Ethical opportunities in deep-sea collection of polymetallic nodules from the Clarion-Clipperton Zone

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EDITOR’S NOTE:

This article is part of the special series entitled: “Implications of Deep-sea Mining on Marine Ecosystems.” The series comprises the current state of the science regarding deep-sea ocean ecosystems and the likely ecological footprints, risks, and consequences of deep-sea mining. There is a focus on: impact assessment, policy solutions, and practices to aid in the implementation of industry guidance prepared by the International Seabed Authority and other authorities, new monitoring and assessment methods, best management practices, and emerging scientific research related to deep-sea ecosystems.

Abstract

Infrastructure supporting the transition of human societies from fossil fuels to renewable energy will require hundreds of millions of tons of metals. Polymetallic nodules on the abyssal seabed of the Clarion-Clipperton Zone (CCZ), eastern North Pacific Ocean, could provide them. We focus on ethical considerations and opportunities available to the novel CCZ nodule-collection industry, integrating robust science with strong pillars of social and environmental responsibility. Ethical considerations include harm to sea life and recovery time, but also the value of human life, indigenous rights, rights of nature, animal rights, intrinsic values, and intangible ecosystem services. A “planetary perspective” considers the biosphere, hydrosphere, and atmosphere, extends beyond mineral extraction to a life-cycle view of impacts, and includes local, national, and global impacts and stakeholders. Stakeholders include direct nodule-collection actors, ocean conservationists, companies, communities, interest groups, nations, and citizens globally, plus counterfactual stakeholders involved with or affected by intensification of terrestrial mining if ocean metals are not used. Nodule collection would harm species and portions of ecosystems, but could have lower life-cycle impacts than terrestrial mining expansion, especially if nodule-metal producers explicitly design for it and stakeholders hold them accountable. Participants across the value chain can elevate the role of ethics in strategic objective setting, engineering design optimization, commitments to stakeholders, democratization of governance, and fostering of circular economies. The International Seabed Authority is called to establish equitable and transparent distribution of royalties and gains, and continue engaging scientists, economists, and experts from all spheres in optimizing deep-sea mineral extraction for humans and nature. Nodule collection presents a unique opportunity for an ambitious reset of ecological norms in a nascent industry. Embracing ethical opportunities can set an example for industrial-scale activities on land and sea, accelerate environmental gains through environmental competition with land ores, and hasten civilization’s progress toward a sustainable future. Integr Environ Assess Manag 2022;18:634–654. © 2021 The Authors. Integrated Environmental Assessment and Management published by Wiley Periodicals LLC on behalf of Society of Environmental Toxicology & Chemistry (SETAC).

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INTRODUCTION

The deep sea is a potential source of critical metals soon to be needed in massive quantities to build renewably powered economies as one tactic to fight climate change (World Bank, 2020a). In this paper, we delve into the ethical issues and opportunities of using deep-sea metals—specifically, polymetallic nodules in the Clarion-Clipperton Zone (CCZ) of the eastern North Pacific Ocean.
The 2011 commodity boom brought a renewed interest in metals from the deep sea so that, by 2017, the International Seabed Authority (ISA; a 168-member international body responsible for both the regulation and protection of the seabed) had circulated working-draft documents toward a mining code to govern commercial access to CCZ metals (Ardron et al., 2018). The ISA Council’s plans to finalize and adopt regulations by 2020 were delayed by COVID-19 (Shukman, 2021), and recent press has highlighted drawbacks and uncertainties related to accessing these metals. The question of whether to disturb the abyssal seabed for these metals requires inputs from physics, biology, economics, law, and other disciplines—among those, ethics. Although accessing the metals would necessarily entail harming sea life, it could also help accelerate the green transition and marginally offset some terrestrial mining’s harming sea life, it could also help accelerate the green transition and marginally offset some terrestrial mining’s damaging effects (Koschinsky et al., 2018). Challenging ethical discussions are therefore provoked—including trade-offs between the rights of different groups or geographies of species, utilitarian concerns for a society facing multiple global crises with confluence of species, utilitarian concerns in the face of uncertainty. If or when the regulations pass, supply-chain participants will furthermore face numerous decisions with potential ethical consequences—or ethical opportunities—for those wishing to take advantage.

**Ethical and moral frameworks**

There is no single definition of ethics, and it is often used interchangeably with morals (e.g., Gardiner, 2011). We use morals as the sense of right and wrong that individuals develop in the context of values and behaviors shared within their culture(s) (Jia & Krettenauer, 2017; Saucier, 2018) and ethics to indicate how such moral values are expressed in decisions and actions. Morals vary among cultures, religions, sects, classes, and so forth, so no single ethical framework is available to guide all people in all situations. Moreover, individuals typically apply ethical principles using several approaches: the Utilitarian (Consequentialist) Approach favors actions resulting in the most good for anyone directly or indirectly affected; the Rights Approach seeks to protect the moral rights of others; the Fairness (Justice) Approach emphasizes equal treatment for equals; the Duty Approach aligns actions with a perceived sense of duty to a god, leader, employer, or social group; the Common Good Approach aims to enhance connected life in community, including respect, compassion, and relationships; and the Virtue Approach mirrors actions of a fully virtuous person developing their own humanity and character to the highest level (Bonde & Firenze, 2013; Markkula Center, 2015). These diverse ethical mindsets and approaches play important roles in how different actors view right and wrong in a given situation, and they complicate the development of a shared ethic.

Morals and ethics also evolve with changing knowledge and circumstances. Perceptions of the relationship between humans and nature are shifting from “dominion” to “stewardship”; from “outside of nature” to “part of nature”; and from “local” to “global” as human activities expand to globally impactful scales. Utilitarian ethical approaches to produce “the greatest good for the greatest number” or “maximize the amount of happiness” (Shermer, 2018) were traditionally anthropocentric (and culture-centric), but now nonhuman actors play increasingly larger roles. Environmental ethics (Palmer et al., 2014), rights of nature and nonhuman entities (e.g., rivers, forests; Borras, 2016; Stilt, 2021; Stone, 2010; see also Kurki, 2021), species rights (e.g., Soulé, 1985, “Species have value in themselves, a value neither conferred nor revocable but springing from a species’ long evolutionary heritage and potential”), and “personhood” for nonhuman species (e.g., Staker, 2017) have entered social consciousness. The precept, “Above All, Do No Harm,” Hippocrates’ ~480 BCE guidance for the physicians–patient relationship, now extends to human interactions with the living and nonliving environment (e.g., Niner, 2018; Van Dover et al., 2017).

A planetary perspective for an ethical dilemma

In a world confronting ominous global change (e.g., IPCC, 2021) and sensitive to historical failures to anticipate harmful consequences of industrial innovations (pesticides: Carson, 1962; plastics: Stubbins et al., 2021; ozone-depleting halocarbons: Miller, Zaelke, et al., 2021), the public’s trust in science, politicians, and government has decreased (Bergeron, 2021; Pew Research Center, 2021). These factors, along with insufficient scientific knowledge of the deep sea (Weaver & Billett, 2019), have fostered resistance to deep-sea mining as a whole, with some calling for a temporary or permanent moratorium (Fauna and Flora International [FFI], 2020; Greenpeace International, 2019; World Wildlife Fund [WWF] [Reuters, 2021]; Deep-Sea Mining Science Statement, 2021; International Union for the Conservation of Nature [IUCN], 2021).

Pausing to learn more about the consequences of nodule collection may initially seem ideal. We know that using nodule metals would harm sea life (Levin et al., 2020; Weaver & Billett, 2019), kill nodule organisms, disrupt food web integrity, and reduce biodiversity (Stratmann et al., 2021), disrupt sediment structure (Gausepohl et al., 2020), disrupt microbial communities (Vonnahme et al., 2020) and benthic fauna (Simon-Lledó et al., 2019), create sediment plumes that would affect water-column fauna (Christiansen et al., 2020; Drazen et al., 2019, 2020; Robison, 2009), and potentially affect ecosystem services (Armstrong et al., 2012; Le et al., 2017; Thurber et al., 2014); and much is still unknown about the extent of likely impacts or the best ways to mitigate them. However, realistic constraints add complication. Contracting firms and their investors support a large portion of deep-sea research (Shabahat, 2021). A long and uncertain pause before industrial commencement poses the risk that the needed research might not be done, or that the industry might never commence (Minerals in Depth, 2021). The increased regulatory uncertainty may simultaneously affect the investment environment, as it is unclear precisely how much knowledge...
or time would satisfactorily create the social license to commence. Equally important are the ecological, social, and economic consequences if nodule collection does not occur (the “counterfactual” option). A sharp increase in the demand for metal to build a global green energy infrastructure is expected (International Energy Agency (IEA), 2021; Habib et al., 2020; World Bank, 2017, 2020a). Terrestrial mining project pipelines respond to the expected demand for metal with technological innovations, investment, and/or price levels adjusting so that enough projects enter the pipeline; absent deep-sea metals, terrestrial mining pipelines would likely expand to meet demand (Koschinsky et al., 2018; World Resources Institute, 2003). This would intensify known impacts from land mining: pollution of air, water, and soil (Agboola et al., 2020; Sergeant & Olden, 2020); degradation of habitats including rainforests and harm to biodiversity (Sonter et al., 2018); increased human morbidity and mortality (Cornwall, 2020; Lyu et al., 2019; Mucha et al., 2018; Nkulu et al., 2018); disruption of indigenous cultures and societies (Bainton, 2020; Tovonen et al., 2018) and harm to their traditionally used sacred sites, habitats, and biota (Aborigen Forum, 2020; BBC, 2013; Cultural Survival, 2018; FIDH-KontraS, 2014).

Thus, ethical discussions of nodule collection necessarily include comprehensive analysis of the consequences of not commencing, with comparison of two potential futures. Instead, reports opposing deep-sea mining (e.g., Chin & Hari, 2020; FFI, 2020; Greenpeace International, 2019) and calls for a moratorium (e.g., Deep-Sea Mining Science Statement, 2021, signed by 571 marine science and policy experts from more than 44 countries, and IUCN, 2021) have not included such counterfactual analysis. Meanwhile, the ISA and actors in the nodule-metal supply chain, including contractors, design engineers, and others, focus mainly on the ISA’s (2019) scientific requirements for assessing environmental impacts and the economic dimensions of mining. There is occasional mention of broader principles, but many further opportunities exist to expand the ethical dimensions of their activities.

Therefore, we suggest that a broad discussion of ethical considerations could help establish a path forward that meets the physical and intangible needs of humans, while equally representing the interests of nature and its systems of support. Taken from a comprehensive and global systems standpoint, we refer to such a framework as a “planetary perspective” (Figure 1). This spans ecosystems, species, stakeholders, and geographies, and provokes consideration of metal sources’ roles in major global concerns—climate change, the biodiversity crisis, water supply, equity, and so forth. The planetary perspective underpins the discussion in this paper.

We are not the first to consider the role of ethics in preserving and restoring the ocean’s health. Auster et al. (2008) recognized two main perspectives for marine conservation: Utilitarian, concerned with valuing and maintaining the ocean’s ability to produce ecological goods for extraction and other ecosystem services, and Ethical, concerned with conserving organisms and ecosystems for their own sake simply because they exist. As framed, both are ethical, the former emphasizing sustainable production, the latter rights of nature. Thatje (2021), who also called for a moratorium on deep-sea mining, advocated ethical reasoning to mitigate differences between the scientific knowledge-based approach, resulting ecosystem management challenges, and economic demand, and to inform the decision-making process on deep-sea mining and its regulations, but did not provide details. As Hallgren and Hansson (2021) stated, if debate is only about whether to permit deep-sea mining to proceed or not, the opportunity to set the best possible mining practices from the start and the wider scientific and societal debates concerning moral implications, equity, and risk trade-offs are at risk of being overlooked.

This paper adds to the ethical discussion by (1) providing planetary context relevant to ethical questions about deep-sea mining, (2) summarizing potential inherent ethical advantages of CCZ nodules, (3) outlining key ethical objections to their use, and (4) highlighting practical opportunities for ethical action in operating the industry.

BUILDING AN ETHICAL CONTEXT FOR PRODUCING METALS FROM NODULES

Decisions governing the polymetallic nodule resource involve a diverse constellation of stakeholders with varying interests. First and foremost, the ISA, established under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 UN Implementation Agreement (1994 Agreement) and comprising 167 states plus the European Union, oversees ocean resources in areas beyond national jurisdiction (ABNJ, also known as the Area), or 54% of the world’s ocean. It is assisted by a 30-member Legal and Technical Committee that approves work plans and proposes technical and environmental regulations to a Council; and by the Council, consisting of 36 member states including major consumers, investors, and exporters with an aim of equitable representation of developmental status and geography. The ISA’s most immediate task is to establish environmental and economic policies governing exploitation of CCZ polymetallic nodules; it has already granted 18 exploration contracts and set protocols for required environmental impact assessments. Other stakeholders in the regulation of polymetallic nodule exploitation include mining contractors, metal supply-chain participants, scientists, and nongovernmental advocates for marine or terrestrial conservation. The full set of stakeholders with a vested interest in CCZ nodules (and the decisions of whether and how to collect and process them) is quite extensive (Figure 2). It must include counterfactual stakeholders who participate, benefit from, or are affected by terrestrial mining today; local and global communities affected by externalities of nodule collection or terrestrial mining, such as local tailings dam collapses, and global climate change; and consumers of metal products. Thus, most world citizens will be affected to varying degrees by whether CCZ nodules are exploited.
Integrating the various moral and ethical perspectives of these stakeholders into a single shared ethic is not simple. But although individual stakeholders may prioritize localized concerns relevant to a state or special interest group, they also generally agree on a shared set of priorities encapsulated by the UN Sustainable Development Goals (SDG; UN, 2015)—and among them, that urgent priorities of climate change, biodiversity loss, rainforest preservation, and water scarcity be strongly considered. Indeed, there is global agreement that humanity must find a sustainable path forward for human development that conserves living and nonliving resources, preserves ecosystem services, strengthens human well-being, and protects intergenerational equity (Convention on Biological Diversity [CBD], 2020; UN, 2015).

Historically, miners paid little attention to harm done or remediating damage; for example, approximately 500,000 abandoned hard rock mines exist in the United States with cleanup costs estimated as high as $54 billion (US House of Representatives, 2016). As environmental and social impacts become internalized through economic (EU, 2021; OECD, 1992), reputational (Farha et al., 2017), or other costs, including for mining (e.g., Carvalho, 2017; University of Victoria, 2019), business models and profit equations are evolving. Although financial viability is still foundational for any enterprise, the dominion model of doing business is somewhat shifting toward sustainability and stewardship (Bennett et al., 2018; Heuer, 2010).

Mining of primary metals is not sustainable per se, because the extracted ores are not available for future generations and can only be replaced in geological time. However, the produced metals are durable goods, which can be available for future recycling (i.e., as secondary metals). As societies approach stable, low-growth populations and economic systems, circular metal economies can emerge, reducing or eliminating the need for primary mining and its associated impacts (EU, 2020). Until then, new primary metals are required, and obtaining them in the least harmful way is ethically desirable and practically urgent.

Are deep-sea metals needed?

Some opponents of deep-sea mining argue this point, suggesting there is no need for the new metal source (e.g., FFI 2020, Greenpeace International, 2019; Harris, 2019; LaBossiere, 2018; Miller, Brigden, et al., 2021). Three common suggestions to eliminate the need are reduction in overall metal consumption, development of new battery technologies, and/or increased recycling. All are aspirational
objectives, but they are currently insufficient to meet projected mid-term metal and environmental needs.

The first contention is that perhaps metal consumption can be reduced. However, a substantial rise in metal demand in the next 20 years appears highly likely, driven by global trends and government targets (e.g., Campagnol et al., 2017). In a projected scenario for constraining temperature rise by 2050 to 2°C, base metal demands for electric vehicle (EV) batteries could increase 11-fold beyond today’s levels (Watari et al., 2020; World Bank, 2017); or even more, as Xu et al. (2020) estimated a 17–19 fold increase for cobalt and a 28–31 fold increase for nickel from 2020 to 2050 if lithium nickel-manganese-cobalt (NMC) oxide batteries continue to dominate. Still, Teske et al. (2016) asserted that land-based metal resources are more than adequate to support a transition toward a 100% renewable energy supply, even assuming aggressive growth rates and ambitious energy standards. However, adequate in-the-ground resources do not equate to an economically mineable project pipeline. Multiple factors such as ore grades; the costs of obtaining, transporting, and refining ores; and available extraction and processing technologies determine the extent to which resources in the ground can be economically mined. Based on project pipeline and investment levels compared with expected demand, shortages of cobalt and/or class 1 nickel are expected as soon as 2025 (Azevado et al., 2020; Campagnol et al., 2018; Desai, 2019). Indeed, the Scientific and Technical Committee (STAP) of the Global Environmental Facility has recently added Oceanic Minerals to its agenda for technical critical elements (Ali & Katima, 2020).

The second contention is that battery manufacturers might innovate away from heavy reliance on these critical metals. Indeed, although much of the global EV industry relies on NMC-type batteries, innovations are underway. Whether and how quickly advances in batteries might obviate the need for seabed metals has substantial material significance, but also ethical consequences related to the types and amounts of environmental or social harm that result. Efforts are underway to reduce or eliminate cobalt—largely to reduce corporate exposure to unregulated mining in the Democratic Republic of Congo (DRC) that employs children (Lichner, 2020). For instance, batteries for Ford Motor Company’s 2022 all-electric F-150 pickup truck will reduce cobalt and manganese proportions to 5% each, although increasing nickel content to 90%

| STAKEHOLDER TYPE: GOVERNING AND INTERNATIONAL | SUPPLY CHAIN | INDIVIDUAL, LOCAL, OR SPECIAL INTEREST |
|-----------------------------------------------|--------------|---------------------------------------|

**FIGURE 2 Relevant stakeholders to consider in an ethical discussion of CCZ nodule collection**

| International and State Actors. (Governments and national and international authorities with a vested interest in DSM in ABNJ or lack thereof) |
|---------------------------------------------------------------------------------------------------------------------------------|
| • The International Seabed Authority (ISA) and ISA member states |
| • Countries sponsoring ISA exploration contracts |
| • Coastal countries which may develop new processing plants |
| • Developing countries which may benefit from ISA royalties |
| • Countries currently involved in mining the same minerals on land |
| • Countries with deep-sea mineral deposits within their national jurisdictions |
| • Countries downstream participation in the metal industry |
| • Countries interested in rare earth metals |
| • Public authorities regulating environmental and social issues |

| Companies. (Any companies affected by introduction of nodule metals or lack thereof) |
|---------------------------------------------------------------------------------------------------------------------------------|
| • Companies mining or producing class 1 nickel, cobalt, manganese, copper |
| • Nodule-collection operators and producers |
| • Product manufacturers, e.g., battery cells, manganese alloy products |
| • Supply-chain actors, e.g., material and energy input and service providers, suppliers of machinery, systems, other equipment, transport |

| Interest Groups. (Advocacy groups, NGOs, experts, universities, and groups and coalitions focused on environmental, social, or economic impacts) |
|---------------------------------------------------------------------------------------------------------------------------------|
| • Universities and scientific ecosystem including marine and terrestrial ecologists, industrial ecologists, climate scientists, data-based policy advocates |
| • Ecosystem-preservation groups and conservationists |
| • Climate change advocates |
| • Waste reduction, recycling, circular economy advocates |
| • Child labor, labor standards advocates |
| • Indigenous rights advocates and representatives |
| • Organizations concerned with rights and prosperity of developing nations |

| Communities. (Groups directly or indirectly affected by CCZ nodule collection or expansion of terrestrial mining) |
|---------------------------------------------------------------------------------------------------------------------------------|
| • Residents living in proximity to mines, processing plants, tailings dams |
| • Developing-country communities dependent on mining income |
| • Communities of child and artisanal laborers |
| • Indigenous communities |
| • Supporting ecosystems of metal-production value chain |

| Individuals. (People directly or indirectly affected by CCZ nodule collection or expansion of terrestrial mining) |
|---------------------------------------------------------------------------------------------------------------------------------|
| • Consumers of products containing these metals |
| • Individuals affected by climate change, water use, pollution, etc. |
| • Miners, construction workers, nodule-collection workers, engineers, employees |
ethically.”—Halvorson, 2020). In addition, cobalt- and nickel-free battery formulations are being investigated (Grey & Hall, 2020), with lithium–iron–phosphate (LFP) batteries a viable solution for low-cost, low-range EVs (Ali & Katima, 2020) although with lower energy density and poorer low-temperature performance (Randall, 2020; Rudimsua, 2020). Lithium–iron–phosphate batteries make up 14.3% of the EV battery market as of 2021 (Elis, 2021), with Tesla equipping them in some Model 3 EVs for Chinese markets (Elis, 2021), and China’s BYD, the second-largest EV producer, using LFP for its entire fleet (Mining.com, 2021). Lithium–iron–phosphate batteries may complement NMC for differing product requirements; meanwhile manufacturing lines to build LFP and nickel-based batteries at high volume are under development. Once they are in place, if a more favorable battery chemistry is invented and brought to market, large-scale replacement of NMC batteries would likely require a decadal time scale. Twenty-five years has been a typical investment cycle for major refurbishments (IEA, 2020), and generational improvements in heavy industry have historically taken several decades (Pae & Lehmann, 2003). Supply-chain development, production, and fleet-wide deployment of a new battery technology (or fuel, such as hydrogen) that eliminates the need for node-derived metals might proceed somewhat faster, but it would likely still require a decade or more (Grey & Hall, 2020).

If LFP or other chemistries cannot displace nickel-based batteries, then the third contention remains: Perhaps recycling could eliminate the need for seabed metals. However, recycling cannot meet current battery-metal demand, let alone mid-term future battery-metal demand in a growing market, because there is insufficient metal in circulation or in landfills to be reclaimed (Ali et al., 2017; Ali & Katima, 2020; Herrington, 2021; World Bank, 2020a). As one example, in 2020 recycled material supplied only 37% of the nickel for its major current use, stainless steel production (International Nickel Study Group [INSG], 2021). Moreover, many of today’s EV batteries are constructed in ways that hinder recycling (Morse, 2021), and repurposing used EV batteries for stationary energy storage, although environmentally beneficial, could also slow the rate of recycling (Xu et al., 2020). Because metal economies are global, with numerous consumers and producers and intricate supply chains (e.g., Melin et al., 2021), creating a circular economy is very complex, and doing it quickly would require cooperation at unprecedented speed and scale (Ghisellini et al., 2015).

Because demand reduction, technology innovation, and/or circular economies cannot quickly meet metal demands for the renewable energy transition, primary metals will be extracted in the interim. These marginal metal quantities can come from terrestrial mines and/or the deep sea. In their demand-reduction argument, Teske et al. (2016) did not evaluate the incremental environmental, social, and economic effects of increased terrestrial mining should deep-sea metals not be used. Nickel mining relies increasingly on laterites underlying biodiverse tropical rainforests. Hein et al. (2020) stated that use of deep-ocean metals might help to reduce the pressure for deforestation in ecologically sensitive ecosystems; this is particularly important when forests are needed to fulfill recent climate treaties and UN SDGs. Environmental, social, and economic effects of terrestrial mining are further exacerbated by declining ore grades of copper and nickel, with greater ore required for the same metal output, so a greater life-cycle footprint to produce the same metal (see e.g., dynamic life-cycle analyses by van der Voet et al., 2018). Amid a shrinking time frame to mitigate multiple global crises, considering potential roles and impacts of both terrestrial and deep-sea metals is critical.

**Ethical advantages of polymetallic nodule metals**

We continue our discussion with an exploration of inherent ethical advantages that polymetallic nodules may provide. Subsequently, we discuss their ethical objections.

Direct harm to humans largely avoided. The CCZ’s remote location, hundreds of miles from any human habitation, avoids direct harm to communities often encountered in terrestrial mining. Such avoided impacts include pollution of air or freshwater, drawdown of freshwater resources, impacts on human health, desecration or taking of ancestral lands, and reduction or elimination of large, often toxic, tailings ponds, as nodules’ high ore grades produce less waste and contain lower levels of heavy elements (e.g., Paulikas et al., 2021; Sommerfeld et al., 2018).

Indirect harm to indigenous peoples can be reduced. Sections of UNCLOS may support heightened rights of adjacent coastal states and indigenous peoples if their coastal communities value and depend on highly migratory species culturally, socially, and economically, including for their food security, and when the life histories of such species span entire oceans and encounter threats and pressures beyond the control of any one entity (Dunn 2017). Impacts on food species such as tuna might be largely avoided by discharging riser water below 1000 m (van der Grient & Drazen, 2021), but near-surface impacts typical of ship operations could affect them and nonfood species, including noise (Erbe et al., 2019; Jones, 2019; Weilgart, 2018), lights (Miller et al., 2017), exhaust emissions, wastewater discharge, and the possibility of oil spills. Very slow speeds of the collector machine and production ship (~0.5 kt) strongly reduce the likelihood of striking marine mammals, turtles, or other large animals; although relatively slow speeds (<15 kt) are expected for ore transport ships, even lower speeds might be preferable depending on season, location, and known presence of such animals (e.g., Rockwood et al., 2017).

Indigenous peoples are guaranteed opportunities for input to ABNJ resource issues, both as humans (Hunter et al., 2018) and because their traditional knowledge can broaden the diversity of perspectives and solutions for ABNJ resource governance (Dunn et al., 2017; see also Tilot et al., 2021). Additionally, the UN Declaration on the Rights
of Indigenous Peoples (UN, 2007) codifies the standard for states to obtain “free, prior and informed consent” from indigenous peoples before initiating or approving projects with potential harmful impacts on their traditional lands, territories, and resources, although notably, it does not provide a right for groups’ direct consultation with the ISA, other than through the state.

Child labor avoided. Employment of children below the legal working ages of 15 years or 18 years (International Labour Organization [ILO], 1973) is a major problem globally, particularly in Africa and Asia. UNESCO reported that, in 2012, approximately 40,000 children aged 7–17 worked in cobalt mines in the Katanga region of DRC, making up approximately one-third of the total number of workers (Walther, 2012) and exposing them to numerous hazards and potential health consequences (Broom, 2019; ILO, 2019; O’Driscoll, 2017). Cobalt from deep-sea nodules will not solve the global problem of child labor, but it can avoid that abuse, because there is no place for children to work in the deep-sea mining supply chain.

Reduced opportunities for armed conflict. Resources and commodities with inelastic demand curves, including battery metals, have played important roles in shaping territorial war incentives (Acemoglu et al., 2012; Chin & Hari, 2020). National interests may differ, for example, on whether to permit exploitation or on the details of royalty sharing, and sediment plumes from mining in one country’s contract area could drift into another’s. However, any such disagreements would more likely be solved diplomatically, not militarily.

Public ownership. UNCLOS (Part XI, Sec. 2, Art. 136, 137) designates ABNJ resources and rights thereto as the “common heritage of mankind” (not particular states), giving all people rights to participate in resource and benefit decisions through existing channels—or emerging ones (e.g., decisions governing how marine genetic resources [MGR] and other biodiversity beyond national jurisdiction [BNJ]) will be used (Collins et al., 2020, Young & Friedman, 2018).

Broadly shared economic benefits. On 9 September 2020, the ISA requested proposals for creating a “Seabed Sustainability Fund” (or Global Fund) as an instrument for channeling some or all financial benefits from seabed mineral exploitation into “programmes, projects and activities consistent with the status of seabed minerals as the common heritage of mankind” (ISA, 2020). UNCLOS (Part XI, Sec. 2, Art. 140) specifies that ABNJ activities be done for the benefit of mankind as a whole, “…taking into particular consideration the interests and needs of developing States and of peoples who have not attained full independence or other self-governing status recognized by the United Nations....” The necessary payment regime for distributing financial and other economic benefits is not yet complete. Feichtner (2019a, 2019b), and Van Nijen et al. (2019) summarized the history of the legal and philosophic framework for equitable distribution of financial and other economic benefits and progress on ISA’s payment regime negotiations. Types and rates of royalties and/or profit shares to sponsoring countries and mining contractors, shares to ISA, equity of payments to countries, and reparations for losses to countries with existing mines, among others, remain contentious (e.g., African Group, 2019). Formulae under consideration generally performed similarly (Kirchain et al., 2019): payouts calculate each country’s population as a percentage of the world’s population, weighted to redistribute income from higher income states to developing countries.

Reparations illustrate an ethical dimension of deep-sea mining that is absent on land; creation of a new terrestrial mine entails no obligation to consider negative economic impacts of the new production on other mining companies or countries. In contrast, the definition of Area resources as the common heritage of humankind provides a unique basis for such reparations. As can occur with any new mineral supply, deep-sea metals could reduce metal prices relative to the counterfactual, including for those mined from terrestrial ores. This could cause economic losses in countries economically dependent on terrestrial mining. A report to the ISA (Lapteva et al., 2020, see Table 8.2) identified 13 countries in which mining makes up a large share of export revenues and/or of GDP, including Zambia, DRC, Eritrea, Chile, Lao People’s Democratic Republic, Mongolia, and Peru (copper); Madagascar and Zimbabwe (nickel); DRC (cobalt); Gabon (manganese); Mauritania, Namibia, and Papua New Guinea (cumulative). Whether reparations could make up for such losses remains to be seen.

Potential for lower environmental impacts. Depending on the processes selected, nickel, manganese, cobalt, and copper from nodules could have a lower environmental impact than obtaining those same metals from land ores, including up to 70% less global warming emissions to make one billion EV batteries and up to 94% less sequestered carbon loss (Paulikas, Katona, Ilves, & Ali, 2020), substantially reduced waste streams (Paulikas et al., 2021), up to 90% less freshwater used, fewer toxic exposures, and fewer injuries and fatalities to miners and inhabitants of surrounding communities (Hein et al., 2020; Paulikas, Katona, Ilves, Stone, et al., 2020).

If society’s objective is to obtain metals (or other materials) to support the green transition with the lowest possible negative impact, then deep-sea mining is not a yes-or-no question, but rather a broader consideration of choosing the best overall strategy for sustainability. “Best” can be viewed from a broad, global standpoint: What will be best for ecosystems and species on land and at sea, along with what will be best for the atmosphere, freshwater cycle, human health, and economic health of nations and their societies—in short, a planetary perspective. Accomplishing this equitably will require representative input from all stakeholders—a tall order in any case, but especially when crucial decisions are time limited.
**Ethical objections to deep-sea nodule collection**

Most opposition to deep-sea mineral extraction focuses on the large area to be disturbed, impacts on biodiversity, and possible impacts on broader oceanic or atmospheric processes. We evaluate each of these in turn.

**Large size of area.** As one scenario to provide intuition about impact scale, we consider the seabed area that would be needed to supply metals for a global automotive fleet of one billion Tesla 3-type EVs with NMC-811 (75 kWh) batteries. This total area is large—~432,000 km² over a 30-year period—in part because nodules are collected at the seabed surface, a two-dimensional problem. By comparison, an estimated 156,000 km² of land would be affected for metals to build those batteries, including deforestation of 66,000 km² (Paulikas et al., 2020). The billion-EV seabed area is ~36% of the CCZ area contracted for exploration (1.2 million km²); ~10% of the entire CCZ (4.5 million km²); 2% of the North Pacific Ocean’s abyssal seabed; 0.2% of the global abyssal seabed; and equivalent to ~1% of the world’s agricultural land (Sala et al., 2021). The remaining risk perspectives are not unique to deep-sea mineral extraction and are ethically relevant considerations for any mineral-exploitation activity, but they command heightened interest because nodule exploitation may begin in the near future.

**Recovery time.** Nodule exploitation will indeed harm deep-sea organisms and the abyssal seabed. Recovery time will be very long, and recovered systems will probably differ from predisturbance baselines in species composition, diversity, and population densities. We suggest that recovery for most groups would proceed at a comparable, slow pace as occurs after disturbance in terrestrial habitats; and in similar nonlinear fashion, with different species and ecosystem functions (e.g., carbon fixation, nitrogen fixation, nitrification, denitrification, and mineralization) recovering at different rates. As is typical for recovery after disturbance, widely distributed species that are actively mobile or transported by currents or wind may pioneer areas within years or a few decades after disturbance ceases, with serial addition and turnover of species as well as recovery of community functions continuing for hundreds of years or more (Haynes, 2014).

Considering the ocean first, responses to a few short (days), small-scale (<tens of km) experimental commercial and scientific disturbance studies are available for the abyssal seabed, although results are confounded by major methodological differences (Jones et al., 2017). At seven sites in the Pacific, multiple surveys assessed faunal recovery over periods of up to 26 years. Almost all exhibited some recovery in faunal density and diversity for meiofauna and mobile megafauna, often within one year, but very few faunal groups returned to baseline or control conditions after two decades (Jones et al., 2017), and different faunal and functional groups responded differently. At the best studied site, the DIS-turbance and reCOLonization (DISCOL) experiment in the Peru Basin, the loss of the surface sediment layer caused long-term (i.e., beyond several decades) reduction in microbial activities, organic matter turnover, nitrogen cycling, and microbial growth rates. Because microbial communities form the very basis of the abyssal benthic food web, all fauna directly or indirectly dependent on microbial biomass production would take longer to recover than microbial communities themselves (Vonahnme et al., 2020). Processing of fresh phytodetritus by bacteria, nematodes, and holothurians in DISCOL plow tracks had not fully recovered after 26 years compared with reference sites (Stratmann et al., 2018). In general, mobile and smaller organisms tended to have greater potential for recovery of both population density and diversity, but high variance in recovery rates among taxa obscured any general pattern of recovery or successional stages (Gollner et al., 2017). Recovery times for all organisms and functions would be even longer in the CCZ, where sedimentation rates are much lower than in the Peru Basin, and certainly with the prolonged disturbance of full-scale industrial nodule exploitation.

Large sessile fauna exhibited no recovery during the 26 years since the DISCOL disturbance (Jones et al., 2017), and it is clear that nodule-dependent megafauna would suffer most harm and recover only very slowly. Fauna attached to any collected nodules would die. Similar specimens may survive on nodules that remain uncollected within a contract zone or elsewhere in a designated Area of Particular Environmental Interest (APEI), reference zone, or undesigned portion of the CCZ, which makes proper design of APEIs and ecological studies of different CCZ regions critical. To the extent that organisms capable of bioturbation recovered from disturbance, bioturbation could in time uncover buried nodules (Dutkiewicz et al., 2020) as radiochemical studies of nodules from North Pacific sites near the CCZ indicated average rollover rates of 1000 to 100,000 years (Hun & Teh-Lung, 1984), so some buried or partially buried nodules could be available for recolonization faster than the million years or so needed to form new ones. This might be more likely in areas with greater bioturbation depths, such as portions of the eastern CCZ where it is usually limited to the upper 7 cm but reached 13 cm at one site (Volz et al., 2018). In any case, it seems likely that time scales of many millennia will be needed for recovery of nodule-dependent organisms, although initial recolonizations would begin sooner.

By comparison, centuries or millennia are also required for recovery of forest ecosystems disrupted by terrestrial mining. For example, ~60-year-old secondary forests in Amazonian Brazil contained just over 41% of the average carbon density and 56% of the tree diversity as in the nearest primary forests (Elias et al., 2020). Furthermore, after cutting in the Atlantic Rain Forest, an estimated 100–300 years were needed for animal-dispersed species, non-pioneer species, and understory species to reach levels found in mature forests. However, regaining pre-impact
levels of endemism would need 1000–4000 years (Liebsch et al., 2008).

Species extinction. The risk of species extinctions is problematic (e.g., Heffernon, 2019). As summarized in Jones et al. (2021), it is hypothesized that the CCZ benthos includes both species with widespread distributions and many rare species. Extinctions could occur in species endemic to very restricted distributions within exploited zones, for example, in meiofauna such as nematodes (Macheriotou et al., 2020). Such extinctions may be very difficult to confirm, because of the effort needed to baseline truth distributions with sufficient resolution to demonstrate the lack of living individuals of rare species. If high percentages of nodules are removed, nodule-obligate megafauna may also face the highest risks of extinction (Smith et al., 2020); such fauna contributed approximately 50% of all morphotypes observed in the UK-1 exploration contract area, eastern CCZ (Amon et al., 2016).

The ISA has set aside nine APEIs totaling ~1.4 million km² (31% of the CCZ), intended to “Protect biodiversity and ecosystem structure and function by a system of representative seafloor areas closed to mining activities” (ISA, 2011). In addition, portions of each contract area would remain undisturbed, including areas with lower nodule cover, topographies too steep to mine, and ISA-required set-aside preservation reference zones (PRZ) within the contracted areas. Impact reference zones (IRZ), also required by the ISA, will further aid in measuring, managing, and preventing impacts including species harm within each contractor zone.

The ISA’s APEI system and other set-asides should reduce the likelihood of extinctions, but it is uncertain whether this will be enough to prevent them. Not all APEIs have been surveyed in sufficient detail to determine whether they are adequate to fulfill their proposed purpose, and some may not be. Surveys of APEI-6, for example, found a lack of large nodules and the habitats they create, thereby differing from areas specifically targeted for mining activities (Jones et al., 2021). This led the authors to suggest that additional APEIs, and/or other management activities beyond the APEI network alone, could be needed to fulfill the ISA mandate.

Harm to global systems. Taken globally, the utilitarian planetary perspective leads one to consider whether polymetallic nodule collection can adversely affect systems at a planetary level. For instance, concern has been expressed that deep-sea mining may contribute to climate change by releasing organic carbon from sediments (e.g., Chin & Hari, 2020; Greenpeace International, 2019). However, Atwood et al. (2020) stated that carbon in deep-sea sediments along the continental slope, abyssal basin, and hadal zones may be more resistant to disturbances than coastal continental shelf sediments; and that even if it were remineralized, this would not influence atmospheric CO₂ in the near future because deep-sea carbon cycling works on millennial time scales. A second systems concern is ocean acidification. Ocean uptake of anthropogenic CO₂ has already begun dissolving sedimentary CaCO₃—which normally neutralizes excess CO₂ and prevents runaway acidification—in sediments of the deep Atlantic Ocean (Sulpis et al., 2018). However, the impact from deep-sea mining would be dwarfed by ocean uptake of CO₂ from the atmosphere: CCZ nodules needed for one billion batteries would displace 5.83 × 10⁸ g of sequestered carbon and disrupt sequestration of an additional 2.44 × 10⁸ g for a total of 8.27 × 10⁸ g over a ~30-year period (Paulikas et al., 2021)—seven orders of magnitude less than the 2.5 ± 0.4 PgCy/year (±2.5 × 10¹⁵ g) annually absorbed by the ocean (Watson et al., 2020). A third concern is pollution by toxic metals (Chin & Hari, 2020; Christiansen et al., 2020; Greenpeace International, 2019). Yet, currently, there is no evidence that dissolved metals would be released along with the sediments and fines (Muñoz-Royo et al., 2021). Paul et al. (2021) evaluated the risk of toxicity from dissolved copper released from pore water by deep-sea mining as negligible; they also called for further research on different size fractions of copper, co-release of several metals, and variations of pH.

Other utilitarian concerns. Local utilitarian concerns may arise, particularly regarding interference with fishing or bioprospecting. Estimated annual fish catches (mainly tuna) in the CCZ within 200 km of nodule contract areas are 35 000–89 000 metric tons, with approximately 10% each taken by Ecuador, Mexico, Panama, and Spain, and 15% by the United States (van der Grient & Drazen, 2021). Substantial negative impacts from nodule collection may be unlikely given the depth of nodule collection if riser-water discharge occurs deeper than 1000 m (van der Grient & Drazen, 2021), but impacts should be monitored by countries highly dependent on those fisheries; stakeholders are encouraged to express concerns during the ISA’s Environmental Impact Assessment (EIA) process. Extensive bioprospecting opportunities are also likely to remain in the region, given the exploited area may be only ~10% of the CCZ or 2% of the abyssal seabed of the North Pacific Ocean. Moreover, because contractors biosample at greater density than bioprospectors can often afford, surveying for seabed metals and genetic resources together could have a positive impact on this utilitarian concern by reducing costs, improving economic viability, and allowing more comprehensive assessment of environmental issues (Royal Society, 2017). Metal contractors can also make archived samples available to bioprospectors, providing more material and at lower cost than might otherwise be possible.

Intrinsic rights and rights of nature. Beside harming groups (i.e., nature, species, populations), some animal-rights supporters advocate the intrinsic rights of individual animals (and sometimes plants) to exist and not be harmed. Intrinsic rights refer to an organism’s worth independent of how others, including humans, use it (de Vere et al., 2018; Francis, 2015). Increased sentience—variously defined as the ability to sense pain, “the ability to feel, perceive, or be
Conscious, or to experience subjectivity” (Bekoff, 2013), or “[an animal] which has feelings and such animals may have some ability to evaluate the actions of others in relation to it and third parties; remember some of its own actions and their consequences; assess risk; and have some degree of awareness” (International Whaling Commission [IWC], 2011) —magnifies the importance of intrinsic rights. Whether ecosystems themselves might have moral rights or legal standing is discussed by Dasgupta (2021).

Ethical concerns based on existence rights of nature (Harvard Law Review, 2016; Surma, 2021) and intrinsic rights of organisms or species, although well intentioned, can become problematic if only considering a narrow ecosystem such as the seabed. This is because competing rights of nature become relevant once the planet as a whole is considered. If CCZ nodules are not used, the footprint and impacts of terrestrial mining will increasingly affect nature on land as terrestrial mining expands to meet rising battery-metal (or other green transition) demands. Falling terrestrial ore grades imply that existing mines will either need to excavate more ore—with the consequent increases of greenhouse gases, wastes, and toxins—or find new higher-grade ores in virgin territory. Laterites that underlie tropical forests and grasslands are the most promising new source of high-grade nickel ore. Mining them brings the potential for increased conflict with indigenous cultures and with the high biodiversity of those regions.

In the CCZ, some animals (e.g., marine mammals) possess the higher “IWC” rank of sentience, and perhaps some others possess the lower “de Vere” rank; but most multicellular animals likely feel some version of pain. Animals at risk in some terrestrial habitats where battery metals are mined contain many more species of “higher rank” sentience, including some that may qualify for personhood, such as orangutans, elephants, whales, and great apes and gorillas (Grant, 2020; Nowlan, 2019; Staker, 2017). An ethical rights-of-nature-based approach to CCZ nodule collection includes generating awareness of the unavoidable harm or pain being caused, while also weighing the pressing reasons for it, including the harm it can avoid to humans, plants, animals, and other organisms on land.

Enablement of future undesirable action (slippery slope). Permitting nodule exploitation in the CCZ could spur more of it, or other types of deep-sea mineral exploitation (or other uses) in the Area (Ramirez-Llodra et al., 2011) or elsewhere. At the same time, opposing it based on a slope argument risks ignoring investigation of benefits it could produce. Counterintuitively, a decision by the ISA not to permit nodule collection in the Area could spread environmental and social impacts elsewhere, with reduced opportunity for international oversight, if countries respond by mining within their exclusive economic zones. Economic supply–demand forces would provide some limit to expanding mineral extraction initiatives, and each project would require thorough evaluation on its own. Any projects in territorial waters should be governed by state regulations and procedures that are no less effective than those required by ISA for projects in the Area (Levin et al., 2020). If nodule exploitation is approved, the ISA should judge any further proposals for Area projects on their own merits, but with increased attention to cumulative effects, and applying ethical lessons from the nodules case when appropriate.

Practical opportunities for ethical choices

Numerous opportunities exist for ethical input in the nodule-metals industry to reduce harm, accelerate emergent opportunities for environmental or social gains, and even have positive spillover effects on other industries. Figure 3 summarizes a full range of ethical opportunities by category. Figure 4 shows specific opportunities for each value-chain step.

Broadly, ethical results of deep-seabed mineral exploitation can manifest through:

- **Strategic objective setting**, leading to long-term strategic plans guided by ethical principles
- **Specific engineering and operational decisions** in offshore collection and onshore processing
- **Stakeholder commitments**, and incorporation of stakeholder viewpoints
- **Democratization of ethical governance** through ISA processes and individual contractor actions
- **Investment and alignment around circular-economy futures** and recycling
- **Deepening ethical opportunities manifestly present with CCZ nodule exploitation**

Strategic objective setting. As Billett et al. (2019) stated, “Unless contractors include ecosystem services, and the costs associated with their loss or impairment, as part of their decision-taking, and as part of an ethical approach to ensuring the health of the oceans for the Common Heritage of Mankind, it is unlikely that resource and engineering managers will be stimulated to devise technical solutions to reduce environmental harm.” In addition to the ISA’s explicit biodiversity-preservation objectives, incorporating heartfelt engagement with the environment into system-design processes, for instance, as an explicit component of cost–benefit analyses, can lead to more successful solutions. Ethics and environmental impact management can also be set as a highest-level objective, directly driving subsystem requirements, to help ensure that engineering optimizations are not made in a vacuum and do not cause unintended environmental problems or harm (e.g., Melin et al., 2021). The Environmentally Responsible Company/Entity Ethic section of the International Mining and Minerals Society’s Code of Conduct (IMMS, 2011) is a good start, but it could be strengthened.

Engineering and operational design decisions. Cuvelier et al. (2018) summarized options available for mitigating harm during offshore collection and afterward. Their
potential effectiveness can be estimated after each contractor completes ISA-required, on-site tests of reduced-scale collection systems, and more accurately known after deployment of full-scale systems, about 2026 or later (Shukman, 2021). Among other objectives will be designing collection robots that minimize harmful lighting and noise, sediment compaction and disruption, and that direct the elevated sediments in directions or patterns that reduce sediment flow to the riser system and deposition thickness on the seabed. Operation of collectors could also be informed by real-time feedback from video monitors. Minimizing sediment disturbance depth will be a priority to limit the number of organisms directly harmed, reduce benthic plumes, and reduce the sediment content of riser water. Collection patterns and practices can be designed to minimize collateral damage in ways analogous to forestry initiatives, such as reduced impact logging (RIL; Bicknell et al., 2014) and RIL-C for climate (The Nature Conservancy [TNC], 2019). Riser systems can be engineered to minimize the temperature difference between slightly warmed deep-sea water and ambient water at its point of discharge. Fine filtration or centrifugation of water on the collection vessel can capture metal-containing nodule fragments and reduce the sediment load in discharge water. Discharge depth, whether

![FIGURE 3 Summary of ethical opportunities and calls to action for CCZ nodule collection](image-url)
in the water column or at the bottom, can be chosen carefully to minimize harm to inhabitants of the seabed and overlying water column, which has until recently received less attention (Christiansen et al., 2020; Drazen et al., 2020; Robison, 2009). Even if the sediment content of riser streams is minimized by reducing sediment entrainment and optimizing on-board filtration, discharge plumes will contain large quantities of small particles that can spread for hundreds of kilometers or more during the year or more they require to sink (Muñoz-Royo et al., 2021). The important unknowns are (1) how long it will take for dilution of plume sediments to background levels (~20 μg/L in the CCZ); and (2) over what area or volume will sediment loads exceed tolerable levels that do not clog feeding or respiratory structures, compromise neutral buoyancy of jelly organisms, or jeopardize visual range and acuity in organisms that depend on vision for communication, reproduction, or predation (Drazen et al., 2020; Robison, 2009). Dilution of sediment load to background level (10 μg/L) reportedly occurred within 1 km for flocculated benthic plumes produced during experimental mining of cobalt-rich crust on a seamount 300 nm SSW of the Canary Islands (Spearman et al., 2020). Based on flocculation and the higher levels of background sediment present in the CCZ, those authors expressed confidence that the area over which plume turbidity exceeds natural turbidity would be similarly limited, but such data will not be available until reduced-scale collection system tests are completed. The utility and feasibility of actions to restore habitats or populations (e.g., distribution of artificial substrata for colonization, larval seeding, transplantation of organisms) are not yet known.

Collected nodule ores would be transported by ship to a port, then additional ground transport as needed, to reach onshore processing plants and refineries. Transport will

![Figure 4: Smart nodule collection: opportunities for ethical influence from cradle to grave. This paper specifically focuses on metal production, which has a “cradle” (seabed) to “gate” (refined metal) scope, but a circular economy encompasses processes from “cradle” to “grave.” This figure includes the entire cradle-to-grave process, adding in gate-to-grave steps of product manufacture, use, and disposal to illustrate opportunities for ethical influence along the entire life cycle. Photo credits: Columns 1, 2, 4: Bjarke Ingels Group, Copenhagen. Column 3: The Metals Company, Vancouver. Column 5: General Motors. Column 6: Volkswagen.](image-url)
generally use fossil fuels and emit gaseous and particulate pollutants; all have ethical opportunities for future upgrades by incorporating renewable energy. Preferential use of ships seems beneficial; at approximately 0.2 MJ/ton-km, shipping is currently approximately 1.5 and 13 times more energy efficient than rail or truck, respectively, with associated CO2 emissions of approximately 0.14 kg CO2e/ton-km (Wakeland et al., 2012; see also Fenhann, 2017) also proportionately lower, although particulate emissions are much higher as a result of diesel combustion of less refined fuel. Environmental impacts also decrease with shorter transport distance, slower speeds, and use of newer carriers. Battery-powered ferries, coastal freighters, and coastal tankers are operating or under construction (Crider, 2021; Hockenos, 2018). Renewably powering ocean-going vessels is harder to achieve, but Maersk (2021) is developing large container ships operable with carbon-neutral methanol or biofuel; and hydrogen or ammonia fuels could further decarbonize ocean shipping (Timperley, 2020). Some trains already operate with overhead grid power, and new versions will incorporate rechargeable batteries (Halvorson, 2020). Battery-operated trucks are on the horizon. Operation of EVs of all sorts will be most environmentally advantageous if they are recharged by renewably powered electric grids.

**Stakeholder commitments.** Actors are called to make commitments to stakeholders that uphold sustainable and equitable principles (Figure 3), including ongoing funding of scientific research, real-time monitoring of impacts, and a commitment to cease operation if serious harm is caused. In alignment with their strategic objectives, contractors can add environmental, social, and governance (ESG) commitments to their bylaws; at a minimum, they can commit to transparency in sustainability reporting. All parties up and down the value chain can commit increased attention to the ethical implications of their decisions.

**Democratization of ethical governance.** Multiple opportunities for governance democratization present themselves. The ISA is charged with representing its member states; members can push to set ambitious impact standards and hold contractors accountable, and to set high environmental standards in the EIA process. Contractors can offer scientific and stakeholder engagement with real-time adaptive management systems and create open discussion forums. Stakeholders can hold contractors accountable for ESG practices and encourage best-practice transparency. Contractors employing ethical practices could also gain opportunities in the marketplace through third-party certifications, as has occurred in the seafood industry (Marine Stewardship Council, Aquaculture Stewardship Council), forest products industry (Forest Stewardship Council), environmental management systems (International Organization for Standardization [ISO 14001]), and others. Those bodies drew their power from the ethical framework shared by many consumers who, in turn, encouraged decisions based on sustainability and long-term health of a resource and its consumers and workers. Whether there will be a callout for a “best practice label” for metals remains to be seen.

**Circular economy.** Also uncertain is whether participants in the CCZ nodule industry and its supply chains might undertake collaborative actions toward sustainability that could support such a label, perhaps by striving to create circular economies at micro scale, emphasizing cleaner production and energy conservation, sharing information, and always prioritizing environmental health. Many opportunities exist for larger scale, longer term actions and policies by industry, governments, and international organizations to hasten development of circular economies (e.g., Haugan et al., 2020; Söderholm & Ekvall, 2020).

However, if new metal supplies from nodules (or other sources) do ease supply-chain concerns for nickel and cobalt, then pressure to invest in upgrades in recycling technology or other supply-chain improvements could decrease. Deep-sea mineral players could counter this effect by prioritizing working with manufacturers to invest in circular metal economies, using a portion of profits to promote recycling research, and committing within their bylaws to end-to-end ownership of the eventual recycling and reuse of all metals they mine.

**Deepening inherent opportunities.** Some opportunities are particularly available to a new industry with no infrastructure to retrofit, potentially able to take advantage of global momentum for sustainability and ESG reporting (WEF, 2020) in its design, and to benefit from lessons learned from the terrestrial mining industry. In such ways, CCZ nodules create the potential for unique benefits in the nascent industry. The ISA can enforce strict environmental mandates in their regulations, raising the bar far higher than typically seen in terrestrial mining. Individual contractors can also set an example of clean onshore processing, due to nodules’ inherent high ore grades and low levels of heavy elements; new metallurgical processing plants can be optimized for waste-free processing and refining of nodule ores (Sommerfeld et al., 2018). Ore transport by ship allows greater optionality in the location of processing facilities, greater ethical choices in the use of renewable sources, low land ecosystem impact, and proximity to end markets to ensure byproducts are not stockpiled or turned into waste streams. Setting this environmental example with nodule processing could force similar competitive progress for terrestrial mining as well.

In concluding, we emphasize that the opportunities listed in Figures 3 and 4, as well as discussed in the text, represent situations in which ethical input could improve decisions. The various stakeholders involved in CCZ nodule exploitation may not all capitalize on such opportunities in the same way or to the same degree. Yet, taken as a whole, participants in the new industry have a novel chance to demonstrate ethical leadership. In doing so, actors ranging from regulating authorities, states with vested interests in deep-sea mineral extraction, mining supply-chain actors,
and communities are called to take ethical action. If these ethical opportunities are taken, they may help improve overall outcomes to biodiversity, ecosystems, and the entire planet.

CONCLUSION

On 25 June 2021, Nauru exercised its right to invoke the two-year rule, pursuant to the Annex to the 1994 Implementing Agreement. In doing so, Nauru triggered a firm deadline for the ISA to adopt rules, regulations, and procedures for approving work plans for exploitation in the CCZ (ISA, 2021). Four days later, a response came from the Deep-Ocean Stewardship Initiative (DOSI)—a global union of interdisciplinary experts who pool research, skills, and expertise to advise on sustainable deep-ocean governance and resource management. They wrote to the ISA that two years is not sufficient to understand deep-sea mining’s potential impacts on species and ecosystems (DOSI, 2021), and that this ran counter to the precautionary approach required by the ISA (see Jaeckel, 2017).

On the other hand, Article 3 of UNESCO (2017) provides conflicting guidance: “Precautionary approach: Where there are threats of serious or irreversible harm, a lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to anticipate, prevent, or minimize the cause of climate change and mitigate its adverse effects.” This leaves stakeholders to question which is the greater threat: commencing nodule exploitation before impacts are completely understood? Or risking a long delay in nodule-mortals delivery that could compromise terrestrial species and habitats, and possibly lead to metal shortages that delay transitions to a renewably powered economy?

On one hand, a clear, shared ethic has emerged and persisted in recent years, prioritizing environmental protection and sustainable production of the very materials required to construct the global green transition. In 2019, Amnesty International launched an “ethical batteries campaign,” calling for action by governments, industry, innovators, investors, and consumers to create ethical and sustainable batteries free of human rights abuses, conflict minerals, and climate harm within five years (Amnesty International, 2019; Church & Crawford, 2018). The World Bank launched a new fund to support Climate-Smart Mining for Energy Transition (World Bank, 2019). Apple, Tesla, and other corporations (Sancroft Team, 2018) along with governments (EU, 2018; Mancini et al., 2020) and labor unions (United Auto Workers, 2021) are moving toward insisting on ethically sourced and sustainably produced batteries.

Yet other aspects of the shared ethic remain less clear. Some corporations and organizations prefer inaction until risks are understood and alternatives are exhausted—including Google, BMW, Volvo, Samsung SDI (Reuters, 2021), and the IUCN (2021). The IUCN resolution’s exhaustive requirements before commencement of the nodule industry go far beyond impact risk assessments, to include implementation of “polluter pays principle,” reduction in primary metal demand, transformation to a circular economy, responsible terrestrial mining practices with public consultation mechanisms, informed consent of potentially affected communities, and reformation of the ISA for greater transparency, accountability, inclusion, and effectiveness. Accomplishing these laudable objectives may be improbable within the proposed <10-year time frame, the same critical period during which use of nodule metals might help mitigate crises of climate, biodiversity, water, and other nested emergencies.

Furthermore, the IUCN (2021) resolution seems to ignore impacts of accelerated terrestrial mining on the 4885 species animals and 5740 species of plants included on its Red List, for which “Mining” and “Quarrying” are shown as threats, despite having passed another resolution that 30% of Earth’s surface be designated as “protected areas” to halt and reverse the loss of wildlife. Calls to halt deep-sea mining also seemingly fail to acknowledge the large role that deep-sea metal contractors play in sponsoring the research needed for the rigorous impact assessments called for in moratoria.

It is for these reasons that an ethical approach to deep-sea mining demands broad and comprehensive consideration. Can the question, Is polymetallic nodule collection an ethical choice? be answered: by mapping the nexus of competing objectives and needs of many stakeholders, and holding ethics as a top priority across the value chain? It requires an inclusive and ethically purposeful effort to amass factual scientific information, acknowledge the risks of commencing the industry with incomplete scientific understanding, and acknowledge the risks of a moratorium shifting the environmental burden to terrestrial mining and introducing nickel and cobalt supply-chain risks.

An ethical approach to deep-sea mining would have the industry see itself playing a critical role in the global quest for sustainability, as set out in UN (2015), CBD (2020), and related plans. Academic scientists can evaluate existing evidence of favorable climate, waste, water, and human health advantages that nodule mining might provide and encourage contractors to prioritize environmental best practices (see, e.g., Hein et al., 2020; Paulikas, Katona, Ilves, & Ali, 2020; Paulikas, Katona, Ilves, Stone, et al., 2020; Paulikas et al., 2021). The industry and its stakeholders must honestly and transparently acknowledge the harm it inflicts, estimate its extent, and do everything reasonably possible to minimize it. The terrestrial mining industry is encouraged to do the same. Voices championing preservation of the ocean should be balanced by attention to harm to rainforests and other terrestrial ecosystems affected by the decision. Those defending rights of nature would also seek that balance.

As Hein et al. (2020) stated, the growth of the deep-ocean mining industry offers an opportunity to develop green technologies and policies as the industry develops, while also initiating new strategies to mitigate its environmental effects. All stakeholders would need to take responsibility for shaping the new industry, while recognizing its interconnectedness to the global economy and environment, as
well as humanity’s interconnectedness with nature. Bennett et al. (2017) advocated the development of a comprehensive, broadly accepted code of conduct to ensure marine conservation processes and actions are fair, just, and accountable, as well as ecologically effective. Many of the social concerns those authors noted do not exist in the CCZ per se, but developing an agreed-upon code of conduct shared by members of the CCZ value chain (and periodically updating it as needed) would contribute to the credibility of conservation efforts, both within the Area and beyond it.

It is also worth internalizing, both in our individual consciousnesses and into corporate strategic planning and institutional visioning, a new paradigm: that primary extraction of any metal ores from Earth should be a time-limited industry. Achieving this would require widespread anticipation, encouragement, and participation in one of the greatest challenges humanity faces—the creation of sustainable circular economies that will allow people and nature to live in greater harmony. Such harmony would not be pain free, as humans may still need to fish, plow, practice forestry, and animal husbandry, and cull some species to protect others (Barkham, 2020). While granting the assertion by Griffin et al. (2020) that compassion should not be the sole basis for conservation, we still may hope that such empathy, along with care and respect even for species less likely to kindle emotions in humans (Miralles et al., 2019; Tonino, 2020), may help guide our actions in the deep sea and elsewhere.

Given the variety of moral and ethical backgrounds, vested and financial interests, and problem-solving approaches represented among the many polymetallic nodule stakeholders, compromises will be needed. The best hope may be for policies, decisions, regulations, and agreements that produce the fewest negative impacts on air, water, land, sea, people, nature, and species, while providing the most broadly equitable suite of benefits across those categories. That formula, a Utilitarian Approach, would by definition include the Rights Approach, Fairness (Justice) Approach, Common Good Approach, and—if each stakeholder acted with the integrity, fairness, generosity, and tolerance of which we humans are capable—the Virtue Approach.

The day before we submitted the revised manuscript for this paper, Claudet et al. (2021) published “Transformational opportunities for an equitable ocean commons” online. Without mentioning ethics, those authors nevertheless framed pragmatic goals in ethical terms: an equitable future, equity for people and nature, expansion beyond anthropocentric notions of equity and rights in ABNJ to explicitly encompass the natural world and its components, intrinsic value of the ocean, rights of nature, and the ocean as a rights-bearing entity. Expanding such considerations to all aspects of the green transition, including where and how metals are sourced, will produce a more beneficial future for all.

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