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Jeffrey C. Drazen

Craig R. Smith

Kristina Gjerde

Steven Haddock

Glenn S. Carter

See next page for additional authors

Authors

Anela Choy

University of California at San Diego

Malcolm R. Clark

New Zealand Institute of Water and Atmospheric Research

Pierre Dutrieux

Columbia University

Erica Goetze

University of Hawaii at Manoa

Chris Hauton

University of Southampton - United Kingdom

Mariko Hatta

University of Hawaii at Manoa

Julian Koslow

University of California - San Diego

Astrid Brigitta Leitner

University of Hawaii at Manoa; Monterey Bay Aquarium Research Institute

Aude Pacini

University of Hawaii at Manoa

Jessica Nicole Perelman

University of Hawaii at Manoa

Thomas Peacock

Massachusetts Institute of Technology

Tracey Sutton

Nova Southeastern University, tsutton1@nova.edu

Les Watling

University of Hawaii at Manoa; University of Maine

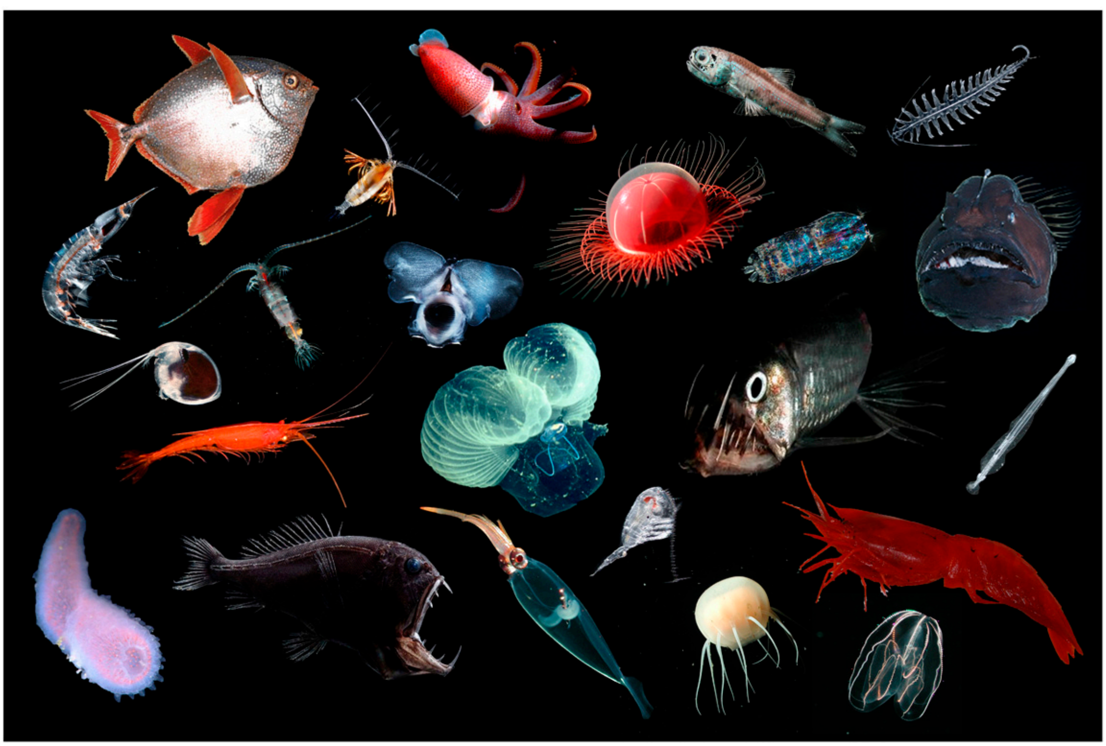
Hiroyuki Yamamoto

Japan Agency for Marine-Earth Science and Technology

Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining

Jeffrey C. Drazen[a,1], Craig R. Smith[a], Kristina M. Gjerde[b,c], Steven H. D. Haddock[d], Glenn S. Carter[a], C. Anela Choy[e], Malcolm R. Clark[f], Pierre Dutrieux[g], Erica Goetze[a], Chris Hauton[h], Mariko Hatta[a], J. Anthony Koslow[e], Astrid B. Leitner[a,d], Aude Pacini[i], Jessica N. Perelman[a], Thomas Peacock[j], Tracey T. Sutton[k], Les Watling[l,m], and Hiroyuki Yamamoto[n]

Despite rapidly growing interest in deep-sea mineral exploitation, environmental research and management have focused on impacts to seafloor environments, paying little attention to pelagic ecosystems. Nonetheless, research indicates that seafloor mining will generate sediment plumes and noise at the seabed and in the water column that may have extensive ecological effects in deep midwaters (1), which can extend from



Midwater animal biodiversity: Squid, fish, shrimp, copepods, medusa, filter-feeding jellies, and marine worms are among the midwater creatures that could be affected by deep sea mining. Photos by E. Goetze, K. Peijnenburg, D. Perrine, Hawaii Seafood Council (B. Takenaka, J. Kaneko), S. Haddock, J. Drazen, B. Robison, DEEPEND (Danté Fenolio), and MBARI.

[a]Department of Oceanography, University of Hawaii at Manoa, Honolulu, HI 96822; [b]International Union for the Conservation of Nature, Cambridge, MA 02139; [c]Deep-Ocean Stewardship Initiative, Cambridge, MA 02139; [d]Monterey Bay Aquarium Research Institute, Moss Landing, CA 95039; [e]Integrative Oceanography Division, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093; [f]National Institute of Water and Atmospheric Research, Wellington 6241, New Zealand; [g]Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964; [h]School of Ocean and Earth Science, National Oceanography Centre, University of Southampton, Southampton SO14 3ZH, United Kingdom; [i]Hawaii Institute of Marine Biology, University of Hawaii at Manoa, Honolulu, HI 96822; [j]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139; [k]Department of Marine and Environmental Sciences, Nova Southeastern University, Dania Beach, FL 33004; [l]Department of Biology, University of Hawaii at Manoa, Honolulu, HI 96822; [m]School of Marine Sciences, University of Maine, Walpole, ME 04573; and [n]Japan Agency for Marine-Earth Science and Technology, Yokosuka, Kanagawa 237-0061, Japan

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[1]To whom correspondence should be addressed. Email: jdrazen@hawaii.edu.

an approximate depth of 200 meters to 5 kilometers. Deep midwater ecosystems represent more than 90% of the biosphere (2), contain fish biomass 100 times greater than the global annual fish catch (3), connect shallow and deep-sea ecosystems, and play key roles in carbon export (4), nutrient regeneration, and provisioning of harvestable fish stocks (5). These ecosystem services, as well as biodiversity, could be negatively affected by mining. Here we argue that deep-sea mining poses significant risks to midwater ecosystems and suggest how these risks could be evaluated more comprehensively to enable environmental resource managers and society at large to decide whether and how deep-sea mining should proceed.

Interest in deep-sea mining for sulfide deposits near hydrothermal vents, polymetallic nodules on the abyssal seafloor, and cobalt-rich crusts on seamounts (6) has grown substantially in the last decade. Equipment and system development are already occurring. The International Seabed Authority (ISA), the international organization created under the United Nations Convention on the Law of the Sea (UNCLOS) to manage deep-sea mining beyond national jurisdiction, is developing mineral exploitation regulations, the Mining Code. Currently, 30 ISA exploration contracts cover over 1.5 million square kilometers. In accordance with UNCLOS, the ISA is required to ensure the effective protection of the marine environment, including deep midwater ecosystems, from harmful effects arising from mining-related activities.

Mining strategies will vary significantly between mineral resource types and perhaps between contractors, but they will involve some combination of seafloor collector vehicle with a vertical transport system to carry the ore and sediments to a surface vessel, shipboard separation of ore-bearing materials (dewatering), and subsequent discharge of sediments and water either back into the water column or at the seabed (ref. 7; Fig. 1). Seafloor vehicles will generate noise near the seabed, particularly from grinding hard sulfides or crusts and through hydraulic pumping and rattling of ore in lift pipes throughout the water column. The vehicles will also resuspend seafloor sediments, creating environmentally detrimental plumes that may disperse for tens to hundreds of kilometers from the mining site (8–11), depending greatly on the nature of the deposit, local currents, and the mining technology used.

Of particular importance for the water column is the discharge of the tailings from dewatering of the ore, which will introduce sediment and dissolved metals over potentially large areas. A single polymetallic-nodule mining operation is estimated to discharge 50,000 meters-cubed of sediment, broken mineral fines, and seawater per day (~8 kilograms per meter-cubed solids) and a hydrothermal vent operation could discharge 22,000 to 38,000 meters-cubed per day (10, 12). These discharges could run continuously for up to 30 years, producing 500,000,000 meters-cubed of discharge over the lifetime of one operation.

Very fine clay sediments could stay in suspension for several years, and along with dissolved metals they could be carried by ocean currents for hundreds of kilometers (11), dispersing far beyond the mining zone in concentrations that are still to be determined. There is currently no regulation or guidance on the depth or manner in which tailings can be discharged into the environment. Given the risk of ecological harm, the need to consider the potential adverse effects from seabed mining to midwater ecosystems and services, and our state of knowledge in evaluating these risks, is critical.

Unique Characteristics

The ocean's midwaters are immense and harbor a vast reservoir of unique biodiversity. The biomass of mesopelagic fishes at depths of 200 to 1,000 meters is estimated to be approximately 10 billion metric tons [i.e., two orders of magnitude higher than the global annual fish catch (3)]. Mesopelagic food webs provision many deep-diving marine mammals and commercially harvested species, including tunas, slope-dwelling bottom fishes, and cephalopods (5). Deep midwaters also strongly connect to life on the rest of the planet. Biogeochemical cycling within deep midwaters connects the surface and benthic realms of the open ocean. Microbes and zooplankton in the mesopelagic zone respire 90% of the organic carbon exported from the surface ocean and provide the vital service of nutrient regeneration (4). Zooplankton and fishes can actively sequester carbon to long-term pools below 1,000 meters through their diel vertical migrations, which can equal approximately 50% of the passive sinking of detritus out of the euphotic zone (13, 14). Despite these critical global ecosystem services, the biodiversity of the ocean's midwaters is still poorly characterized relative to the surface ocean and many areas of the seafloor (15).

Benthic ecosystems have been the focus of impact studies and management discussions about deep-sea mining (16, 17). Deep midwater ecosystems, however, are fundamentally different. Pelagic organisms live in a three-dimensional habitat, and their food webs and populations are connected vertically and horizontally. Detritus from the epipelagic realm sinks through the water column, providing nearly all of the food for organisms in the deeper layers. Many mesopelagic zooplankton and micronekton migrate daily to feed in surface waters at night; this vertical migration helps support high fish biomass on continental and seamount slopes and a host of pelagic predators (5, 18). Another critical difference is that the midwaters are in continuous motion. Individuals and communities routinely are transported or actively travel over hundreds of kilometers. Consequently, biogeographic ecoregions tend to be large (19). Thus, midwater communities (and mining impacts) may mix freely across boundaries, reference areas/zones, and other specially managed areas. Sediment or chemical inputs will travel with currents and associated plankton communities so that flow may extend exposure times beyond that experienced by the benthos. These ecosystem and faunal differences mean that evaluating midwater impacts of seabed mining must include these additional considerations.

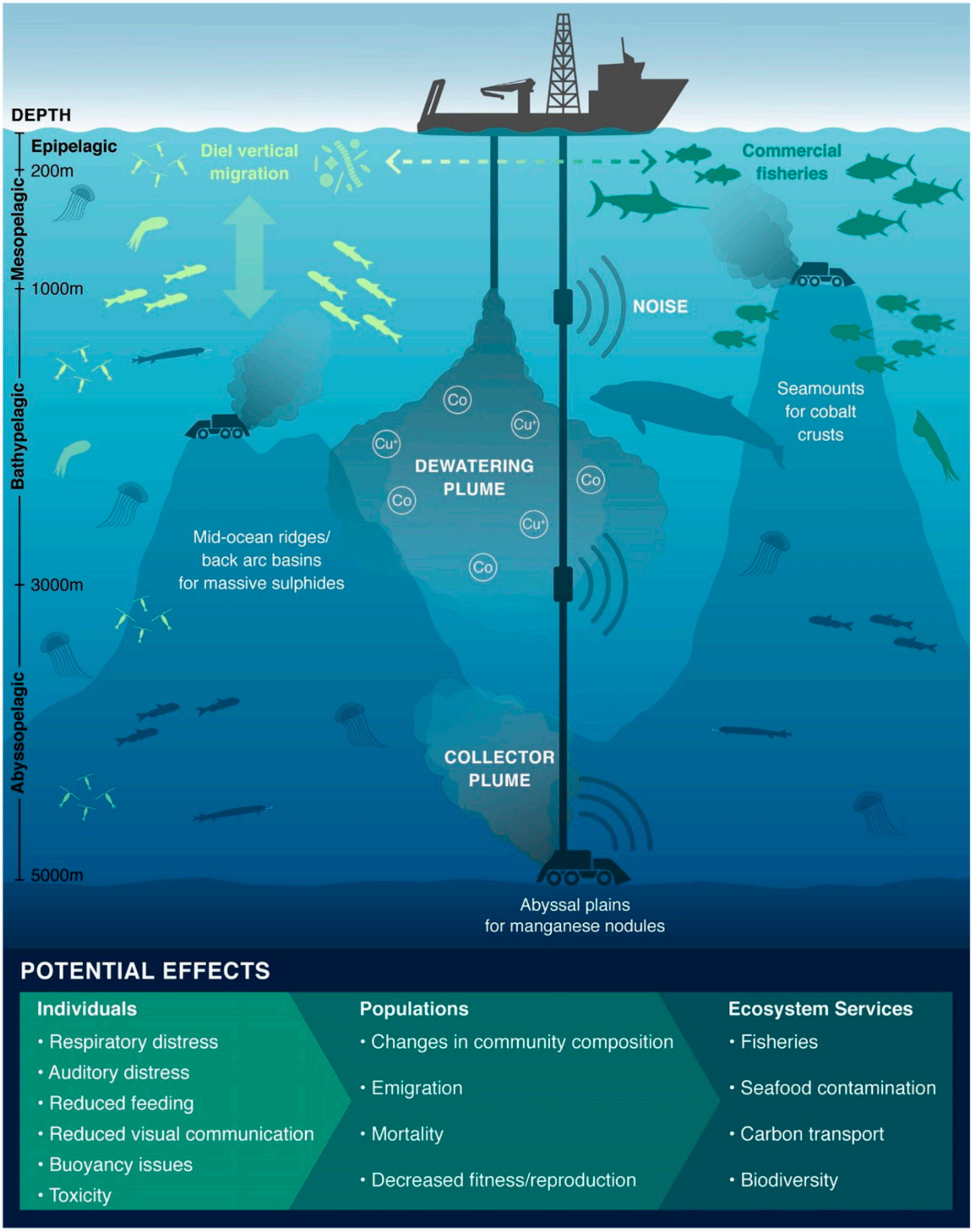

Fig. 1. Mining-generated sediment plumes and noise have a variety of possible effects on pelagic taxa. (Organisms and plume impacts are not to scale.) Image credit: Amanda Dillon (graphic artist).

Specific Potential Effects

Deep-sea mining activities could affect midwater organisms in a number of ways (Figure 1). Sediment plumes from collectors on the seafloor and from midwater discharge that exceed sensitivity thresholds would have a host of negative consequences. Although threshold levels are unknown, sensitivities are likely to be high because most deep midwaters have very low concentrations of naturally suspended sediment even near the seafloor (20). Mining-generated plumes may cause distress by clogging respiratory and olfactory surfaces (21). Abundant suspension feeders, including protists, crustaceans, polychaetes, salps, and appendicularians, filter small particles from the water and form an important part of the pelagic food web (22).

Indeed, studies have shown that the bases of deep mesopelagic and bathypelagic food webs are heavily reliant on very small organic particles as a natural food source (23). Suspension feeders will suffer from dilution of food materials by inorganic sediments and clogging of fragile mucous filter nets (24). Fine sediment may adhere to gelatinous plankton, reducing their buoyancy (2). Metals will be released from pore waters and crushed ore materials (25) and remain in the water column much longer than sediments [potentially 100 to 1,000 years (26)]. The mesopelagic zone is the natural entry point for mercury into oceanic food webs and the human seafood supply (27), raising concerns that discharge of metals and toxins into the mesopelagic zone could contaminate seafood. The structure and function of microbial communities currently regenerating essential nutrients for the pelagic ecosystem may shift as a consequence of enhanced particle surface areas (28).

Deep-sea mining is rapidly approaching. Nonetheless, we lack scientific evidence to understand and manage mining impacts on deep pelagic ecosystems, which constitute most of the biosphere.

Sediment plumes will also absorb light and change backscatter properties, reducing visual communication and bioluminescent signaling that are essential for prey capture and reproduction in midwater animals (29). Noise from mining activities could cause physiological stress or interfere with larval settlement (30), foraging, and communication, such as by marine mammals. This would be particularly important at seamounts, which attract aggregations of feeding marine mammals and fishes (31). Potential effects on individuals would lead to population effects such as emigration (both horizontal and vertical) and changes in community composition, thereby leading to further reductions in ecosystem services.

The nature and extent of these effects must be understood to effectively manage the environmental consequences of seabed mining. They will depend upon the spatial and temporal scales of mining and the mining plumes relative to the spatial scale of biological communities, the depth of discharge of the dewatering plume, and the threshold levels that are determined to cause harmful impacts. The spatial extent of direct mining impacts (i.e., seabed on which a vehicle directly operates) is estimated to be 300 to 600 square kilometers per year per contractor for manganese nodule mining (10) and tens of square kilometers for sulfide and crust mining (32, 33). Collector plume modeling to date suggests that the area of seafloor indirectly impacted would be many times larger; short-term simulations suggest harmful seafloor deposition of sediments at least tens of kilometers from sites of mining (8, 9).

Parallels can be drawn with air pollution generated by terrestrial operations; such effects are not limited to the footprint of the operation itself. Indeed, the concern is greater for the ocean in which suspended particles settle much more slowly in seawater than in air, owing to the much smaller density difference between the particle and the ambient fluid. Modeling studies have focused on seafloor collector plumes and benthic deposition but have generally failed to consider the three-dimensional spread and temporal persistence of plumes in midwaters.

Knowledge Gaps

Consideration of the full scope of ecosystem risks from deep-sea mining requires comprehensive evaluation of impacts on midwater ecosystems. Despite some existing general knowledge, ecological baselines for midwater ecosystems likely to be impacted do not exist. New research to evaluate the oceanography and midwater biota (microbes to fishes) in regions where mining is likely to occur, and to understand their temporal dynamics so that mining effects can be separated from natural variability, is urgent (34). The ISA does include midwater sampling in its baseline study recommendations to contractors (35), but the data collected by contractors to date appear to be very limited. Midwater research should be promoted more generally by international bodies, national funding agencies, contractors, governments, and stakeholders. More specifically, studies should include the entire water column, and particularly the bathypelagic and abyssopelagic zones, from depths of approximately 1,000 meters to just above the seafloor, where both seafloor collector plumes and dewatering plumes may co-occur (15).

The pelagic realm is large and broadly distributed, extending far beyond the scale of single contractors' license areas. A cooperative and/or consolidated regional research approach is needed to provide the relevant information on ecosystem structure and function. Furthermore, suitable standards, thresholds, and indicators of harmful environmental effects should be crafted for pelagic ecosystems. In particular, ecologically important suspension feeders are likely to be highly sensitive to sediment plumes and could be important indicator species (i.e., "canaries in the coal mine"). We need to increase our knowledge of metal leaching from ores (25) and evaluate the best approaches to monitor the spatial and temporal extent of dissolved plumes. In addition, although some midwater modeling efforts have begun (36), much more modeling and empirical study of dewatering plumes are needed to assess the spatial and temporal extent of plumes resulting from different technologies and mining scenarios. Some key inputs to these models, such as physical oceanographic and sediment parameters in mining regions, are lacking and should be acquired empirically.

Although models are important, to fully appreciate the nature and extent of midwater effects mining tests would need to be conducted and monitored carefully. In addition to monitoring benthic sediment settlement and seafloor ecology, research associated with the discharge of dewatering fluids is needed. Well-funded observational studies of water column perturbations, particularly of dewatering plumes, and of the ecological responses should be included in future system components or test mining activities. They could represent unique partnerships between industry and scientific communities.

Management Considerations

Management of the deep midwaters requires a broadening of the ecosystems considered as well as more specific actions to evaluate environmental risks. Pelagic ecosystem studies need to be an important component of environmental baseline studies and monitoring efforts to ensure that the risks from collector and midwater dewatering plumes are fully evaluated (1). Pelagic ecosystems should be an integral part of environmental impact assessment and environmental monitoring plans that are region- and resource-specific. Potential broad-scale impacts on pelagic ecosystems should be considered in deliberations about the choice of stations for environmental baselines, monitoring studies, environmental quality objectives, indicators and thresholds, environmental management plans, and other area-based management measures, such as no-mining zones. More specifically, minimizing mining effects in the epipelagic (0 to 200 meters) and mesopelagic (200 to 1,000 meters) zones is essential because of links to the human seafood supply and other ecosystem services. This minimization could be accomplished, for example, by delivering dewatering discharge well below the mesopelagic/bathypelagic transition (i.e., below a depth of 1,500 to 2,000 meters) or by requiring discharge to be delivered to the seafloor where a sediment plume will already exist from seafloor activities. The option with the least impact is yet to be determined and will likely be region- and resource-specific. This recommendation should be incorporated now into the developing mining regulations, while contractors develop their technologies. Noise from ore grinding at seamounts and hydrothermal vents, which could affect deep diving marine mammals and other species, is another potential stressor that would need to be mitigated. One way to reduce the footprint of sound impacts could be to strictly limit activities in the sound-fixing-and-ranging (SOFAR) channel (typically at depths of 700 to 1,300 meters), which transmits sounds over thousands of kilometers.

Deep-sea mining is rapidly approaching. Nonetheless, we lack scientific evidence to understand and manage mining impacts on deep pelagic ecosystems, which constitute most of the biosphere. Understanding the biodiversity and dynamics of midwater ecosystems and their value to ecosystem services is an imperative for the scientific community, contractors, managers, and the full suite of stakeholders. To minimize environmental harm, mining impacts on the deep-water column must be considered in research plans and technological development. Expanded and focused midwater research efforts, and adopting precautionary management measures now, are needed to avoid harm to deep midwater ecosystems from seabed mining.

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