Policy brief

Scaling up in the Clarion-Clipperton Zone

Overview

- Commercial-scale exploitation of polymetallic nodules can have a **large footprint** of impacted seabed, potentially doubling the footprint of global mining land use. We need to consider **if, and how, our current understanding of ecology and impacts can be scaled up**.
- The CCZ has significant **environmental variation at every spatial and temporal scale** investigated by SMARTEX, so there is no 'one size fits all' for management.
- **Higher than expected temporal variability** may hamper differentiating mining impacts from natural processes, so a consistent monitoring methodology is required.
- Temporal dynamics could form the basis of some **mitigation measures**, such as temporary closures, in relation to natural processes such as seafloor currents or reproductive seasons.
- **Upscaling is not straightforward** as relationships between scales are not necessarily linear. Multi-driver studies combined with experiments, nested-sampling, and nested-modelling approaches, can aid upscaling exercises.

Figure 1. Sea cucumber on the abyssal seafloor (4700 m depth) of the Pacific Clarion Clipperton Zone (National Oceanography Centre and Natural History Museum / SMARTEX).

Policy context

Commercial-scale nodule mining may have a large footprint.

The Clarion-Clipperton Zone (CCZ) in the Central Pacific stretches over roughly 5000 km from east to west (ISBA/17/LTC/7). Assuming 10% of all current exploration contract areas will be exploited over 30-50 years (Smith et al., 2008), this equates to 142,500 km^2 of the CCZ seabed to experience direct disturbance[1]. For comparison, the footprint of global terrestrial mining land use is currently estimated to be just over 100,000 km^2 (Maus et al., 2022), but may more than double in the near future[2].

Scaling up the science for management.

With the current ambition to soon finalize the ISA Exploitation Regulations (Pickens et al., 2024), the occurrence of commercial-scale mining and multiple parallel operations is increasingly likely. Understanding these potential wide-area and long-term impacts needs understanding of ecological processes and impacts at the same scales for effective management. To meet this challenge, we need to assess if and how we can scale up our understanding of habitats, species, and processes and their potential change (Figure 3).

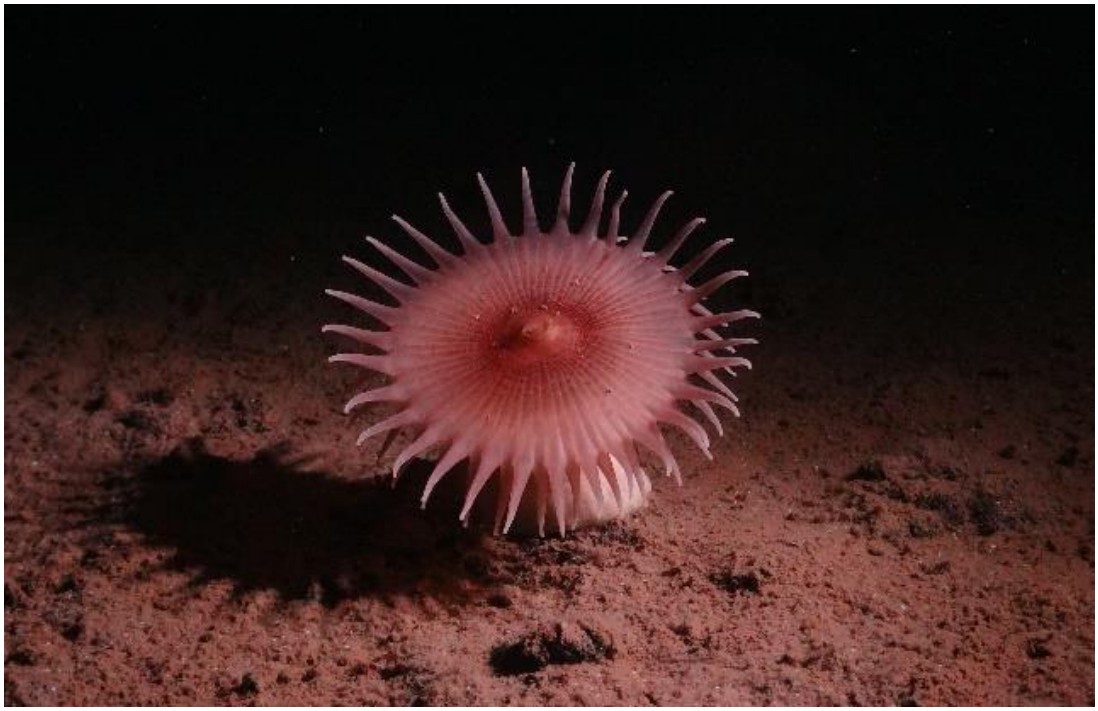

Figure 2 Large anemone in the CCZ at 4100 m (National Oceanography Centre and Natural History Museum / SMARTEX).

[1] The CCZ is roughly 4,500,000 km^2, with currently 19 exploration contracts covering approximately 1,425,000 km2 (32% of CCZ). Additionally, there is a network of 13 Areas of Particular Environmental Interest (APEIs) representing 1,970,000 km2 of seabed (44% of CCZ).

[2] In the next 30 years, it is expected a similar amount of material will be mined on land to what has been mined throughout humanity's history in total, to meet material demands for decarbonisation in light of decreasing ore grades and increased need of diversity of elements (Lusty et al., 2021).

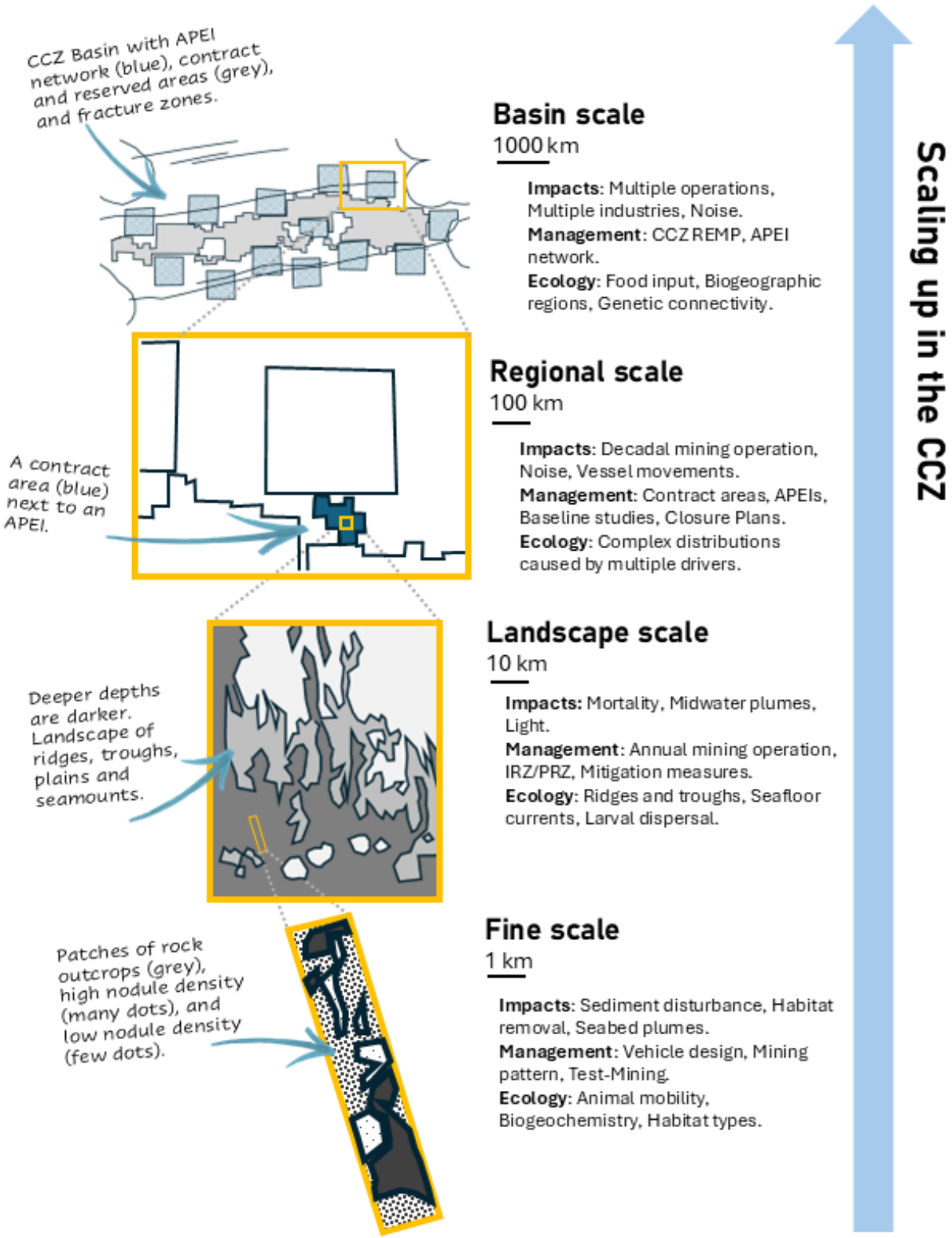

Figure 3. Scaling up in the CCZ from fine scale (<100 m) to landscape scale (100s m - 10s km) to regional scale (10s – 100s km) to basin scale (100s-1000s km). A non-exhaustive list of examples is given of impacts, management, and ecology relevant at each spatial scale (Danielle de Jonge / SMARTEX).

SMARTEX findings

Spatial variability exists at every investigated scale.

Basin scale (100s – 1000s km): At a basin-scale, SMARTEX and other studies are showing clear environmental patterns that extend across the CCZ (Washburn et al., 2021). Ocean circulation causes an overall reduction from east to west in food supply sinking to the seafloor, correlated to a reduction in megafauna[3] and macrofauna[4] density (Bonifácio et al., 2020; Simon-Lledó et al., 2023a). From east to west, there is a step change in the composition of animal communities, likely related to seawater chemistry which regulates the depth at which calcareous shells and skeletons[5] dissolve (Simon-Lledó et al., 2023a). Organisms that require calcareous materials (such as shellfish and corals) mostly occur in the Eastern CCZ, whereas in the Western CCZ organisms that do not require shell materials (such as anemones) are more dominant. These SMARTEX results are supported by other studies that suggest similar patterns occur in microbes and meiofauna[6] (Hauquier et al., 2019; Wear et al., 2021).

Regional scale (10s – 100s km): Regional patterns are complex and likely driven by multiple factors. Generally, communities become less similar to each other as distance increases, dropping from around 50% similarity at 100 km to 25% similarity at 1,000 km distances in both megafauna and macrofauna (Simon-Lledó et al., 2025; Stewart et al., 2023). Communities of highly-mobile animals remain relatively similar across greater distances.

Landscape scale (100 m – 10s km): The landscape of the CCZ is one of rolling hills and valleys[7] up to a few hundred meters high that typically run from north to south, interspersed with flatter plains and occasional seamounts. The distance between hill ridges is often around 10 km, but is variable. The hill tops and valleys have a different faunal composition, likely related to local bottom-water flows and the availability of hard substrate (Simon-Lledó et al., 2019). For example, SMARTEX demonstrated faster seafloor currents on a ridge compared to an adjoining valley.

Fine scale (<100 m): Within each landscape feature, there are patches of different fine-scale habitat types, such as exposed rocks, and high versus low nodule density habitats. For example, rocky outcrops support a lower density but a higher diversity of megafauna compared to nodules (Mejía-Saenz et al., 2023). Similarly, SMARTEX visited such fine-scale features and found visibly distinct and likely important communities (contact: L. Van Audenhaege).

Figure 4. Sponge and sea star on nodules (National Oceanography Centre and Natural History Museum / SMARTEX).

[3] Large animals (>1 cm) living on the seafloor.
[4] Smaller animals (<1 cm) living within the sediment and in and on nodules.
[5] The Carbonate Compensation Depth (CCD) regulates the solubility of calcium carbonates.
[6] Even smaller organisms (<1 mm) living among sediment grains.
[7] Called 'ridges' and 'troughs', respectively, in a marine setting.

Temporal variability appears higher than previously thought, with dynamic processes ranging from decades to minutes.

Evidence is emerging of benthic communities responding to climate cycles (Kaiser et al., 2024). **SMARTEX had the opportunity to study multi-decadal differences** in macrofauna between 1989 and 2023 (Wilson, 2017; and contact: R. Drennan) and megafauna between 1978 and 2023 (Figure 5, contact: B. Fleming), and several groups in detail between 2023 and 2024, using consistent sampling methods. Preliminary results indicate changes in community composition over multi-decadal timescales.

SMARTEX insights suggest certain **surface currents**[8] **can lead to changes in deep-ocean currents on timescales of a month or longer**. Generally, seafloor currents are weak and go back and forth with the tide. However, we measured periods of stronger flow in a single direction across an extensive region (Aleynik et al., 2017). Strong currents can lead to changes in feeding activity, behaviour (contact: L. Van Audenhaege), and larval dispersal (contact: M. James), as well as the potential behaviour of mining plumes. Separately, episodic food falls have also been observed, which can take minutes to years to process, depending on the source (Simon-Lledó et al., 2023b; and contact: L. Van Audenhaege).

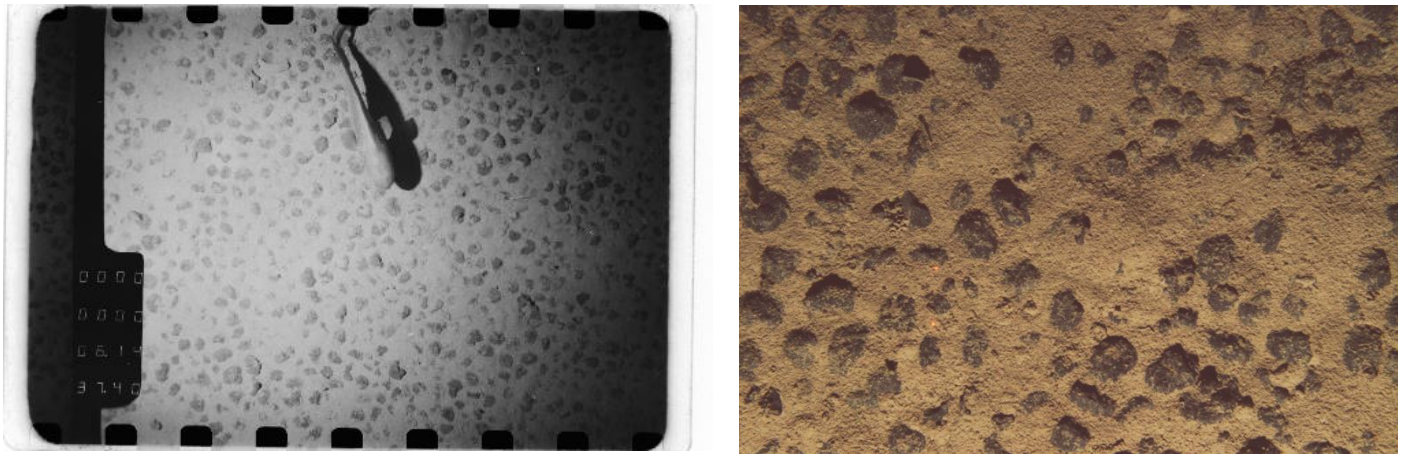

Figure 5. CCZ seafloor in 1978 (left, OMCO) and 2023 (right, SMARTEX).

[8] Eddies and meanders, with a scale of around 200 km.

Policy implications

The CCZ has significant environmental variation at every investigated scale in time and space, so there is no 'one size fits all' for management.

Although broad-scale patterns set the scene for regional management, finer-scale assessments are required because most impacts will likely occur at local scales. For example, the general north-south orientation of hills and valleys will be reflected in mining survey planning, with mining restricted to near-flat areas for operational reasons (slope < 3° - 7°). **Such near-flat areas cannot automatically be considered similar** as local variations in seafloor features exist within those areas, for example in micro-topography and sediment type (Peukert et al., 2018).

Because of the high environmental variability, it **may be necessary to obtain fine-scale data** for all environmental variables of interest until sufficient similarity across wider spatial scales is demonstrated. Furthermore, **multiple preservation reference zones may be required** to sufficiently cover a representative variety of landscape features and habitats, with a trade-off between representativity (e.g. areas within ~10 km) and distance from the mining site to prevent impacts. Finally, fine-scale features and processes should be considered in planning. For example, **the density of mining activity may affect recovery**, as currently being modelled by SMARTEX (contact: S. Oliver).

Understanding temporal variability is crucial for identifying impacts and mitigation measures.

The greater than expected temporal variability in the CCZ **may hamper differentiating mining impacts from natural processes**. It may therefore be necessary to plan site-specific monitoring over various relevant timescales at both impacted and unimpacted areas, unless baseline studies can demonstrate sufficient similarity across longer time periods. For temporal monitoring **sampling techniques should be kept consistent over time** for at least some proxy variables, even if technology develops, as highlighted by the multi-decadal studies in SMARTEX (contact: R. Drennan and B. Fleming).

Adjusting mining operations (such as through temporary closures) in response to natural processes (such as seafloor currents and reproductive seasons), could form **the basis of some mitigation measures** to avoid, minimise, and recover from impacts. For example, whether periods of unidirectional high flow result in changes to the extent, magnitude, and ecotoxicological effects of the mining plume could be studied drawing on baseline data from SMARTEX (contact: A. Dale and M. Hartl). Potentially, higher flows may aid recovery through faster and wider larval dispersal. More information on temporal life history patterns, such as periods of reproduction and migrations, is required as this is currently severely understudied (contact: M. James and J. Copley).

Deep-sea ecosystems will additionally be affected by **climate change** (Levin et al., 2020). Ocean acidification will move the boundary beyond which calcareous materials dissolve eastwards in the

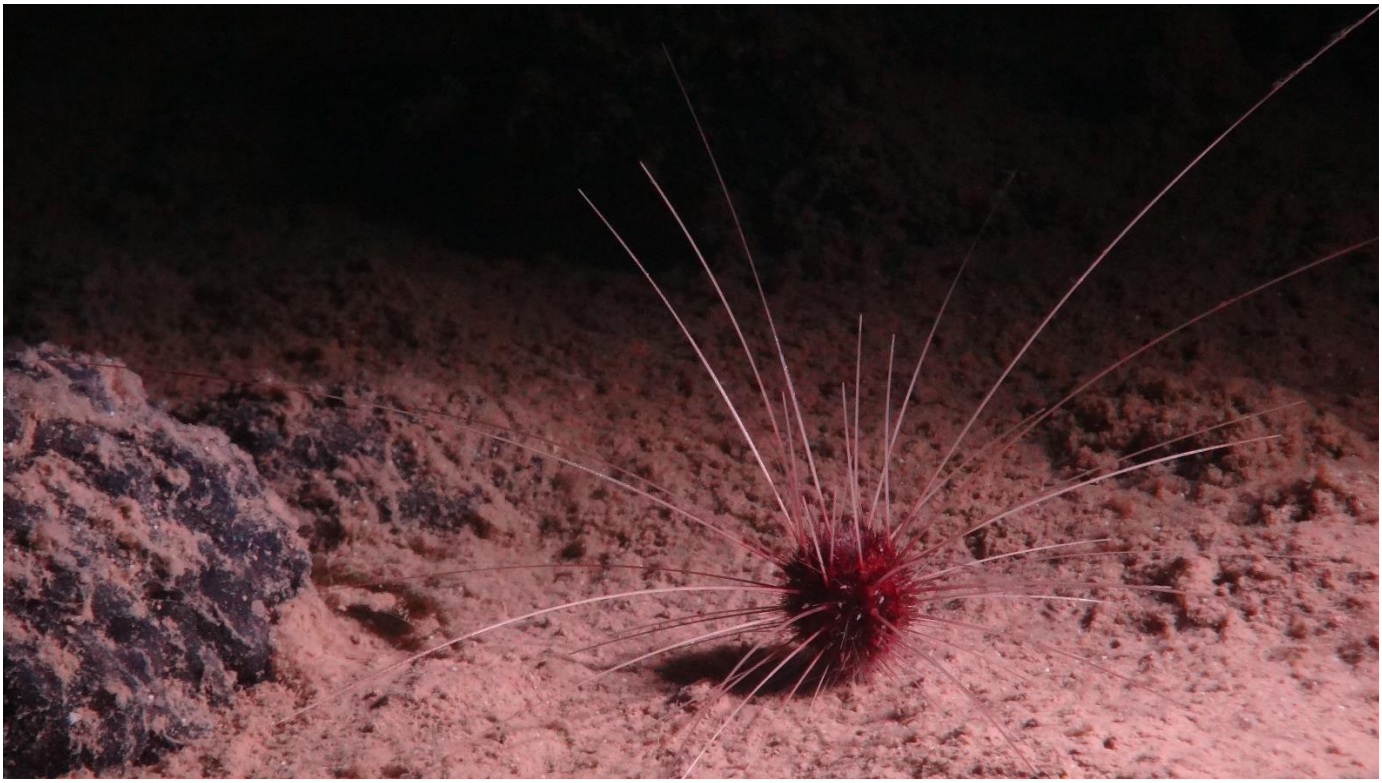

Figure 6. Sea urchin on the abyssal seafloor of the Pacific Clarion Clipperton Zone (National Oceanography Centre and Natural History Museum / SMARTEX).

CCZ, and communities beyond this boundary will likely change in their composition (Simon-Lledó et al., 2023a). In SMARTEX, some changes in the physical and biological environment were suggested to be related to El Niño[9] events. With stronger El Niño events expected due to climate change, such episodes of change may increase in frequency, strength, and duration.

Upscaling baselines and impacts in limited space and time to wider areas and longer time frames is not straightforward.

SMARTEX insights suggest that if the biology of a ~1 km^2 area is sufficiently characterised, then directly adjacent areas with the same physical characteristics likely have similar biological characteristics over several kilometres. Areas tens to hundreds of kilometres away with the same physical characteristics will be more biologically distinct, thus limiting the amount of direct upscaling possible (Simon-Lledó et al., 2025; Stewart et al., 2023). Research into both **small- and large-scale drivers of environmental change combined with nested approaches will aid upscaling** baseline patterns. Upscaling predicted impacts from component testing or test mining to commercial-scale mining and parallel operations requires insight into ecological tipping points and non-linear responses. **Experiments and models can help identify such tipping points and non-linearities**, such as those currently being conducted in SMARTEX (contact: A. Sweetman and S. Oliver).

[9] La Niña and El Niño link to a climatic forcing mechanism involving wind and ocean currents. El Niño years are characterised by generally warmer global temperatures, while La Niña years are generally cooler.

About this policy brief

This policy brief was produced by the SMARTEX research project, a UK science-funded multi-disciplinary research project studying the Pacific abyss. The main contacts are listed for ongoing work, and the full project team can be found on the website (https://smartexccz.org). For further information you can contact project lead Prof. Daniel Jones (dj1@noc.ac.uk) or policy lead Dr. Danielle de Jonge (danielle.dejonge@jncc.gov.uk). Funding for the SMARTEX project is provided by the UK's Natural Environment Research Council. SMARTEX is an endorsed UN Ocean Decade Project under the 'Challenger 150 - A Decade to Study Deep-Sea Life' Programme.

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