Noise from deep-sea mining may span vast ocean areas:
Potential harm is understudied and largely overlooked

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Despite increasing interest in mining the deep ocean for valuable minerals, concerns about environmental impacts of deep-sea mining on vulnerable and poorly understood ecosystems have been raised by marine scientists and policy experts for decades and continue to be poorly addressed (*1*, *2*, *3*). These concerns took on a new sense of urgency on 30 June 2021, when the Republic of Nauru notified the International Seabed Authority (ISA) of their intent to sponsor an application to mine polymetallic nodules in the deep Pacific in two years[1]. This notification triggered a provision in the 1994 Agreement related to U.N. Convention on the Law of the Sea that leaves two years for the ISA to either adopt final or provisional regulations, or, failing that, to consider Nauru's nodule mining application under existing rules of international law.

Environmental concerns for deep-sea mining include permanent removal/burial of critical seafloor habitat and the creation of large suspended sediment plumes, but a concern that has received little study is the underwater noise potentially generated by mining activities (*4*). Sound is the primary modality for many marine organisms to probe their environment and to communicate, either through sensing of pressure or particle motion. Noise from human activities can impact organisms ranging from plankton to whales via, e.g., acoustic masking, behavioral disturbance, stress, and hearing loss (*4*). Here we focus on extraction of polymetallic

[1] http://naurugov.nr/government/departments/department-of-foreign-affairs-and-trade/faqs-on-2-year-notice.aspx

nodules in the abyssal fields of the Clarion-Clipperton Zone (CCZ) to illustrate the broad issue of potential ocean noise generated by mining. Many cetacean species occur throughout the CCZ, including endangered migratory baleen whales such as blue and sei whales, vulnerable fin and sperm whales, near-threatened false killer whales, and deep-diving beaked whales (*5*).

In the absence of empirical data on sound-source characteristics, we used reasonable analogs to estimate potential noise levels expected from nodule mining equipment (Fig. 1A). For the mining tools that will remove nodules from the seabed, we used coastal dredges that remove gravel and sediment in shipping lanes and ports as a stand-in (181 dB re 1 µPa m, 20 Hz - 20 kHz; *6*). Noise generated by each booster pump along the riser was approximated by pump-out operations from coastal dredging (183 dB re 1 µPa m, 20 Hz - 20 kHz; *6*). For the mining vessel, we took recordings from Floating Production Storage and Offloading (FPSO) vessels used by the oil and gas industry (188 dB re 1 µPa m, 20 Hz - 2 kHz; *7*) (Figure 1A). We then applied commonly used sound propagation models *(8)* to make predictions about how noisy full-scale operations may be throughout the water column. These are expected to be underestimates, because shallow-water recording surrogates likely missed acoustic energy below 100 Hz that will be particularly important with the heavier machinery required by seabed mining. Sonars, support vessels, and additional pipes and pumps that will likely be needed for the discharge of dewatering plumes into deep waters represent additional sound sources that we have not yet considered (i.e., grayed-out elements in Fig 1A).

Our predictive model shows that the acoustic environment surrounding a mining operation in the CCZ is likely to be substantially altered by even the incomplete list of noise-generating activities we modeled (Fig. 1A). The noise will be distributed throughout the water column from ships at the surface, risers with pumps every ~1 km in depth, and mining tools on the seabed, ultimately creating a cylinder of sound gradually decreasing in amplitude while propagating outward from mining operations (Fig. 1B). The mid-water pumps will couple with the **SO**und **F**ixing **A**nd **R**anging (SOFAR) channel, which efficiently transmits sound over great distances, causing our model to predict that mining noise from a single operation will exceed background conditions to a range of ~500 km (*9*) (Fig. 1C). If each contractor operated one mining system in each contract area, a region of 4-6 km radius about each mine would be above 120 dB re 1 µPa, a threshold used by the US National Marine Fisheries Service to denote the possibility of behavioral impacts, generically, to marine mammals from continuous low-frequency noise (Fig. 1B). Of the modeled area, roughly 5.5 million km^2 would be expected to be ensonified above ambient noise levels currently experienced in gentle weather conditions (~94 dB re 1 µPa; Fig. 1C; *9*). Some acoustically sensitive whales show behavioral responses to low-frequency continuous noise at levels <120 dB re 1 µPa (*10*). Most species in the deep sea have yet to be described, and sensitivities to noise have not been studied for even the most common deep-sea species, so no information is available on their responses to ocean noise. However, in the absence of sunlight, many deep-sea species use sound and vibrations in their ecology and thus are likely to be relatively vulnerable to ocean noise from human activities such as deep-sea mining (*4*, *11*).

Our prediction that noise from any one mine will exceed gentle-weather background levels over hundreds of km^2 appears to be problematic under the requirements of the United Nations Convention on the Law of the Sea (UNCLOS) and for the approach outlined in ISA's draft exploitation guidelines to assess the environmental impacts of nodule mining. The UNCLOS framework requires sufficient protection against harmful effects through precautionary management. Under ISA guidelines, ecological metrics from areas impacted by mining will be compared to similar metrics in zones within contractor areas required to be unimpacted, called Preservation Reference Zones (PRZs). However, to fit within contractor areas, PRZs are expected to be within 100-300 km of mining sites, causing PRZs to be ensonified by mining activities and thus of limited value as controls for understanding the impact of mining noise on deep-sea communities *(3, 12)* (Fig. 1C). To be free of mining noise above ambient levels, it may be necessary to place PRZs outside the entire CCZ (Fig. 1C); however, this would likely cause the PRZs to be ecologically unrepresentative of the areas mined *(13)*.

Based on the costs and logistical challenges to answering basic questions about the impacts of sound on deep-sea ecosystems, it seems unlikely that adequate data to assess ecological risks from mining noise will be collected within ~18 months, or even with the 10-year mining moratorium proposed in 2019 by some scientists and leaders of several South Pacific island nations to allow time for data collection and impact assessment (*12*, *14*). Risk assessments will be even more challenging without access to empirical data on sound-source characteristics of nodule-mining equipment. Testing of reduced-scale, prototype mining machines are underway or planned; however, contractors, thus far, have not released sound-source characteristics data from internal risk assessments or pilot studies, even upon our repeated requests. We urge contractors to release information on sound-source characteristics of all aspects of seabed mining operations in a timely manner, including those activities not included in prototype tests (e.g., from lifting pumps on riser pipes, and the rattling of metal-rich nodules in lifting pipes and on barges).

There is an urgent need for transparency from industry, agencies, and scientists related to the acoustic energy produced from mining prototypes and potentially, from full-scale mining systems. We will need to learn about the mining systems and their impacts iteratively, through real-world experience *(15)*. As such, the regulatory regime should start with cautious thresholds for noise, and enable fast management responses if those thresholds are approached in an individual project, as well as allow for regular review of the thresholds as more data about noise impacts are reported. Our first approximation of the noise likely to be generated by polymetallic nodule mining highlights both the potential extent and uncertainty of this noise and its ecological impacts. Moving forward with nodule mining applications within the next 18 months without data transparency and rigorous standards and guidelines in place would represent the start of a large-scale, uncontrolled experiment. If this industry does proceed through Nauru's claim or elsewhere in the CCZ, we recommend application of the precautionary principle [in keeping with the ISA's duty to provide for the effective protection of the marine environment] such that the ISA allows only one or two mining operations to proceed until the aggregate and cumulative environmental impacts from noise (and other stressors) are well documented (*13*). The ISA should also include noise mapping in environmental impact assessments and the Regional Environmental Management Plan, setting noise-specific requirements for future exploitation contracts. These could involve setting thresholds at precautionary levels, and requiring contractors to collect noise data and make them publicly available. We recommend that, initially, limited mining should be coupled with intensive, independently commissioned, studies of regional baselines and environmental impacts, as well as with the ability to alter or halt operations quickly if newly acquired data indicate significant unexpected impacts.

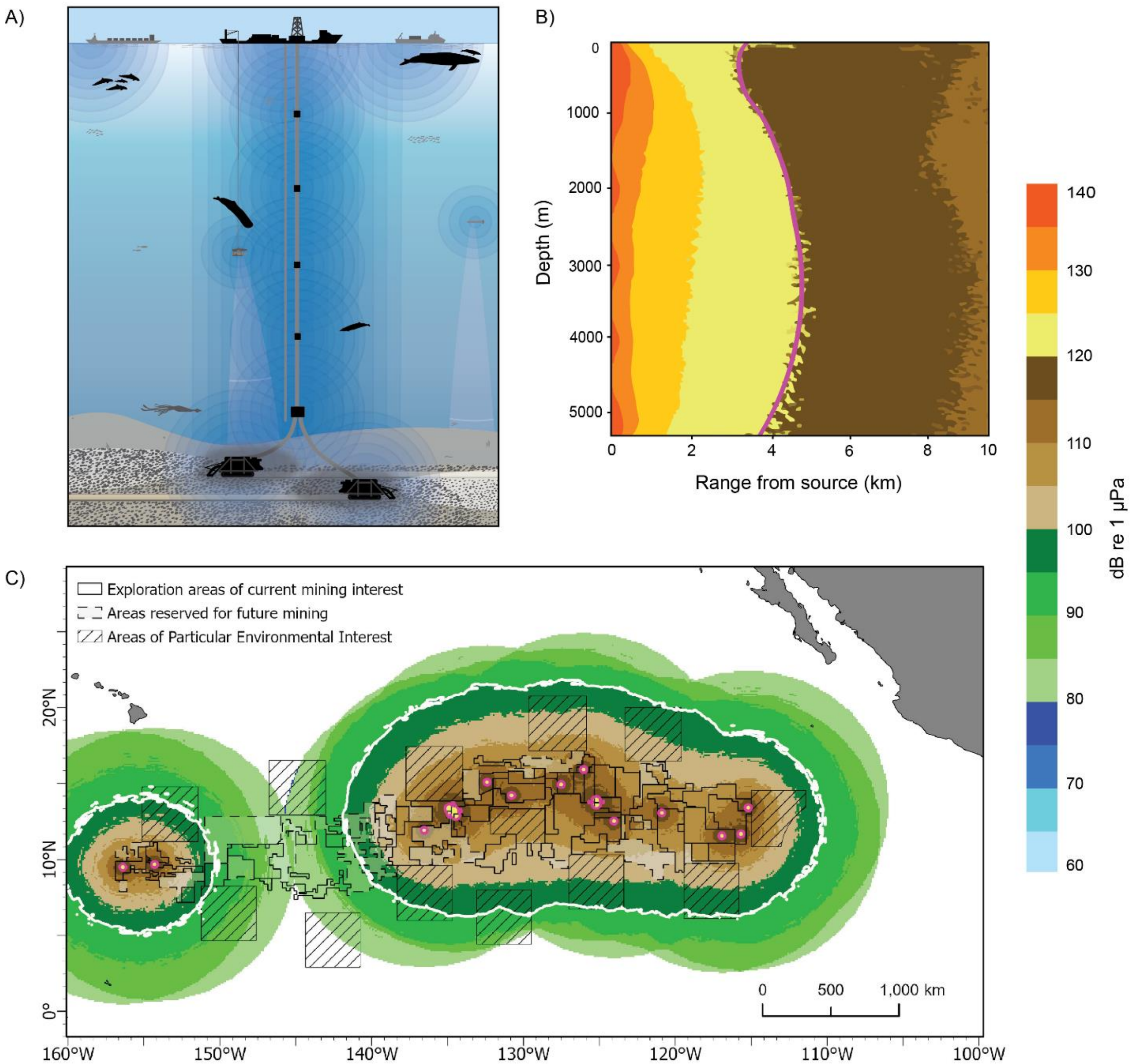

Figure 1. A) Schematic of a deep-sea operation at one mining site in the CCZ and all likely sources of noise including mining tools at the seafloor, booster pumps on the riser throughout the water column, and surface mining and support vessels. Mining infrastructure with black silhouettes was accounted for in sound propagation models; gray silhouettes were not. B) A vertical cross-section along a line due north from one mine operating in the western CCZ showing root-mean-square sound pressure level (SPL) over 20 Hz - 20 kHz with depths corresponding to locations of activities in A. C) Map showing maximum SPL (20 Hz – 1 kHz) over all water depths for the combined sound field from 17 simultaneously operating mines, with one in the area of each exploration contract most likely to be mined first (i.e., area of highest nodule density). Maximum modeled range: 1000 km from each source. The 120 dB re 1 µPa behavioral threshold for cetaceans corresponds to the transition from brown to yellow (pink

isolines, panels B & C). Ambient noise is exceeded beyond 94 dB at the transition from light to dark green (white isoline, panel C). Each mine has one seafloor mining tool operating.

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8. Materials and methods are available as supplementary materials

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