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Metal mining on land versus the ocean in the context of the current Biodiversity Crisis

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As climate change and biodiversity loss intensify, the deep seabed beckons as a source of metals for batteries. Initiating this new exploitation conflicts with international agreements to decelerate biodiversity loss through wider protections of ecosystem integrity. The poor record of terrestrial mining must not be an excuse to mine the ocean floor. Improved oversight and biodiversity protection as miners increase production on land will produce a better global biodiversity outcome.

In 2022, Parties to the Convention on Biological Diversity (CBD) adopted a Framework to reverse biodiversity declines by 2030. Meanwhile, international negotiations on the climate crisis have activated a transition to technologies that aim, *inter alia*, to electrify vehicles with batteries currently fueled by nickel and cobalt. Some projections anticipate shortfalls of these metals within 10–15 years[1], thereby stimulating initiatives to mine untapped metal resources, including polymetallic nodules in the deep sea. The past Secretary General of the International Seabed Authority (ISA) opined that seabed mining "offers a more commercially and environmentally sustainable source of raw material supply [compared with terrestrial mining] far into the future"[2]; one seabed contractor uses this position to solicit shareholders[3].

An extensive global assessment of nickel mines (for 2018)[4] shows that, despite missing data for many mines, land-based reserves and resources are sufficient to meet demand for >100 years at 2018 mining rates. Challenges include mine development times, environmental issues, and market economics, but the nickel industry has demonstrably surmounted them for more than a century[4,5]. Six countries hold 80% of global terrestrial nickel reserves, providing a diversity of supply, of which two countries with high biodiversity ecosystems have about 36% of both nickel reserves and resources[4]. However, ecological degradation and habitat loss will accelerate if terrestrial mining expands without improvements in regulatory oversight and biodiversity protection laws[6].

Most cobalt is sourced from the Democratic Republic of Congo (DRC), where production from high-grade copper-cobalt mines is often mired in foreign control, dismal social conditions, and environmental losses[7]. A key development will be the improvement of responsible and sustainable supply in DRC[8,9]. While a 10-year cobalt supply deficit is likely, recycling can alleviate demand[7] and alternative battery types are already in production[10]. While other terrestrial sources expand, cobalt supply will remain tied to copper and nickel mining from which most cobalt is produced as a by-product[8].

Currently, ISA Member States are discussing mining vast tracts of the abyssal plains for nickel and cobalt in polymetallic nodules that form over millennia on certain areas of the seabed. The UN Convention on the Law of the Sea (UNCLOS) established the ISA as an enabler and regulator for seabed mining in international waters. Under strong pressure from some States to initiate mining, the ISA is nearing completion of exploitation regulations. The developing package of rules, regulations, and standards (the Mining Code) currently lacks science-based assessments of environmental thresholds and indicators of harm, including adequate means to detect damage and biodiversity loss[11]. The dearth of knowledge about marine biodiversity and the consequences of marine species and ecosystem function loss is particularly problematic[11]. These components are necessary to assess whether miners can comply with the ISA's overarching obligation to ensure effective protection of the marine environment from harmful effects from mining, as required by UNCLOS (Article 145). There is mounting concern among stakeholders, potential consumers, the public, and the scientific community over the environmental consequences of deep-sea mining[12,13]. (Fig. 1).

The Kunming–Montreal Global Biodiversity Framework aims to protect 30% of the ocean by 2030, and the recent UN High Seas Treaty will facilitate this process[14]. The growing metal demand drives to the heart of long-term sustainability issues: what mechanisms can limit the ecological footprint to prevent escalating biodiversity losses on land? Is it prudent to proceed, once again, with the exploitation of the natural environment without fully understanding its impacts? Are the inevitable costs to biodiversity and ecological functioning that seabed mining would inflict acceptable?

Compounding biodiversity losses with a deep-sea gamble

Opening the ocean frontier will neither halt nor reduce terrestrial mining for nickel and cobalt. Extraction will continue on land, with associated biodiversity loss[15]. Rather than reducing environmental pressures on land, seabed mining would open an additional realm of ecosystem degradation. Likely ecosystem outcomes are well iterated (e.g., ref. 11), but a chronic lack of knowledge of deep-sea biodiversity and ecosystem functions, such as their role in modulating global nutrient and carbon cycles, limits predictions of broader mining impacts[16].

Information is inadequate to compare impacts on ecosystem integrity from land versus seabed mining– the biomes are too disparate[17]. No comprehensive and systematic data exist for the impacts of nickel or cobalt mining, and predictions for seabed mining are poorly constrained estimates[17]. One crude measure is habitat loss: nodule mining will have a spatial impact orders of magnitude greater than all active terrestrial mines combined, including secondary disturbances from the infrastructure and mining activities. The estimated direct habitat loss in nodule extraction is 508,000 km^2 of seafloor for initial contracts[18]. These operations will likely affect adjacent (seafloor and water column) habitats further extending

Fig. 1 | Polymetallic nodules on the seabed in the eastern Pacific. Top: large glass sponge attached to dense loose nodules, 2600 m depth; lasers 10 cm apart. Credit: NOAA Ocean Exploration. Bottom: sponge and anemone on scattered nodule substratum, about 4000 m depth. Credit: NERC SMARTEX Project. Image provided by Natural History Museum and National Oceanography Centre.

ecosystem damage[19]. In contrast, the total current global land area directly affected by ~6000 mines active from 2000 to 2017 is 57,277 km^2, of which nickel and cobalt mines encompass about 3430 km^2 [20]. It is unlikely that environmental outcomes will be better in the large tracts of poorly accessible seabed. Our history of exploitation before understanding the environmental consequences is long and alarmingly duplicative (e.g., fisheries collapse, aquifer drawdown, etc.).

Environmental impact assessment is typically underpinned by the application of the mitigation hierarchy. This principle, supported by reliable data and evidence, can reduce environmental impacts through a tiered approach of avoidance, minimization, restoration, and offsetting – but strict adherence is necessary. Mining is a destructive activity that removes and/or dislocates the substratum underlying the ecosystem. Impacts on biodiversity can be avoided and minimized through careful project design and, where needed, strict no-go zones. Regulators must ensure that miners proceed only after all reasonable options to avoid impacts are exhausted. Attempts to restore complex ecosystems following severe disturbance have low success on land where only a few mines have met international restoration standards[21]. While restoration, and the less ambitious rehabilitation, are difficult, a focus on biodiversity revitalization is critical. Monitoring and biodiversity assessment require several decades following mine closure[22]. The terrestrial mining industry and its regulators must prioritize research demonstrating that recovery goals are achievable and resilient, especially considering the changing climate. Offsetting strategies commonly rely upon the protection of threatened like-for-like habitats and/or upon restoration of degraded land to achieve a condition similar to the disturbed ecosystem. In the latter case, a net biodiversity loss occurs initially until overall benefits and gains are achieved[23]. Moreover, governance mechanisms must ensure those benefits persist once the mine closes or the mining company changes hands. Clear successes of offsets in mining are hard to demonstrate[23,24].

In contrast, the applicability of the mitigation hierarchy to seabed mining is fundamentally compromised. First, data and models are inadequate to support the 'avoid' principle and ensure that mining does not impact sensitive ecosystems. Second, ecological restoration in the deep sea is an impossible goal as unique, ancient substratum and habitat features cannot be replaced. Third, valid offset opportunities do not exist for the deep ocean as "out-of-kind" offsets will not achieve No-Net-Loss[25]. Thus, only minimization remains. A self-reporting system at the ISA is unlikely to achieve environmental management excellence[26]. Given access challenges to mine sites thousands of meters underwater and far out to sea, there will be a strong reliance on self-monitoring by miners. There is no report of developments of full-time monitoring tools capable of communicating in near real-time over such immense seabed areas. When environmental harm is detected, lengthy response times and a dearth of biodiversity-based protocols would limit successful mitigation, even if technologically possible.

Focus efforts on land to improve ecosystem outcomes

Before advancing deep-sea exploitation, much can be learned from past terrestrial mining, especially for reforming mining regimes. Recurrent ecological disasters highlight limited capabilities to model or mitigate the biodiversity impacts of mining on most terrestrial and freshwater ecosystems. A poor record of satisfactory terrestrial mine closures around the world portends the path ahead for the deep sea[27]. If such is the state of our knowledge and practice despite long recognizing the impacts of terrestrial mining, there is little basis to expect better outcomes when mining the remote seabed. The status quo of poor biodiversity outcomes from terrestrial mining cannot continue. However, it also cannot be the justification for seabed mining as a more environmentally "sustainable" source of needed metals. It is a pivotal moment now for miners, regulators and scientists to reflect on past successes and failures to safeguard biodiversity on land. Here, healthier ecosystems can build upon the foundations of terrestrial biodiversity protection and recovery, including better water, waste, and tailings management.

Most terrestrial industry and regulatory agencies have a large gap to close between current practices and actions to reduce biodiversity loss. An obligatory and strong code of practice applied consistently across jurisdictions in land-based producer countries, that features rigorous ecosystem assessment, monitoring, and protection would narrow that gap. Economic returns from metal extraction might diminish, but consumer and investor focus on sustainability can drive the market in favor of better environmental practices. Sustained services from intact ecosystem integrity will benefit humans. Scrupulous and enduring oversight by regulators will minimize biodiversity impact, including avoidance of mining where conservation values are high. A key area for improvement lies in the planning and execution of post-closure activities that mediate ecosystem harm from mining. Initial financial guarantees that reflect true costs for mine and tailings site remediation and rehabilitation are necessary. Impact monitoring and reporting during mining can help the miner mitigate problems before they become costly. Comprehensive closure plans, regularly updated, will also maintain awareness and ongoing solutions. Requirements for long-term monitoring with necessary interventions will ensure better biodiversity outcomes and a better public profile.

It is clear we know what should be done for terrestrial mining. Why it does not happen in practice is less clear. We lack internationally agreed and legally binding standards for the environmental management of mining. Regimes vary greatly among jurisdictions usually featuring voluntary or industry-led guidelines and standards; such protocols are often ineffective with few requirements for monitoring and adaptation, and lack third-party verification. A multilateral focus on the mining sector may bring about harmonized standards with better environmental outcomes. The Initiative for Responsible Mining Assurance (IRMA) Standard provides requirements for both existing and new mines that include guidelines to maintain biodiversity and ecosystem services[28]. Investors, manufacturers, and consumers should urge the industry to join such initiatives with the intent to meet these standards – ultimately, the consumer pays the price for biodiversity declines. Finally, States must take the lead to reform and implement national laws in a way that respects their international commitments to the biodiversity crisis. Relevant action includes strengthening mining laws in producer countries but also encompasses ocean governance and sustainable consumption sectors globally.

A double win is possible: (i) implement a precautionary pause on the commencement of deep seabed mining[29] while increasing research efforts to understand the ecosystem costs and (ii) improve mining practices and regulations that affect the terrestrial environment. We, the global community, cannot afford, in ignorance, to advance activities that damage ecosystems of the deep ocean, while continuing to erode land-based counterparts. Solutions to address nickel and cobalt supply include increased efficiency and sustainability in metal extraction from mines, re-mining of tailings, novel technologies in battery chemistry, and expanded recycling and urban mining. Improved public transport and consumer awareness of (or surcharge on) the costs to biodiversity can reduce electric vehicle demand. Ultimately, policy must involve a careful accounting of the full costs to the planet, its biodiversity, and its people when enabling mine development. The history of terrestrial mining sets a very low bar for environmental outcomes; it is little wonder that proponents of seabed mining use it as a measure for claims that they can do better. Yet, this new, complex form of mining is bound to follow a similar, if not worse, path toward poor environmental outcomes.

Data availability
No datasets were generated or analyzed during the current study.

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Competing interests
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