impacts of deep sea mining. My expertise includes deep sea ecology and marine technology.

My goal today is to give the Committee an objective overview of the reality of deep sea mining. While I have significant concerns about the long-term environmental harms that can result from mining the deep seafloor, I am not an absolutist against all forms of deep-sea mining. Polymetallic nodule mining in particular has promise. However, I do think there are significant environmental as well as practical hurdles that need to be addressed before any commercial mining is permitted.

While we frequently talk about deep-sea mining as a single cohesive industry, in reality it is three different industries targeting different ore types with wildly different impacts to the marine environment. Recent executive orders and RFIs take an inclusive approach to deep-sea mining permitting, so I think it is important to keep in mind that policies developed for polymetallic nodule mining will be inappropriate and insufficient for seafloor massive sulphide mining at hydrothermal vents or ferromanganese crust mining on seamounts.

In looking at the viability of a deep-sea mining project, I consider three overarching questions:

First, is it urgent? Given the current surpluses in the nickel and cobalt markets, the lack of domestic refining capacity within the United States, and the current pace of technological development, the urgency of deep-sea mining for polymetallic nodules does not exist. Current proposals involve a significant amount of stockpiling of nodules due to lack of refining capacity and the cheapest place to stockpile a nodule is to leave it on the seafloor.

Second, can it be conducted in a manner consistent with environmentally responsible best practices? For hydrothermal vents and seamounts, I do not believe that deep-sea mining is viable. These ecosystems are too small and too fragile. For polymetallic nodules, I remain optimistic that there exists a path forward that respects the ecosystems of the deep sea, but limitations to our knowledge of the long-term impacts and the evolving state of technology means that I am not yet confident that we have reached that point.

While my colleagues in the industry insist that the abyssal plain – the vast, flat areas of the ocean floor that lie 2 to 4 miles beneath the surface – is more akin to a desert than a rainforest, the opposite is true. The deep abyssal plain is more biodiverse than tropical rainforests, with more unique species and genetic novelty than almost any other ecosystem on the planet. High biodiversity coupled with low abundance of individuals makes these species especially vulnerable to extinction. Nodule fields provide unique habitat and species abundance within nodules fields can be two to three times higher than the background abyssal plain.

The direct impact to the seafloor from the mining tool and the benthic plumes which smother the area immediately surrounding extraction leave permanent scars, with species recovery still depressed decades after mining occurred. Nodule fields take millions of years to form and recovery occurs centuries. While I am supportive of the efforts undertaken by Mr. Barron and Mr. Gunasekara to address these impacts, ultimately, the science shows that we should consider any impact to the seafloor environment around a mining site to be permanent.

Beyond the seafloor, there are questions about the impact of mid-water and surface plumes that can spread chemically-polluted waters for hundreds to thousands of miles, impacting marine prey species as well as commercially important fish species. There is the production of marine noise, which persists throughout the lifetime of the mining operation. And there is the physical presence of ships in relatively untrafficked areas, which increase the risk of ship strikes to whales and other marine life.

Third, and, in my view, most important, does the project have local support? Within the US, mining will occur in areas connected to people with strong personal and cultural ties to these waters. Lack of local support has practical logistical impacts. A mining operation off the coast of American Samoa, will depend on American Samoan businesses and services. Without a good faith effort to build inroads in local communities, the realities of overseeing a large offshore operation become exponentially more challenging, expensive, and complex.

The responses to recent RFIs have revealed near-universal, bipartisan community opposition to deep-sea mining in American Samoa, Guam, and the Northern Mariana Islands. A rush towards commercial mining without first building significant relationships within these communities is unlikely to produce a successful venture. One only needs to look to offshore wind development in New Jersey to see how a lack of local support can hinder offshore development.

In international waters, there is an international community to address. Deep-sea mining is, by necessity, an international endeavor, and partner states such as Japan and Korea are party to the Convention on the Law of the Sea. Mining in the CCZ under US permits without the support of the ISA will lead to significant legal challenges, further slowing progress on the international mining code.

The lack of urgency, environmental unknowns, and local opposition does not justify a rush to expedite permitting for deep-sea mining. Deep-sea mining has many issues both environmental and practical that are still unresolved.

Thank you again for the opportunity to testify before this Subcommittee. I look forward to your questions.

Environmental Impacts of Deep-sea Mining[1]

Polymetallic sulphides. The geochemical processes that create these ore deposits provide chemical energy that supports novel ecosystems built on chemosynthetic primary production (Van Dover et al., 2018). The ore cannot be isolated from the ecosystem (Collins et al., 2013). The direct impact to the hydrothermal vent ecosystem will be catastrophic, resulting in complete defaunation and habitat destruction of the immediate vent environment (Van Dover, 2014). In the only study of the environmental impacts of mining a deep-sea hydrothermal vent, biodiversity collapsed following exploitation and had not recovered after 3 years (Washburn et al., 2023a). Hydrothermal-vent communities are well-connected and even in limited, controlled mining trials, downstream impacts will impact hydrothermal vent communities beyond the mining area (Thaler et al., 2017, 2014, 2011). At inactive vent sites, mining may still result in comprehensive removal of endemic ecosystems (Erickson et al., 2009). Even at inactive hydrothermal vent systems, abundant successional communities appear dependent on remnant chemosynthetic activity (Mullineaux et al., 2025).

Cobalt-rich crusts. Mining occurs on thick layers of crust coating the rocky tops and upper walls of seamounts and results in the comprehensive removal of ore-bearing material as well as habitat for numerous species, including long-lived, slow growing sessile species like corals from the encrusted rocky tops and upper walls of seamounts (Weaver and Billett, 2019). Seamounts tend to host high biomass ecosystems, providing habitat and supporting nursery grounds for commercially important fisheries (Morato et al., 2010). Though studies on the environmental impacts of mining cobalt-rich crusts are limited, baseline studies have shown that community structure on crusts differs from that of non-crust seamount regions and that recovery from mining disturbance will be slow (Schlacher et al., 2014). In the only, to date, study of the environmental impacts of mining a cobalt-rich crust, mobile epifauna were less abundant following disturbance (Washburn et al., 2023b).

Polymetallic nodules. Polymetallic-nodule extraction involves collecting nodules directly from the seafloor. The nodules themselves are habitat for many species found exclusively within nodule fields, including sponges, corals, tube-building worms, barnacles, and other species (Amon et al., 2016; De Smet et al., 2021). Nodule fields play a key role in abyssal plain communities, driving biodiversity, abundance, and community composition, and may be critical for maintaining the integrity of deep food webs (Amon et al., 2016; Durden et al., 2021; Simon-Lledó et al., 2023, 2020; Stratmann et al., 2021; Uhlenkott et al., 2023; Vanreusel et al., 2016). Removal of nodules may also reshape the microbial ecosystem beneath the nodules (Wear et al., 2021).

[1] This section has been adapted and expanded from Thaler, Andrew D., 2025. Impacts of Deep-sea Mining on Migratory Species: Review and Knowledge Gaps. CMS Secretariat, Bonn, Germany. [https://www.cms.int/sites/default/files/document/2025-11/cms_cop15_doc.25.2.3_annex1_dsm-report_e.pdf]

Nodule-mining experiments were conducted in the 1970s and 1980s to assess the long-term impacts of deep-sea nodule mining, including at the DIS-turbance and re-COL-onization experiment (DISCOL) site in the Peru Basin, which is among the best studied experimental mining sites (Thiel et al., 2001). Twenty-six years after the disturbance, there has been no sign of recovery of benthic filter feeders and mobile scavengers have a quantitatively different community composition compared with the original community (Jones et al., 2017; Simon-Lledó et al., 2019). Microbial communities and ecosystem function may have also failed to recover (Molari et al., 2020; Volz et al., 2020; Vonnahme et al., 2020). Recent surveys have shown that biological impacts of polymetallic nodule mining persist for at least 44 years, though some mobile species have begun to re-establish (Jones et al., 2025). The direct impacts to the ecosystem of the immediate mining site will likely persist for at least several decades beyond the lifetime of the mine and may never recover to its pre-mining condition, given many of the fauna live directly on the nodules, which take millions of years to form.

Plumes. The extent, and thus environmental impact, from sediment plumes depends on the mining technology used in collecting and processing the ore (Peacock and Ouillon, 2023), the characteristics of the underlying sediment (Gillard et al., 2019), and the current regime and biodiversity present in these specific areas.

Collection plume. All forms of deep-sea mining generate a sediment plume at the seabed, where the activities of the mining tool mobilize sediment. This sediment plume could extend several kilometers across the deep seafloor (Gillard et al., 2019). Though historically spread of up to 100km was suggested, recent studies suggest that the extent of the plume may be much more limited, with the majority of sediment deposited within a few meters of the disturbance site with lower concentration buoyant and passive-transport phases (Peacock and Ouillon, 2023). A recent independent assessment of an experimental nodule collector observed plumes dispersing up to at least 4.5 km (the limit of the monitoring area), with suspended particle concentration of four orders of magnitude greater than background observed 50 m from mining tracks and redeposited sediment adjacent to the mining tracks of approximately 3 cm (Gazis et al., 2025).

While some nodule collector designs may mobilize the top 5 to 15 cm of sediment (Peacock and Ouillon, 2023), others are being designed to operate with a presumptively less aggressive removal process[2]. The duration and propagation of the collection plume will be dependent on the specific design and operation of the collection vehicle. The plume may propagate beyond the immediate mining area, with heavy sedimentation occurring within 100 meters from the nodule collector (Burns, 1980). Observations of an experimental tracked mining vehicle in the Clarion-Clipperton Zone documented a plume that rose 3 meters above the seafloor and propagated for more than 100 meters beyond the immediate mining site (Muñoz-Royo et al., 2022), with 2% to 8% of the mobilized sediment detected more than 2 meters above the seafloor and did not settle out over several hours of observation. As the ultimate evolution of the plume can be mediated by

[2] Collingwood team creating friendlier robot for deep sea mining - https://www.collingwoodtoday.ca/local-news/collingwood-team-creating-friendlier-robot-for-deep-sea-mining-10773843

environmental conditions, such as site-specific tidal influence, benthic currents, and seafloor topography, as well as the specific design of the nodule collector, models predicting the total extent of the broadly dispersed, dilute passive-transport phase of the collection plume may be off by orders of magnitude and precise prediction of plume propagation depends on accurate in-situ observations using operation-specific measurement of plume evolution (Peacock and Ouillon, 2023).

Collection plumes can smother the surrounding ecosystem, resulting in loss of marine habitat and biodiversity (Miller et al., 2018). Ore from deep-sea deposits may be enriched in heavy metals such as lead and arsenic which can be mobilized into the ecosystem during mining (Hauton et al., 2017; Price et al., 2016). One study indicated that deep-sea marine mammals interact with the seafloor in the area around the Clarion-Clipperton Zone and that plume generation may disrupt feeding patterns (Marsh et al., 2018). Recent studies detected minimal residual effects from the sedimentation plume 44 years after a small-scale test nodule mine (Jones et al., 2025), but at the DISCOL site 26 years post-disturbance, megafauna and fish communities still showed impacts in plume-effected seafloor (Drazen et al., 2021; Simon-Lledó et al., 2019).

Return plume. Nodules recovered to the surface carry with them a fraction of benthic sediment. Depending on the method of extraction, this return plume can consist of ore-enriched sediments (including both particulate and dissolved metals produced when recovered ore is dewatered (Spearman et al., 2020). In the majority of proposed mining scenarios, this plume occurs in the midwater, though proposals to discharge the return plume closer to the seafloor have also been presented. As yet, there are no regulations to mandate the depth of the return plume. Midwater plumes can persist for weeks to more than 4 months before finally settling out on the seafloor, allowing these plumes to disperse over hundreds to thousands of kilometers (Peacock and Ouillon, 2023). Midwater plumes have the potential to significantly disrupt marine food webs (Dowd et al., 2025) and heavy-metals from plumes may bioaccumulate in higher trophic levels including migratory and commercially important fish species (Amon et al., 2023).

The epipelagic and mesopelagic, in particular, has received relatively little consideration compared to the deep benthos where mining occurs (Drazen et al., 2020). Dewatering plumes, if released in the photic zone, may disrupt the nutrient flow in otherwise nutrient-limited waters, triggering algal blooms which can ultimately starve a region and smother seafloor communities once the algae begin to die off. Dewatering plumes will discharge large volumes of inorganic mud and ore particles into midwaters (~50,000m3 d-1; Drazen et al., 2020) that could dilute the organic detrital particles that deep-midwater filter feeders rely upon. In one study, deep-sea corals exposed to suspend particles from polymetallic sulphides resulted in tissue loss, necrosis, and the bioaccumulation of copper in coral specimens (Carreiro-Silva et al., 2022). A recent investigation into the potential effects of dewatering plumes on a deep-pelagic jellyfish indicated that deep-sea mining would negatively impact biodiversity and ecosystem function in the midwater zone (Stenvers et al., 2023).

Surface plume. Surface plumes can be produced by the dewatering process but will more likely be the result of accidental or emergency discharge. These discharges can alter the neuston directly surrounding the mining vessel (Helm, 2021) and interfere with migration and feeding behavior of pelagic species, including marine mammals and migratory seabirds, as well as the pelagic communities they are dependent on. As no current deep-sea mining contractor proposes releasing surface plumes as part of their operations, studies on the promulgation of deep-sea mining-derived surface plumes are limited. Mining contractors recognize that intentional surface discharge of nodule waste is "too environmentally challenging to be viable" (Peacock and Ouillon, 2023). At least one case of accidental surface plume discharge has already been reported from a deep-sea mining vessel conducting experimental trials in the Clarion-Clipperton Zone[3]. That unintentional discharge covered and area significant enough to be tracked from space (Yin et al., 2024).

Noise. With the exception of the hydrothermal vents associated with polymetallic sulphides, the soundscape of the deep sea is relatively quiet and poorly studied (Chen et al., 2021). One nodule field soundscape within Japan's EEZ was observed to be quieter even than Challenger Deep in the Mariana Trench (Chen et al., 2021). Deep-sea mining will introduce multiple new sources of marine noise pollution into regions that are historically lightly trafficked and exposed to limited anthropogenic noise. Mining operations involving robotic vehicles are expected to operate around the clock, with ore pumped continuously from the seafloor to the surface via a riser and lift system. A surface vessel, on site for months at a time, also contributes to altering the acoustic environment. Noise from deep-sea mining operations can span vast areas, with acute impacts focused in the area immediately around the mining site and surface vessel (Williams et al., 2022). The cumulative impacts of chronic noise exposure from mining systems will likely have far greater impact than the short-term, acute sound exposure most often assessed in noise exposure studies (Williams et al., 2025).

Habitat-specific soundscapes can serve as cue for settlement and significant alterations to the deep soundscape could mask the acoustic signals that larvae use to locate appropriate habitats (Chen et al., 2021). The noise generated by a commercial nodule operation could produce a cylinder of sound of up to a 6 km radius which exceeds standard thresholds for impacting the behavior of marine mammals (Southall et al., 2019; Williams et al., 2022). Even relatively short-duration scientific research cruises using submersible assets have been shown to significantly alter the immediate soundscape (Chen et al., 2021).

For marine mammals, sea turtles, and other migratory species, anthropogenic noise can cause behavioral changes, including interrupting feeding behaviors, altering vocalizations, and triggering flight response from high noise areas. Behavioral changes associated with anthropogenic noise are often unpredictable and not necessarily correlated with the volume of the noise source, but a multitude of factors (Williams et al., 2025). In the most extreme cases,

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[3] Leaked video footage of ocean pollution shines light on deep-sea mining: https://www.theguardian.com/environment/2023/feb/06/leaked-video-footage-of-ocean-pollution-shines-light-on-deep-sea-mining

high-intensity sound can lead to direct damage to ear structures, which can be lethal (Gomez et al., 2016). At least one study suggests that deep-diving beaked whales may interact with the seafloor in the Clarion Clipperton Zone (Marsh et al., 2018). Many deep-sea mining contract areas are not only located where cetaceans are active, but in regions that are otherwise rarely disturbed by human activities. The noise produced by mining operations are known to overlap with the frequency at which many cetaceans communicate, which may lead to permanent alteration in the behavior of populations still in recovery from two centuries of commercial whaling (Thompson et al., 2023).

Commercially Important Fisheries. Bigeye, skipjack, and yellowfin tuna populations are present within the CCZ, and fall under the aegis of two regional fisheries management organizations in that part of the oceans (van der Grient and Drazen, 2021). The populations fished in the CCZ represent some of the most valuable commercial fisheries in the world. There is significant spatial overlap between deep-sea mining contract areas and fishing grounds (van der Grient and Drazen, 2021), which will likely lead to direct conflict between these two industrial activities, especially as climate change drives increasing overlaps between the two activities (Amon et al., 2023). Metal-enriched discharge plumes may also cause heavy metals to enter the food web, resulting in bioaccumulation within apex predators and spoiling the value of the fishery, much the same as mercury bioaccumulation in swordfish resulted in devaluing of the fishery (Amon et al., 2023). The bioaccumulation of heavy metals can result in significant adverse health effects for high-trophic-level predators (Ray and Vashishth, 2024).

Underwater Cultural Heritage. Relatively little consideration has been given to the social and cultural impacts of deep-sea mining. Lack of stakeholder engagement with the peoples that may be most immediately affected by deep-sea mining is a frequent point of contention among ISA delegations (Jaeckel et al., 2023). Deep-sea mining comes in direct conflict with, in particular, the cultural heritage of Pacific Islanders[4]. Deep-sea mining leases fall within both the Micronesian and Polynesian Voyaging Triangles – areas where traditional navigators established and maintained millennium-spanning connections between remote islands, as well as recent proposals within the EEZs associated with American Samoa and Papua New Guinea. Further, many culturally significant migratory species occur in proposed mining areas in the Pacific (Tilot et al., 2021).

Deep-sea hydrothermal vents have significant cultural and scientific value. The first deep-sea marine protected areas were established around historically important hydrothermal vent fields within the Marine Park of the Azores and the Endeavour Hydrothermal Vents Marine Protected Area in Canada (Menini and Van Dover, 2019). The Middle Passage, a region of the Mid-Atlantic, encompasses the historic route through which millions of enslaved people were transported from West Africa to the Americas and Caribbean and serves as a maritime graveyard for up to 2 million people (Turner et al., 2020). Several ISA-issued deep-sea mining leases fall

[4] Connecting Conservation and Culture in Oceania - https://www.angelovillagomez.com/2022/09/connecting-conservation-and-culture-in.html

within the historic seaways of the Middle Passage. At least one campaign to declare the seafloor of the Middle Passage as a maritime cemetery is underway[5].

Comment on Commonwealth of the Northern Mariana Islands[6]

The area proposed by BOEM in the CNMI is inadequate for deep-sea polymetallic nodule mining. There is almost no environmental baseline data for this area. There are no known commercially viable nodule field within the area. The area is topographically complex, with numerous seamounts that make deep-sea mining based on current established best practices nearly impossible. There are roughly 125 seamounts and 22 knolls consolidated into 38 major seamount and guyot structures in the BOEM RFI representing some of the oldest seafloor and seamounts in the world. Analyses of seamounts elsewhere in the Pacific Ocean have resulted in a recommendation for an Ecologically of Biologically Significant Marine Area buffer of at least 30 km around existing seamounts. Approximately 99.9% of the lease area is within 100 km of a seamount, and 92% of the lease area is within 30 km of a seamount.

Biodiversity in the CCZ[7]

The Clarion-Clipperton Zone harbors immense species richness. Conservative estimates indicate that the CCZ is highly biodiverse and that current undersampling underrepresents the full extent of biodiversity. Studies confirm trends of both high biodiversity and low abundance. A third of species (37%) are represented by a single individual. 436 named species had been catalogued, of which 185 were new to science (Rabone et al., 2023). This likely represents a small fraction of true biodiversity. There is an estimated 6,200 and 7,600 species in the region. Macrofauna like brittle stars show high site-to-site turnover, with 44% of species known from just a single site (Macheriotou et al., 2025), while meiofaunal like nematodes are widespread. 12 of the 19 most abundant species occurring at all sampling locations but still account for a small fraction of the estimated 360 species identified in this group (Macheriotou et al., 2025). Polychaetes are highly diverse, with over 1,600 species estimated across the CCZ but fewer than 3% formally described (Bonifácio et al., 2024).

Ninety percent recovery of by-products from existing domestic metal mining operations could meet nearly all US critical mineral needs

In terms of defense and national security, where we’re really losing ground is in discovery. Scientific discovery. For the last 50 years, every major discovery in the deep-sea has happened

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[5] Group urges Atlantic seafloor be labeled a memorial to slave trading - https://today.duke.edu/2020/11/group-urges-atlantic-seafloor-be-labeled-memorial-slave-trading

[6] These comments compiled from Comment from Deep-sea subject matter experts in response to the BOEM RFI - https://www.regulations.gov/comment/BOEM-2025-0351-0694

[7] Adapted from a paper in prep by Thaler, Betters, and McClain

aboard an American ship or with the major contribution of US researchers. And these are real, economically tangible discoveries. Discovering hydrothermal vents fundamentally changed how we think about biology and revolutionized the medical industry to the tune of trillions of dollars. And we keep discovering new and totally novel ecosystems in the deep sea about once a decade. This year, for the first time, a Chinese research team discovered the deepest know complex ecosystem at 10,000 meters. So by pulling back on research in favor of mineral extraction, we are ceding American research dominance, and that can have real, long-lasting impacts that vastly exceed any economic benefits from mining the deep.

Works Cited

Amon, D.J., Gollner, S., Morato, T., Smith, C.R., Chen, C., Christiansen, S., Currie, B., Drazen, J.C., Fukushima, T., Gianni, M., Gjerde, K.M., Gooday, A.J., Grillo, G.G., Haeckel, M., Joyini, T., Ju, S.-J., Levin, L.A., Metaxas, A., Mianowicz, K., Molodtsova, T.N., Narberhaus, I., Orcutt, B.N., Swaddling, A., Tuhumwire, J., Palacio, P.U., Walker, M., Weaver, P., Xu, X.-W., Mulalap, C.Y., Edwards, P.E.T., Pickens, C., 2022. Assessment of scientific gaps related to the effective environmental management of deep-seabed mining. Mar. Policy 138, 105006. https://doi.org/10.1016/j.marpol.2022.105006

Amon, D.J., Palacios-Abrantes, J., Drazen, J.C., Lily, H., Nathan, N., van der Grient, J.M.A., McCauley, D., 2023. Climate change to drive increasing overlap between Pacific tuna fisheries and emerging deep-sea mining industry. Npj Ocean Sustain. 2, 1–8. https://doi.org/10.1038/s44183-023-00016-8

Amon, D.J., Ziegler, A.F., Dahlgren, T.G., Glover, A.G., Goineau, A., Gooday, A.J., Wiklund, H., Smith, C.R., 2016. Insights into the abundance and diversity of abyssal megafauna in a polymetallic-nodule region in the eastern Clarion-Clipperton Zone. Sci. Rep. 6, 30492. https://doi.org/10.1038/srep30492

Burns, R.E., 1980. Assessment of environmental effects of deep ocean mining of manganese nodules. Helgoländer Meeresunters. 33, 433–442. https://doi.org/10.1007/BF02414768

Carreiro-Silva, M., Martins, I., Riou, V., Raimundo, J., Caetano, M., Bettencourt, R., Rakka, M., Cerqueira, T., Godinho, A., Morato, T., Colaço, A., 2022. Mechanical and toxicological effects of deep-sea mining sediment plumes on a habitat-forming cold-water octocoral. Front. Mar. Sci. 9.

Chen, C., Lin, T.-H., Watanabe, H.K., Akamatsu, T., Kawagucci, S., 2021. Baseline soundscapes of deep-sea habitats reveal heterogeneity among ecosystems and sensitivity to anthropogenic impacts. Limnol. Oceanogr. 66, 3714–3727. https://doi.org/10.1002/lno.11911

Collins, P., Kennedy, B., Copley, J., Boschen, R., Fleming, N., Forde, J., Ju, S.-J., Lindsay, D., Marsh, L., Nye, V., Patterson, A., Watanabe, H., Yamamoto, H., Carlsson, J., David Thaler, A., 2013. VentBase: Developing a consensus among stakeholders in the deep-sea regarding environmental impact assessment for deep-sea mining–A workshop report. Mar. Policy 42, 334–336. https://doi.org/10.1016/j marpol.2013.03.002

De Smet, B., Simon-Lledó, E., Mevenkamp, L., Pape, E., Pasotti, F., Jones, D.O.B., Vanreusel, A., 2021. The megafauna community from an abyssal area of interest for mining of polymetallic nodules. Deep Sea Res. Part Oceanogr. Res. Pap. 172, 103530. https://doi.org/10.1016/j.dsr.2021.103530

Dowd, M.H., Assad, V.E., Cazares-Nuesser, A.E., Drazen, J.C., Goetze, E., White, A.E., Popp, B.N., 2025. Deep-sea mining discharge can disrupt midwater food webs. Nat. Commun. 16, 9575. https://doi.org/10.1038/s41467-025-65411-w

Drazen, J.C., Leitner, A.B., Jones, D.O.B., Simon-Lledó, E., 2021. Regional Variation in Communities of Demersal Fishes and Scavengers Across the CCZ and Pacific Ocean. Front. Mar. Sci. 8. https://doi.org/10.3389/fmars.2021.630616

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., Hatta, M., Koslow, J.A., Leitner, A.B., Pacini, A., Perelman, J.N., Peacock, T., Sutton, T.T., Watling, L., Yamamoto, H., 2020. Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. Proc. Natl. Acad. Sci. 117, 17455–17460. https://doi.org/10.1073/pnas.2011914117

Durden, J.M., Putts, M., Bingo, S., Leitner, A.B., Drazen, J.C., Gooday, A.J., Jones, D.O.B., Sweetman, A.K., Washburn, T.W., Smith, C.R., 2021. Megafaunal Ecology of the Western Clarion Clipperton Zone. Front. Mar. Sci. 8. https://doi.org/10.3389/fmars.2021.671062

Erickson, K.L., Macko, S., Van Dover, C.L., 2009. Evidence for a chemoautotrophically based food web at inactive hydrothermal vents (Manus Basin). Deep Sea Res. Part II Top. Stud. Oceanogr. 56, 1577–1585. https://doi.org/10.1016/j.dsr2.2009.05.002

Gazis, I.-Z., de Stigter, H., Mohrmann, J., Heger, K., Diaz, M., Gillard, B., Baeye, M., Veloso-Alarcón, M.E., Purkiani, K., Haeckel, M., Vink, A., Thomsen, L., Greinert, J., 2025. Monitoring benthic plumes, sediment redeposition and seafloor imprints caused by deep-sea polymetallic nodule mining. Nat. Commun. 16, 1229. https://doi.org/10.1038/s41467-025-56311-0

Gillard, B., Purkiani, K., Chatzievangelou, D., Vink, A., Iversen, M.H., Thomsen, L., 2019. Physical and hydrodynamic properties of deep sea mining-generated, abyssal sediment plumes in the Clarion Clipperton Fracture Zone (eastern-central Pacific). Elem. Sci. Anthr. 7, 5. https://doi.org/10.1525/elementa.343

Gomez, C., Lawson, J.W., Wright, A.J., Buren, A.D., Tollit, D., Lesage, V., 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. Can. J. Zool. 94, 801–819. https://doi.org/10.1139/cjz-2016-0098

Hauton, C., Brown, A., Thatje, S., Mestre, N.C., Bebianno, M.J., Martins, I., Bettencourt, R., Canals, M., Sanchez-Vidal, A., Shillito, B., Ravaux, J., Zbinden, M., Duperron, S., Mevenkamp, L., Vanreusel, A., Gambi, C., Dell'Anno, A., Danovaro, R., Gunn, V., Weaver, P., 2017. Identifying Toxic Impacts of Metals Potentially Released during Deep-Sea Mining—A Synthesis of the Challenges to Quantifying Risk. Front. Mar. Sci. 4.

Helm, R.R., 2021. The mysterious ecosystem at the ocean's surface. PLOS Biol. 19, e3001046. https://doi.org/10.1371/journal.pbio.3001046

Jaeckel, A., Harden-Davies, H., Amon, D.J., van der Grient, J., Hanich, Q., van Leeuwen, J., Niner, H.J., Seto, K., 2023. Deep seabed mining lacks social legitimacy. Npj Ocean Sustain. 2, 1–4. https://doi.org/10.1038/s44183-023-00009-7

Jones, D.O.B., Arias, M.B., Van Audenhaege, L., Blackbird, S., Boolukos, C., Bribiesca-Contreras, G., Copley, J.T., Dale, A., Evans, S., Fleming, B.F.M., Gates, A.R., Grant, H., Hartl, M.G.J., Huvenne, V.A.I., Jeffreys, R.M., Josso, P., King, L.D., Simon-Lledó, E., Le Bas, T., Norman, L., O'Malley, B., Peacock, T., Shimmield, T., Stewart, E.C.D., Sweetman, A.K., Wardell, C., Aleynik, D., Glover, A.G., 2025. Long-term impact and biological recovery in a deep-sea mining track. Nature. https://doi.org/10.1038/s41586-025-08921-3

Jones, D.O.B., Kaiser, S., Sweetman, A.K., Smith, C.R., Menot, L., Vink, A., Trueblood, D., Greinert, J., Billett, D.S.M., Arbizu, P.M., Radziejewska, T., Singh, R., Ingole, B., Stratmann, T., Simon-Lledó, E., Durden, J.M., Clark, M.R., 2017. Biological responses to disturbance from simulated deep-sea polymetallic nodule mining. PLOS ONE 12, e0171750. https://doi.org/10.1371/journal.pone.0171750

Marsh, L., Huvenne, V.A.I., Jones, D.O.B., 2018. Geomorphological evidence of large vertebrates interacting with the seafloor at abyssal depths in a region designated for deep-sea mining. R. Soc. Open Sci. 5, 180286. https://doi.org/10.1098/rsos.180286

Menini, E., Van Dover, C.L., 2019. An atlas of protected hydrothermal vents. Mar. Policy 108, 103654. https://doi.org/10.1016/j marpol.2019.103654

Miller, K.A., Thompson, K.F., Johnston, P., Santillo, D., 2018. An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts, and Knowledge Gaps. Front. Mar. Sci. 4.

Molari, M., Janssen, F., Vonnahme, T.R., Wenzhöfer, F., Boetius, A., 2020. The contribution of microbial communities in polymetallic nodules to the diversity of the deep-sea microbiome of the Peru Basin (4130–4198 m depth). Biogeosciences 17, 3203–3222. https://doi.org/10.5194/bg-17-3203-2020

Morato, T., Hoyle, S.D., Allain, V., Nicol, S.J., 2010. Seamounts are hotspots of pelagic biodiversity in the open ocean. Proc. Natl. Acad. Sci. 107, 9707–9711. https://doi.org/10.1073/pnas.0910290107

Mullineaux, L.S., Beaulieu, S.E., Mills, S.W., Jones, R., Weston, J.N.J., Best, A.C., Zúñiga Mouret, R., Meneses, M.J., Tivey, M.K., Harris, M.J., Achberger, A.M., Sylvan, J.B., 2025. Unique gastropods dominate the fauna on inactive vent sulfide features in the eastern Pacific. Deep Sea Res. Part Oceanogr. Res. Pap. 219, 104475. https://doi.org/10.1016/j.dsr.2025.104475

Muñoz-Royo, C., Ouillon, R., El Mousadik, S., Alford, M.H., Peacock, T., 2022. An in situ study of abyssal turbidity-current sediment plumes generated by a deep seabed polymetallic nodule mining preprototype collector vehicle. Sci. Adv. 8, eabn1219. https://doi.org/10.1126/sciadv.abn1219

Peacock, T., Ouillon, R., 2023. The Fluid Mechanics of Deep-Sea Mining. Annu. Rev. Fluid Mech. 55, 403–430. https://doi.org/10.1146/annurev-fluid-031822-010257

Price, R.E., Breuer, C., Reeves, E., Bach, W., Pichler, T., 2016. Arsenic bioaccumulation and biotransformation in deep-sea hydrothermal vent organisms from the PACMANUS hydrothermal field, Manus Basin, PNG. Deep Sea Res. Part Oceanogr. Res. Pap. 117, 95–106. https://doi.org/10.1016/j.dsr.2016.08.012
Ray, S., Vashishth, R., 2024. From water to plate: Reviewing the bioaccumulation of heavy metals in fish and unraveling human health risks in the food chain. Emerg. Contam. 10, 100358. https://doi.org/10.1016/j.emcon.2024.100358
Schlacher, T.A., Baco, A.R., Rowden, A.A., O'Hara, T.D., Clark, M.R., Kelley, C., Dower, J.F., 2014. Seamount benthos in a cobalt-rich crust region of the central Pacific: conservation challenges for future seabed mining. Divers. Distrib. 20, 491–502. https://doi.org/10.1111/ddi.12142
Simon-Lledó, E., Amon, D.J., Bribiesca-Contreras, G., Cuvelier, D., Durden, J.M., Ramalho, S.P., Uhlenkott, K., Arbizu, P.M., Benoist, N., Copley, J., Dahlgren, T.G., Glover, A.G., Fleming, B., Horton, T., Ju, S.-J., Mejia-Saenz, A., McQuaid, K., Pape, E., Park, C., Smith, C.R., Jones, D.O.B., 2023. Abyssal Pacific Seafloor Megafauna Atlas.
Simon-Lledó, E., Bett, B.J., Huvenne, V.A.I., Köser, K., Schoening, T., Greinert, J., Jones, D.O.B., 2019. Biological effects 26 years after simulated deep-sea mining. Sci. Rep. 9. https://doi.org/10.1038/s41598-019-44492-w
Simon-Lledó, E., Pomee, C., Ahokava, A., Drazen, J.C., Leitner, A.B., Flynn, A., Parianos, J., Jones, D.O.B., 2020. Multi-scale variations in invertebrate and fish megafauna in the mid-eastern Clarion Clipperton Zone. Prog. Oceanogr. 187, 102405. https://doi.org/10.1016/j.pocean.2020.102405
Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D.P., Tyack, P.L., 2019. Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. Aquat. Mamm. 45, 125–232. https://doi.org/10.1578/AM.45.2.2019.125
Spearman, J., Taylor, J., Crossouard, N., Cooper, A., Turnbull, M., Manning, A., Lee, M., Murton, B., 2020. Measurement and modelling of deep sea sediment plumes and implications for deep sea mining. Sci. Rep. 10, 5075. https://doi.org/10.1038/s41598-020-61837-y
Stenvers, V.I., Hauss, H., Bayer, T., Havermans, C., Hentschel, U., Schmittmann, L., Sweetman, A.K., Hoving, H.-J.T., 2023. Experimental mining plumes and ocean warming trigger stress in a deep pelagic jellyfish. Nat. Commun. 14, 7352. https://doi.org/10.1038/s41467-023-43023-6
Stratmann, T., Soetaert, K., Kersken, D., van Oevelen, D., 2021. Polymetallic nodules are essential for food-web integrity of a prospective deep-seabed mining area in Pacific abyssal plains. Sci. Rep. 11, 12238. https://doi.org/10.1038/s41598-021-91703-4
Thaler, A.D., Plouviez, S., Saleu, W., Alei, F., Jacobson, A., Boyle, E.A., Schultz, T.F., Carlsson, J., Van Dover, C.L., 2014. Comparative population structure of two deep-sea hydrothermal-vent- associated decapods (Chorocaris sp. 2 and Munidopsis lauensis) from southwestern Pacific back-arc basins. PLoS ONE 9. https://doi.org/10.1371/journal.pone.0101345
Thaler, A.D., Saleu, W., Carlsson, J., Schultz, T.F., Van Dover, C.L., 2017. Population structure of Bathymodiolus manusensis, a deep-sea hydrothermal vent-dependent mussel from Manus Basin, Papua New Guinea. PeerJ 2017. https://doi.org/10.7717/peerj.3655
Thaler, A.D., Zelnio, K., Saleu, W., Schultz, T.F., Carlsson, J., Cunningham, C., Vrijenhoek, R.C., Van Dover, C.L., 2011. The spatial scale of genetic subdivision in populations of Ifremeria nautilei, a hydrothermal-vent gastropod from the southwest Pacific. BMC Evol. Biol. 11, 372–372. https://doi.org/10.1186/1471-2148-11-372
Thiel, H., Schriever, G., Ahnert, A., Bluhm, H., Borowski, C., Vopel, K., 2001. The large-scale environmental impact experiment DISCOL—reflection and foresight. Deep Sea Res. Part II Top. Stud. Oceanogr., Environmental Impact Studies for the Mining of Polymetallic Nodul es from the Deep Sea 48, 3869–3882. https://doi.org/10.1016/S0967-0645(01)00071-6
Thompson, K.F., Miller, K.A., Wacker, J., Derville, S., Laing, C., Santillo, D., Johnston, P., 2023. Urgent assessment needed to evaluate potential impacts on cetaceans from deep seabed mining. Front. Mar. Sci. 10.
Tilot, V., Willaert, K., Guilloux, B., Chen, W., Mulalap, C.Y., Gaulme, F., Bambridge, T., Peters, K., Dahl, A., 2021. Traditional Dimensions of Seabed Resource Management in the Context of Deep Sea Mining in the Pacific: Learning From the Socio-Ecological Interconnectivity Between Island Communities and the Ocean Realm. Front. Mar. Sci. 8. https://doi.org/10.3389/fmars.2021.637938
Todd, V.L.G., Todd, I.B., Gardiner, J.C., Morrin, E.C.N., MacPherson, N.A., DiMarzio, N.A., Thomsen, F., 2015. A review of impacts of marine dredging activities on marine mammals. ICES J. Mar. Sci. 72, 328–340. https://doi.org/10.1093/icesjms/fsu187

Turner, P.J., Cannon, S., DeLand, S., Delgado, J.P., Eltis, D., Halpin, P.N., Kanu, M.I., Sussman, C.S., Varmer, O., Van Dover, C.L., 2020. Memorializing the Middle Passage on the Atlantic seabed in Areas Beyond National Jurisdiction. Mar. Policy 122, 104254. https://doi.org/10.1016/j marpol.2020.104254
Uhlenkott, K., Meyn, K., Vink, A., Martínez Arbizu, P., 2023. A review of megafauna diversity and abundance in an exploration area for polymetallic nodules in the eastern part of the Clarion Clipperton Fracture Zone (North East Pacific), and implications for potential future deep-sea mining in this area. Mar. Biodivers. 53, 22. https://doi.org/10.1007/s12526-022-01326-9
van der Grient, J.M.A., Drazen, J.C., 2021. Potential spatial intersection between high-seas fisheries and deep-sea mining in international waters. Mar. Policy 129, 104564. https://doi.org/10.1016/j marpol.2021.104564
Van Dover, C.L., 2014. Impacts of anthropogenic disturbances at deep-sea hydrothermal vent ecosystems: a review. Mar. Environ. Res. 102, 59–72. https://doi.org/10.1016/j.marenvres.2014.03.008
Van Dover, C.L., Arnaud-Haond, S., Gianni, M., Helmreich, S., Huber, J.A., Jaeckel, A.L., Metaxas, A., Pendleton, L.H., Petersen, S., Ramirez-Llodra, E., Steinberg, P.E., Tunnicliffe, V., Yamamoto, H., 2018. Scientific rationale and international obligations for protection of active hydrothermal vent ecosystems from deep-sea mining. Mar. Policy 90, 20–28. https://doi.org/10.1016/j marpol.2018.01.020
Vanreusel, A., Hilario, A., Ribeiro, P.A., Menot, L., Arbizu, P.M., 2016. Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna. Sci. Rep. 6. https://doi.org/10.1038/srep26808
Volz, J.B., Haffert, L., Haeckel, M., Koschinsky, A., Kasten, S., 2020. Impact of small-scale disturbances on geochemical conditions, biogeochemical processes and element fluxes in surface sediments of the eastern Clarion-Clipperton Zone, Pacific Ocean. Biogeosciences 17, 1113–1131. https://doi.org/10.5194/bg-17-1113-2020
Vonnahme, T.R., Molari, M., Janssen, F., Wenzhöfer, F., Haeckel, M., Titschack, J., 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
Washburn, T.W., Iguchi, A., Yamaoka, K., Nagao, M., Onishi, Y., Fukuhara, T., Yamamoto, Y., Suzuki, A., 2023a. Impacts of the first deep-sea seafloor massive sulfide mining excavation tests on benthic communities. Mar. Ecol. Prog. Ser. 712, 1–19. https://doi.org/10.3354/meps14287
Washburn, T.W., Simon-Lledó, E., Soong, G.Y., Suzuki, A., 2023b. Seamount mining test provides evidence of ecological impacts beyond deposition. Curr. Biol. 33, 3065-3071.e3. https://doi.org/10.1016/j.cub.2023.06.032
Wear, E.K., Church, M.J., Orcutt, B.N., Shulse, C.N., Lindh, M.V., Smith, C.R., 2021. Bacterial and Archaeal Communities in Polymetallic Nodules, Sediments, and Bottom Waters of the Abyssal Clarion-Clipperton Zone: Emerging Patterns and Future Monitoring Considerations. Front. Mar. Sci. 8.
Weaver, P.P.E., Billett, D., 2019. Environmental Impacts of Nodule, Crust and Sulphide Mining: An Overview, in: Sharma, R. (Ed.), Environmental Issues of Deep-Sea Mining: Impacts, Consequences and Policy Perspectives. Springer International Publishing, Cham, pp. 27–62. https://doi.org/10.1007/978-3-030-12696-4_3
Williams, R., Cox, K.D., Amon, D., Ashe, E., Chapuis, L., Erbe, C., de Vos, A., Nielsen, K.A., Collins, M.S., Smith, C., Washburn, T., Young, K.F., Clark, C.W., 2025. Noise from deep-sea mining in the Clarion-Clipperton Zone, Pacific Ocean will impact a broad range of marine taxa. Mar. Pollut. Bull. 218, 118135. https://doi.org/10.1016/j.marpolbul.2025.118135
Williams, R., Erbe, C., Duncan, A., Nielsen, K., Washburn, T., Smith, C., 2022. Noise from deep-sea mining may span vast ocean areas. Science 377, 157–158. https://doi.org/10.1126/science.abo2804
Yin, Z., Lu, Y., Liu, Y., Zhan, W., Zhang, H., Dou, C., Wu, C., Sun, D., Liu, Z., Wang, C., Wang, Y., 2024. Monitoring discharge from deep-sea mining ships via optical satellite observations. J. Oceanol. Limnol. 42, 1853–1864. https://doi.org/10.1007/s00343-024-3264-0