

Deep-seabed mining needs evidence-based decisions

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EVIDENCE BEFORE COMMERCIAL DECISIONS

Jaeckel's recent Science Editorial argues that seabed mining needs "integrity, not haste" and rightly emphasizes the risks of unilateral action, incomplete regulation, and premature commercial exploitation.¹ In a subsequent Science Letter, Rühlemann argues that prolonged regulatory paralysis poses risks of its own to the authority of the ISA and maintains that regulatory integrity and timely governance are not mutually exclusive.² In a later online response, Rühlemann further argues that timely governance can strengthen, rather than weaken, multilateralism. Jaeckel's subsequent online response, in turn, reiterates the importance of regulatory integrity and sufficient scientific evidence before decisions on Commercial Production are made. We agree that robust environmental safeguards, enforceable rules, and multilateral governance are essential, and that any future decisions on deep-seabed mining must be grounded in a credible and effective governance framework. However, we would add that the immediate challenge is not simply how quickly the exploitation regulations should be adopted or whether Commercial Production should proceed, but how to establish an evidence-based process through which scientific and technical findings can progressively reduce uncertainty and inform regulatory decisions. Environmental uncertainty calls not only for careful investigation and strong safeguards, but also for a practical means of reducing that uncertainty. Such a process must connect evidence generation with regulatory learning, enabling new findings to progressively inform and refine governance mechanisms. Without evidence generated through observation, experimentation, and testing, environmental thresholds cannot be robustly validated, technological performance cannot be adequately assessed under realistic conditions, and regulators cannot determine whether particular resources, sites, or mining approaches could satisfy acceptable environmental requirements.

Recent syntheses of empirical research further show that the magnitude, persistence, and reversibility of environmental impacts vary substantially across mineral resources and ecological settings, while major knowledge gaps remain regarding long-term ecosystem responses. Deep-seabed mining should therefore be assessed on a resource-, site-, and technology-specific basis rather than treated as a single, uniform activity. Polymetallic nodules, cobalt-rich crusts, seafloor massive sulfides, and rare-earth-rich sediments occur in different geological and ecological settings and require different extraction technologies. Their environmental effects, exposed habitats, recovery potential, and opportunities for mitigation may consequently differ substantially. The same is true of mining technologies: collector-seabed interaction, penetration depth, sediment handling, discharge strategy, route planning, and monitoring capability can all influence the magnitude and extent of disturbance. A universal judgement on "deep-seabed mining" therefore risks obscuring the differences that regulation actually needs to resolve. This need for differentiated assessment is reflected in the ISA's current legal position. The ISA currently has no general mining ban that would automatically reject applications for a Plan of Work for Exploitation. At the same time, ISA Council decisions ISBA/28/C/9, ISBA/28/C/24, and ISBA/28/C/25 confirm that commercial exploitation should not commence in the Area before the exploitation regulations are adopted. The relevant regulatory question is therefore whether a particular combination of specific resources, technologies, and sites can meet defined environmental and technical conditions.

Such evaluation must also consider realistic alternatives. Excluding seabed resources does not eliminate demand for primary minerals; it changes where and how that demand is supplied. Recycling, substitution, and demand reduction are indispensable, but they do not remove the need to assess the environmental consequences of remaining primary supply. Terrestrial mining can impose substantial pressures on habitats, freshwater, carbon stocks, and communities, and recent modelling of nickel supply indicates increasing overlap between future production and high-priority terrestrial and coastal conservation areas.³ This does not establish that deep-seabed mining is environmentally preferable. Rather, it means that responsible mineral policy

requires comparison across the full supply system—terrestrial mining, recycling, substitution, demand reduction, and seabed resources—rather than judging one option as though its alternatives were impact-free.

FIELD EVIDENCE MUST BE GENERATED

Models, laboratory experiments, and baseline surveys are essential, but they cannot reproduce the full interaction among mining systems, sediments, ocean circulation, and ecosystems under deep-sea operating conditions. Field evidence is therefore indispensable. Existing studies illustrate why. Decades after an early collector test, directly disturbed nodule areas remained physically and biologically altered, whereas detectable residual sedimentation effects in surrounding plume-affected areas were much more limited.⁴ Field observations have also shown that plume behaviour and impact extent depend strongly on sediment loading, turbulence, discharge conditions, and the environmental thresholds used for assessment.⁵ These findings do not establish whether mining impacts are acceptable or unacceptable; they show that different impact pathways must be quantified and distinguished under realistic conditions.

Evidence generation should therefore progress through increasingly realistic and carefully controlled field testing. Small-scale scientific disturbance experiments can identify ecological responses, recovery processes, and environmental thresholds, while Test Mining can evaluate collector-seabed interaction, sediment handling, plume control, operational reliability, and monitoring performance. Yet these stages alone cannot resolve all uncertainties associated with integrated mining systems operating at realistic scales. Where key uncertainties remain after these stages, carefully controlled Pilot Mining may provide an additional stage of evidence generation, because cumulative seabed disturbance, sustained plume generation, system-level equipment performance, operational interactions, and the effectiveness of environmental controls may require evaluation at or near realistic operating scales.

Pilot Mining is not equivalent to Commercial Production. In the current ISA draft framework, Pilot Mining refers to the in situ operation of an integrated mining system under defined technical, spatial, and temporal conditions to generate evidence on environmental effects, commercial capacity, and the feasibility of future Commercial Production. Its purpose is to determine, before Commercial Production begins, whether environmental and technical requirements can actually be met under realistic operating conditions. Such Pilot Mining should be spatially and temporally constrained, independently supervised, subject to predefined environmental thresholds and stop rules, and accompanied by transparent data reporting and long-term monitoring. Technology should also not be treated as a fixed source of environmental impact. New mining concepts and operational modes may fundamentally change how the seabed is disturbed, how sediments are collected and managed, and how environmental pressures are generated. Improved collector design, reduced sediment entrainment, controlled discharge, and adaptive operating strategies may substantially reduce impacts, but their effectiveness must be demonstrated through field evidence rather than assumed.

Together, these stages form a progressive evidence pathway in which evidence is generated at increasingly realistic scales and independently evaluated before any decision on Commercial Production is considered (Figure 1).

FROM EVIDENCE TO DECISION

The purpose of this evidence pathway is not to predetermine Commercial Production, but to make any future decision scientifically and regulatorily defensible. Scientific studies, Test Mining, and Pilot Mining should address different uncertainties and generate evidence at progressively more realistic scales. Their results should be evaluated against predefined environmental thresholds, technical performance criteria, and monitoring requirements. Where these requirements are not met, technologies should be modified, additional evidence generated, or the proposed activity rejected. Only where they are met should progression to Commercial Production be considered.

The ISA should continue advancing the exploitation regulations, not to

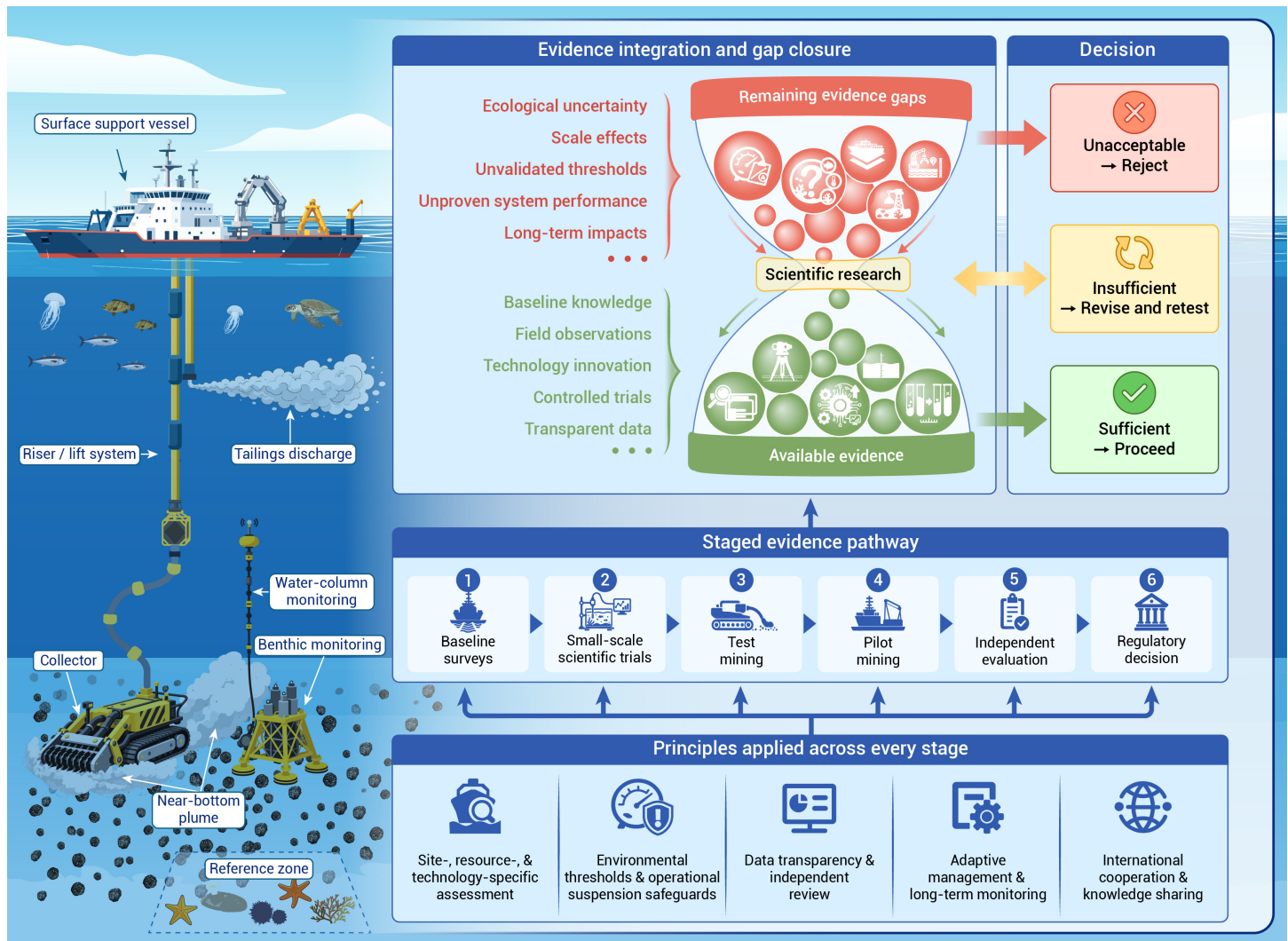


Figure 1. An evidence-based pathway from scientific research and staged field testing to independent evaluation and future regulatory decisions on deep-seabed mining.

predetermine Commercial Production, but to establish a robust, operational, and phased regulatory framework that guides evidence generation at each stage and supports future decision-making. The regulations should clearly distinguish scientific research, Test Mining, Pilot Mining, and Commercial Production, and define the environmental thresholds, monitoring and reporting requirements, data-transparency standards, independent review, liability provisions, and stop rules applicable to each stage. Clear rules are needed not only to regulate any future development, but also to enable the controlled activities required to generate the evidence on which such decisions will depend. Commercial Production should therefore be an outcome of an evidence-based process, not its starting assumption.

This approach also reinforces multilateral governance. The Area and its resources are the common heritage of humankind, and decisions concerning their development should remain within the ISA framework rather than being displaced by unilateral authorization. The immediate task is therefore not to debate whether Commercial Production should be accelerated or delayed, but to use evidence effectively to establish the scientific, technological, environmental, and regulatory basis needed to determine whether, where, and under what conditions Commercial Production should proceed.

CONCLUSION AND OUTLOOK

The debate over deep-seabed mining should move beyond a binary choice between accelerating Commercial Production and halting progress. Scientific research, Test Mining, Pilot Mining, and Commercial Production represent fundamentally different stages, with environmental monitoring and independent evaluation required throughout. Scientific uncertainty warrants precaution, but it also highlights the need for carefully designed research and controlled engineering trials to generate the evidence required to reduce that uncertainty and progressively improve governance mechanisms. Moving forward, both regulatory development and specific decisions should therefore be based on transparent, reproducible, and progressively accumulated evidence, with clear environmental thresholds and independent evaluation at each stage. Such an evidence-to-decision pathway can reconcile precaution

with scientific progress and provide a more robust basis for determining whether, when, and under what conditions future Commercial Production should proceed. From a broader perspective, this approach may also provide a practical research-to-extraction paradigm for guiding decisions on other controversial critical mineral resources.

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DECLARATION OF INTERESTS

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