Questions for Prof. Thomas Peacock, Professor of Mechanical Engineering and Director, Environmental Dynamics Laboratory, Massachusetts Institute of Technology.

1. In your testimony, you mentioned there are only 6,000-8,000 species in the Clarion Clipperton Zone. Other studies specify that this figure is specific to the benthic metazoan species, not the entirety of species in the CCZ. What do you believe to be the full measure of biodiversity in the CCZ?

The estimates cited in my testimony for benthic metazoan species, which make up the bulk of the biomass found in the CCZ, come from the following publication [1]. For additional questions about biodiversity, I recommend reaching out to experts such as Prof. Daniel Jones (National Oceanography Center, UK; *dj1@noc.ac.uk*), Dr. Adrian Glover (Natural History Museum, UK; *a.glover@nhm.ac.uk*), and Dr. Bryan O'Malley (USA; *bjomalle@eckerd.edu*).

2. TMC maintains that the Digital Twin will be a core component of the company's Adaptive Management System which will aim "to ensure operations remain within environmental impact thresholds." Given the dearth of data on deep-sea organisms and processes, as well as data on plumes and their impacts, how can the Digital Twin reliably protect deep sea organisms and ocean ecological functions?

The role of a digital twin is not to identify what the thresholds should be, but to produce the information needed to evaluate whether a threshold would be crossed under certain mining conditions.

An example of a digital twin capability is to perform physical modeling of the sediment plumes - a topic for which there have been significant advances in understanding over the past 5 years - and identify when and where mining activity would exceed environmental impact thresholds, of which no agreed standard currently exists.

An effective digital twin should integrate the latest developments in modeling and thresholds in order to capture the extent of impact of a mining operation. It is recommended that any digital twins used for monitoring deep sea mining impacts utilize modern computing approaches such as graphical processing units (GPUs) and artificial intelligence (AI), as these will outperform legacy modeling systems. Ultimately, a digital twin should have the capability to be queried and answer whatever environmental impact question is posed to it.

Without environmental impact thresholds, the starting point for a digital twin is to identify where environmental metrics (e.g., suspended sediment concentration) approach natural levels. This furthermore requires parcels of the sea floor to be set aside and undisturbed in order to protect deep sea organisms and ocean ecological functions.

A number of new scientific studies of the technology trials carried out in the CCZ by Global Sea Mineral Resources (GSR) in 2021 and The Metals Company (TMC) in 2022 are increasing our knowledge, particularly of the impacts in regions directly mined and those impacted by sediment plumes. Results from these studies have been presented in public scientific conferences but many of the papers are not yet published.

Overall, a precautionary approach to adaptive management is recommended.

3. Is it accurate to say that little is known about the fate of the fine particle or dissolved components of the benthic sediment plume that could rise some distance in the water column in a DSM scenario? What do we know about how far these components will travel and the ecotoxicology associated with it?

A great deal has been learned from the two recent mining trials in the CCZ. In our peer reviewed publications, we provide estimates for horizontal and vertical extents of sediment plumes based on operational parameters and background conditions. We also provide estimates of how far these sediment plumes travel at specific impact thresholds. Some insight into the fate of dissolved components can be gleaned from the results for very fine particles. Three of our relevant publications are [2, 3, 4].

My research group does not study the ecotoxicology of sediment plumes, but relevant researchers who have either led or been involved in recent expeditions include Prof. Daniel Jones (National Oceanography Center, UK; *dj1@noc.ac.uk*) and Dr. Katja Schmidt (BGR, *katja.schmidt@bgr.de*). The CCZ is already among the most well-studied areas of the deep seabed, but increased US investment in research to characterize sediment plumes and their impacts would further improve our understanding.

4. Independent oceanographic modelling predicts the mid water discharge plume may travel from the TMC Tonga license to the waters of Kiribati and Hawaii over a 3-month period. This prediction is based on accredited oceanographic models using the best publicly available data. What specific aspects of the modelling as described in the technical notes supporting the Blue Peril visual investigation do you disagree with?

To properly evaluate any modeling approach and its results, the authors of a scientific study should submit a manuscript to a respected scientific journal to undergo peer-review, as consistent with established scientific practice. To my knowledge, the modeling approach used by the Blue Peril visual investigation has not undergone peer review.

It is widely understood that a slowly settling particle can travel a distance of 1000 km in the ocean; we state this in our 2021 study of midwater plumes [2]: "*Extent of impact of deep-sea nodule mining midwater plumes is influenced by sediment loading, turbulence and thresholds*". The same paper also makes the point - in the title, abstract and conclusions - that for a plume to cause environmental impact, there has to be a sufficient concentration of sediment; the existence of a single particle somewhere does not constitute a plume. By analogy, when an air freshener is sprayed, someone standing 10 feet away may clearly sense it, but someone standing 100 feet away won't detect it at all, even though some of the air freshener molecules technically traveled that distance.

The Blue Peril video and accompanying paper, for which the modeling was undertaken by Austides Consulting, state that a given area of the ocean could be expected to be "impacted" by sediment plumes. But neither the Blue Peril video nor the accompanying paper disclose the values of any impact thresholds they use, such as suspended sediment particle concentrations or sediment deposition rates. Without disclosing the impact thresholds that are being used, the Blue Peril simulation does not provide enough information to be useful for evaluating the environmental impact of a sediment plume.

Two of our publications [3,4], both cited by the Blue Peril paper, predict the distances at which different thresholds of sediment plume concentrations can be detected coming from collector plumes on the seabed and from midwater plumes. Our studies assume that the normal, background level of suspended sediment without any kind of disturbance is 10 micrograms (μg) of sediment per liter (L) of water, which is roughly equivalent to a pinch of sand in an Olympic sized swimming pool.

For seabed collector sites, our studies indicate that sediment plumes can be detected in concentrations of 1,000 μg/L (100 times the normal concentration and roughly equivalent to ¼ cup of sand in an Olympic swimming pool) at a distance of 1 km from the collector site, 100 μg/L (10 times the normal concentration and roughly equivalent to a teaspoon of sand in an Olympic swimming pool) at a distance of 5 km from the collector site, and the concentration of suspended sediment returns to the background level of 10 μg/L at a distance of 17 km from the collector site.

For midwater plumes, our studies indicate that the sediment plumes can be detected in concentrations of 1,000 μg/L at a distance of 4 km from the plume origination site, 100 μg/L at a distance of 20 km from the plume origination site, and the concentration of suspended sediment returns to the normal, background level of 10 μg/L at a distance of 97 km from the plume origination site. These midwater plume predictions are consistent with additional simulations conducted using an independent modeling system, as described in [2]. Note that not all deep-sea mining companies are proposing to create a midwater plume.

Our results do not support the claim that a midwater plume or collector plume at the TMC Tonga license site would produce a measurable impact in the waters of Kiribati or Hawaii.

5. The ISA set up an international expert group that has been tasked with providing inputs in three main areas of environmental concern: (a) toxicity, (b) turbidity and settling of resuspended sediments, and (c) underwater noise and light pollution. Your expertise is in sediments, which is one component of the environmental thresholds being set by the ISA How does your testimony differ from the consensus opinion of the IEG with respect to sediments and why are your predictions better?

The ISA's Intersessional Expert Group (IEG) and its subgroup on turbidity have yet to release any consensus findings, and thus I have no basis to compare my testimony. The contributions of my research group are part of the evidence base being created by the international scientific community and are being incorporated into the IEG's findings.

6. You are listed as a co-author on a long-term study published in Nature in March of this year. The paper concludes: "our results show that mining impacts in the abyssal ocean will be persistent over at least decadal timeframes and communities will remain altered in directly disturbed areas, despite some recolonisation." How do you reconcile that finding with your testimony that seemed to downplay the impact caused by seabed mining?

The findings in the study published in Nature in March of this year [5] are consistent with my testimony, in which I stated persistent biological effects have been observed from mining experiments conducted in the 1970s. One goal of my testimony was to enumerate some of the impacts caused by deep seabed mining, specifically to characterize the current state of scientific understanding around sediment plumes and to contrast that with claims made about sediment plumes that are not based on sound scientific evidence. My testimony was reviewed by several lead authors of the Nature paper and was approved by them.

7. Is it possible to remediate environmental damage in the deep sea? If so, what kind of damage and over what time frame? Is there damage that cannot be remediated? Please be specific about damage to species, sediments, water columns, noise, light, carbon cycle, and other ocean processes.

These are areas of ongoing scientific research. My expertise and ongoing research projects are focused on characterizing sediment plumes. We make our findings available to policymakers for incorporation into the complex decisions surrounding the governance of deep seabed mining. Other research groups are better positioned to provide authoritative inputs on the other topics in question. For example, there are ongoing studies by the JPI-Oceans Mining Impact 2 project investigating the ecosystem impacts of deploying artificial, inert nodules to recreate the physical conditions that preceded the collection of polymetallic nodules [6]. For further information on this, I recommend reaching out to Dr. Sabine Gollner (NIOZ, *sabine.gollner@nioz.nl*).

Expert assessment suggests that other forms of mitigation, such as set-aside areas and impact minimization through engineering design, may be more efficient management strategies than remediation [7,8]. In fact, the approach of deliberately setting aside parcels in the CCZ is already the norm. Approximately 2 million sq. km. (about 30% of the area of the CCZ) has already been set aside for protection under the ISA's CCZ Environmental Management Plan as a network of 13 "areas of particular environmental interest" (APEIs). The design and designation of the APEI network started over twenty years ago based on a series of scientific workshops (led initially by US scientists) and has been refined on several occasions. To date, all entities granted exploration contracts by the ISA have followed ISA guidelines on the protection of these regions.

For matters related to carbon sequestration, the following publication provides an assessment of the risks [9], determining them to be 'trivial'. For further details, I recommend reaching out to Prof. Beth Orcutt (Bigelow Laboratory for Ocean Sciences; *borcutt@bigelow.org*) and Dr. Bryan O'Malley (USA; *bjomalle@eckerd.edu*).

As I stated in my testimony and my remarks, federally-funded research programs that invest in our understanding of the impacts of deep seabed mining on biodiversity and other ocean processes are important and necessary.

References

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