Exploring the Depths: The Effects of Deep-Sea Mining on Marine Diversity

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Abstract: The deep sea—dark, vast, and still largely unknown—has become the latest frontier in humanity's search for resources. As demand for critical metals such as cobalt, nickel, and rare earth elements grows, industries are turning toward the ocean floor thousands of meters below the surface. Deep-sea mining (DSM) offers the promise of supporting renewable energy and green technologies, but it also raises urgent ecological and ethical concerns.

This paper investigates DSM, its methods, its ecological risks, and the debates surrounding its future. Evidence shows that mining threatens fragile ecosystems that took millions of years to form. Recovery from mining scars can take centuries—or may never fully occur. The conclusion argues for precaution, stronger governance, and investment in alternatives such as recycling and circular economies.

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I. INTRODUCTION

The ocean floor covers more than two-thirds of Earth's surface, yet scientists have mapped Mars more thoroughly than the deep sea (NOAA, 2023). This hidden world is home to strange creatures, unique ecosystems, and mineral deposits that have been forming for millions of years.

Governments and corporations see these deposits as vital for renewable energy systems, including electric vehicle batteries, wind turbines, and solar panels (Levin et al., 2020). However, the contradiction is clear: mining meant to support sustainability could destroy species and habitats that we have barely begun to understand (Drazen & Smith, 2020).

This raises the central question: can humanity balance exploration with protection, or are we risking irreversible ecological harm for short-term gains?

➢ *What is Deep-Sea Mining and How Does It Work? DSM Focuses on Three Main Types of Deposits:*

- *Polymetallic Nodules*
  Potato-sized rocks scattered across abyssal plains (3,500–6,000 m deep), rich in manganese, cobalt, nickel, and copper. Each one takes millions of years to form.

- *Polymetallic Sulfides*
  Mineral-rich deposits at hydrothermal vents ("black smokers"), containing copper, zinc, and sometimes gold.

- *Cobalt-Rich Ferromanganese Crusts*
  Found on seamount slopes (800–3,000 m deep), containing cobalt and rare earth elements.

The mining process resembles strip-mining underwater. Remote-operated vehicles (ROVs) scrape or vacuum the seafloor, with material pumped to surface vessels. Waste—slurry, sediment, and wastewater—is dumped back into the ocean, creating plumes that drift unpredictably for hundreds of kilometers (Levin et al., 2020).

Recovery is uncertain. Some mined areas remain visibly scarred decades later (Drazen & Smith, 2020).

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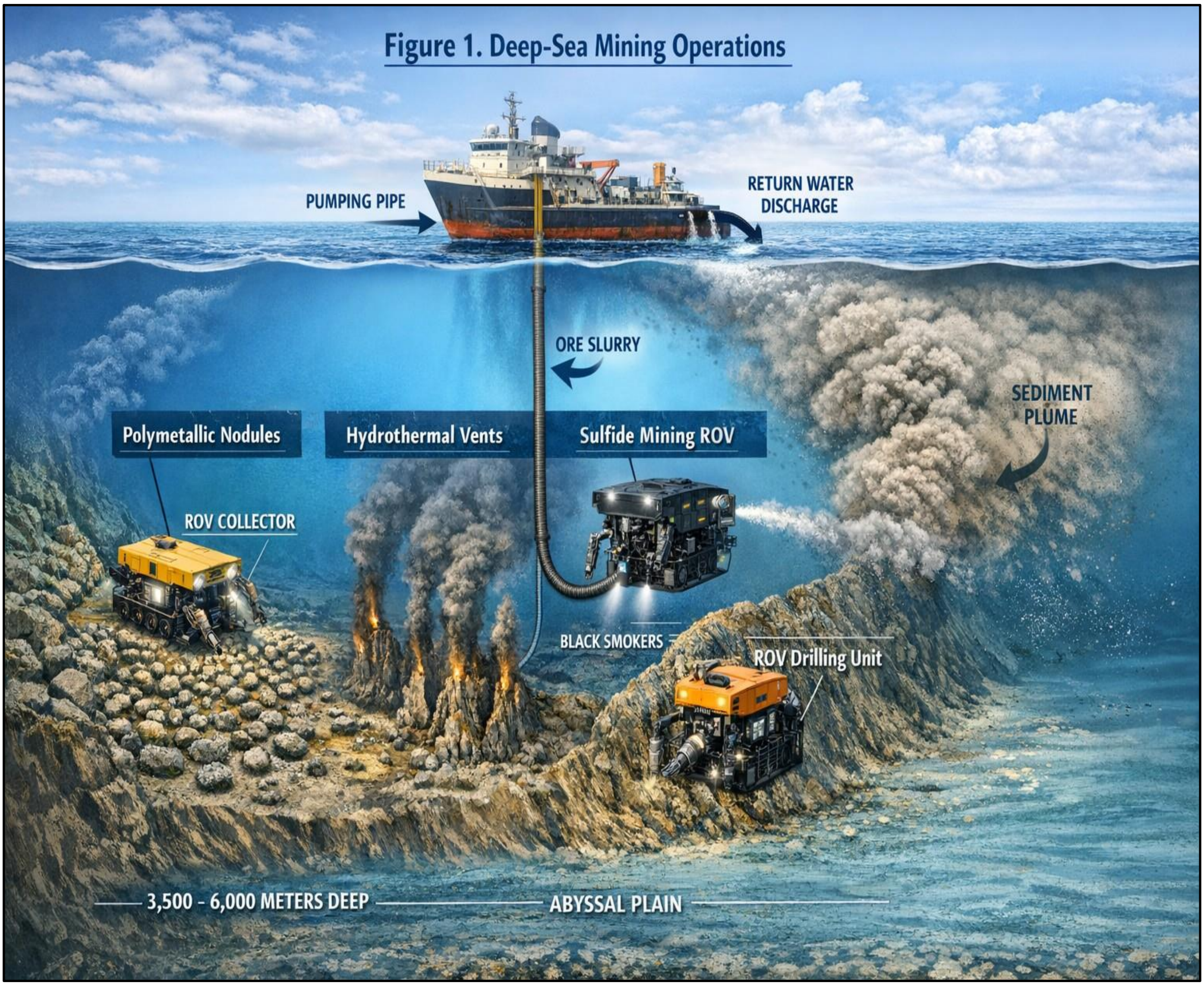

Fig 1 Diagram Showing Deep-Sea Mining Operations Using ROVs to Collect Nodules, Sulfides, and Crusts, with Extracted Material Pumped to a Surface Ship.

II. METHODOLOGY

This study draws from a literature review of scientific reports, policy documents, and legal frameworks, including:

IUCN Issues Briefs (2022)

United Nations Convention on the Law of the Sea (UNCLOS, 1982)

Peer-reviewed studies (Marine Policy, PNAS, Frontiers in Marine Science) NOAA Ocean Exploration resources (2023) These sources provided the foundation for analyzing DSM's ecological risks, global distribution, and governance issues.

- *Global Distribution of Deep-Sea Mining Activities*

DSM exploration is not confined to a single region—it spans multiple oceans. The International Seabed Authority (ISA) has issued over 30 exploration contracts. Key hotspots include:

Clarion–Clipperton Zone (Pacific Ocean): Vast nodule fields, with contracts held by China, Japan, Korea, Germany, and Belgium.

Northwest Pacific (Japan, Korea): Exploration focused on cobalt-rich crusts. Indian Ocean (India, China): Nodule and sulfide exploration zones.

Mid-Atlantic Ridge (Europe, Russia): Sulfide mining potential. South Atlantic (Brazil): Nodule fields. Cook Islands & Tonga (Pacific): Cobalt-rich crust exploration.

These areas highlight DSM's global reach and the growing international competition for resources (ISA, 2021).

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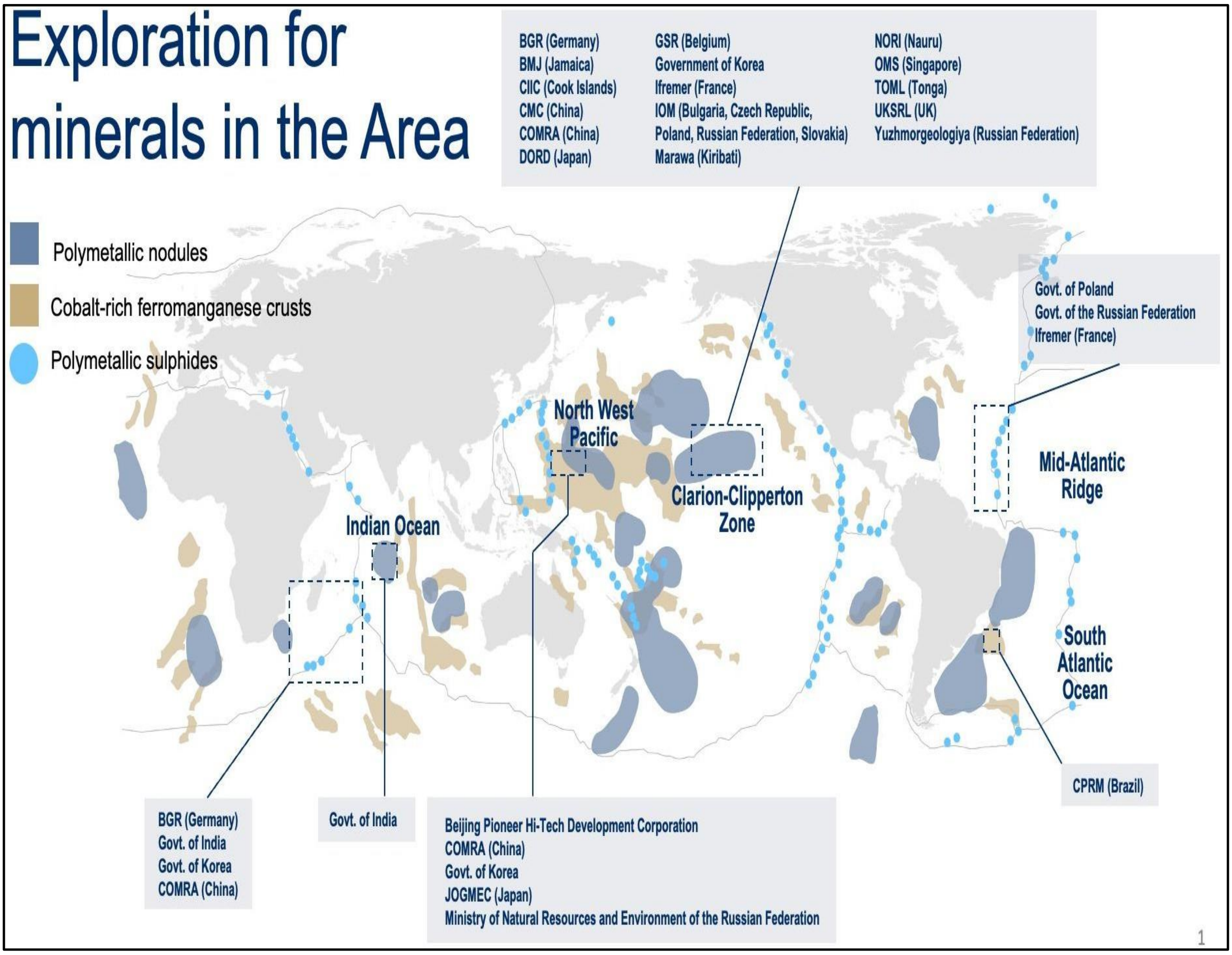

Fig 2 Map of International Exploration Areas for Deep-Sea Minerals, Including Polymetallic Nodules, Cobalt-Rich Crusts, and Sulfides (ISA, 2021).

III. RESULTS

➢ *The Evidence Shows Several Ecological Risks:*

- *Habitat Destruction:*

Nodules and crusts provide critical habitats for corals, sponges, and microbes. Mining removes these ecosystems entirely.

- *Sediment Plumes:*

Waste plumes may drift for hundreds of kilometers, smothering organisms far beyond the mine site (IUCN, 2022).

- *Noise and Light Pollution:*

Mining brings artificial sound and light to an environment adapted to silence and darkness, disorienting marine species.

- *Carbon Cycle Disruption:*

Disturbing sediments may release stored carbon, weakening the ocean’s climate-regulating role (Drazen & Smith, 2020).

- *Extinction Risk:*

Many deep-sea species are endemic. Mining could drive them extinct before they are even recorded (Levin et al., 2020).

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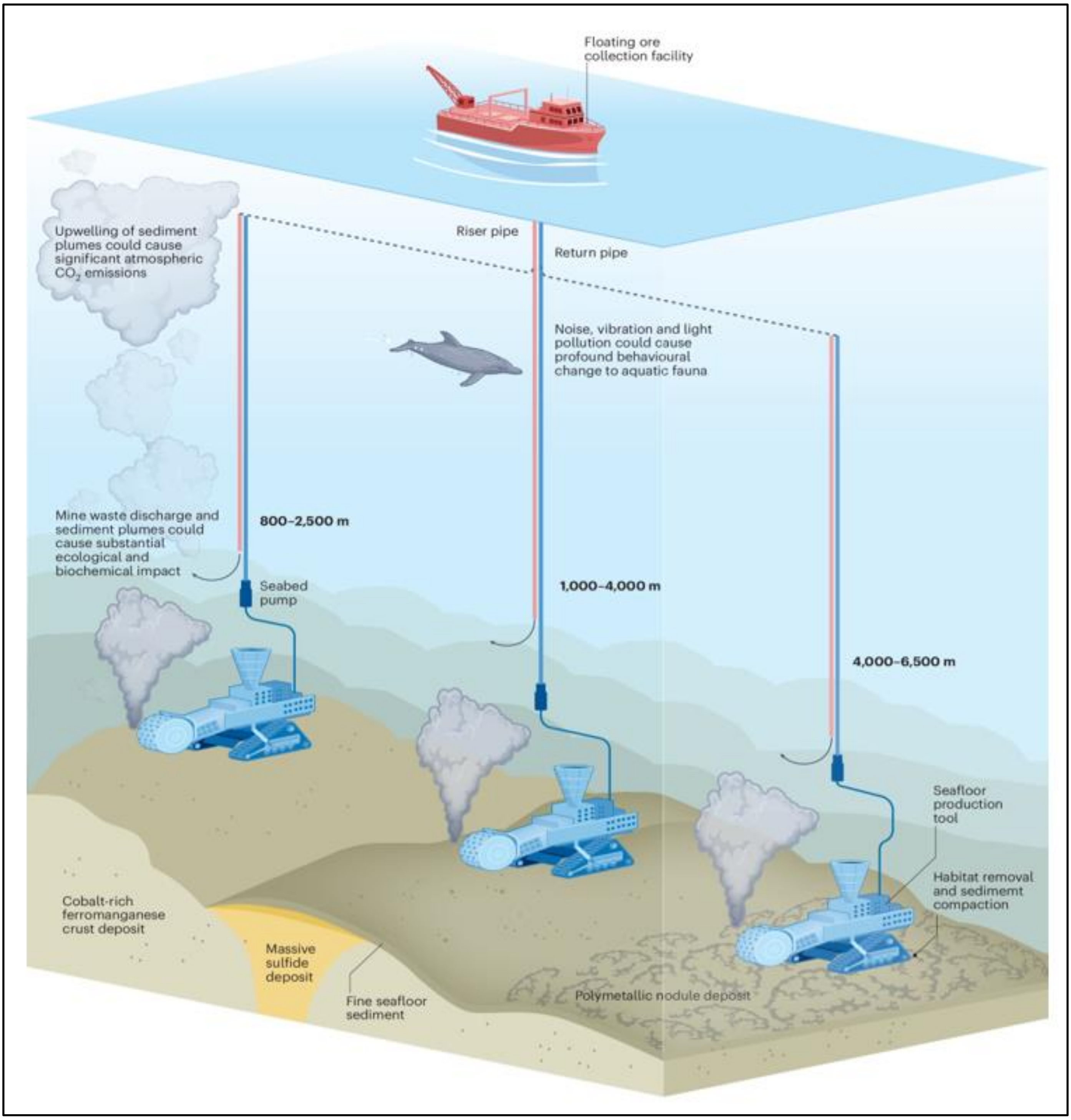

Fig 3 Illustration of Mining Operations Showing Sediment Plumes, Return Water Discharge, and Ecosystem Disruption.

IV. DISCUSSION ECOLOGICAL RISKS

DSM endangers biodiversity hotspots such as hydrothermal vents and abyssal plains. Recovery is extremely slow; scars from past experiments remain visible after decades (Reuters, 2025).

➢ *Carbon and Climate Links*

Sediment disturbance could release stored carbon, reducing the ocean's ability to buffer climate change.

➢ *Human Implications*

Plumes may harm fisheries, which support millions of people globally. Disruptions to food chains threaten coastal communities.

➢ *Legal and Ethical Issues*

The UNCLOS (1982) declares the seabed the "common heritage of humankind." If DSM primarily benefits corporations and wealthy nations while damaging shared ecosystems, it poses serious ethical questions about justice and stewardship.

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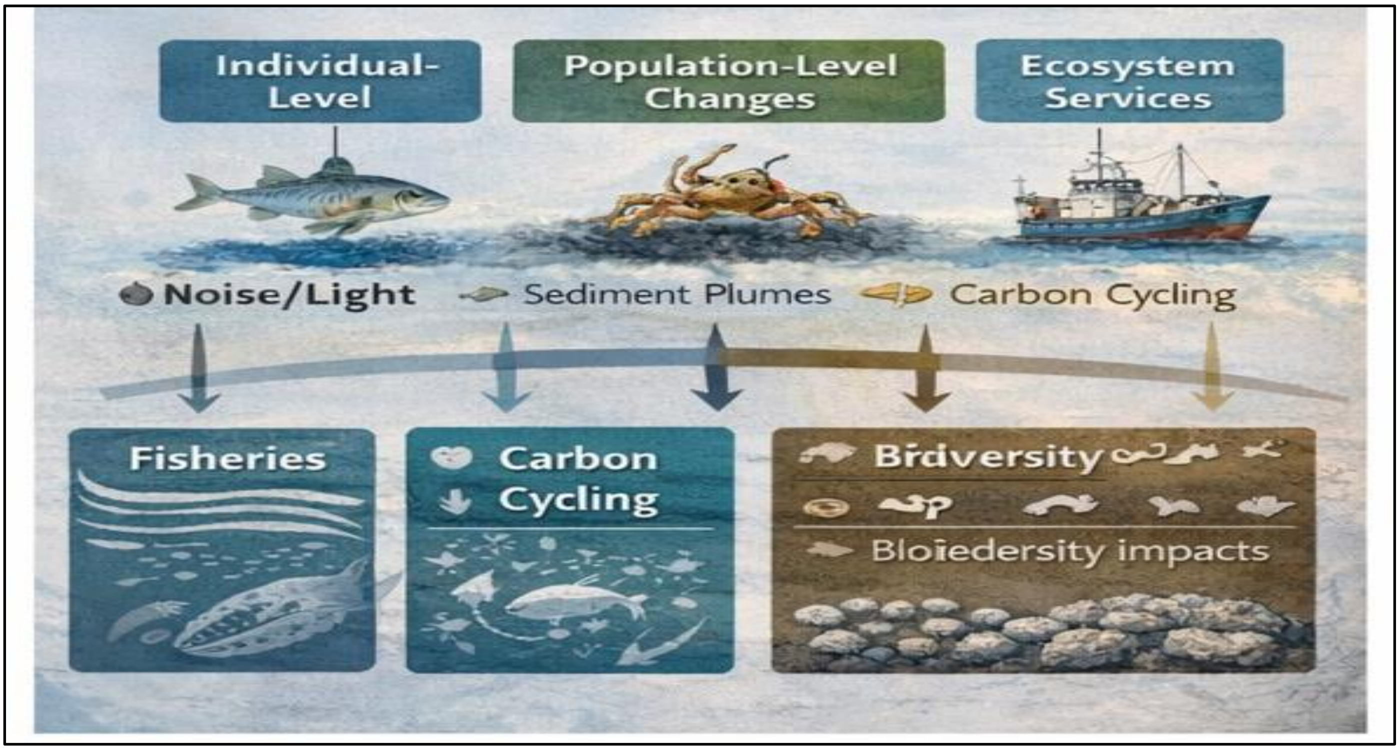

Fig 4 Diagram Showing Ecological and Human Impacts of DSM—from Species-Level Disruption to Ecosystem Services Such as Fisheries and Carbon Cycling.

V. CASE STUDY: THE CLARION–CLIPPERTON ZONE (CCZ)

The CCZ, between Hawaii and Mexico, covers 4.5 million km² and contains the world's richest polymetallic nodule fields. Nodules here act as "islands of life," hosting sponges, worms, and unique species.

- *Evidence of Long-Term Damage is Clear:*

- ✓ In 2020, scientists revisited a site mined 26 years earlier—it remained scarred.
- ✓ In 2025, further research confirmed visible mining marks even after 40 years (Reuters, 2025).
- ✓ The CCZ illustrates DSM's potentially irreversible impacts on biodiversity and ecosystem services.

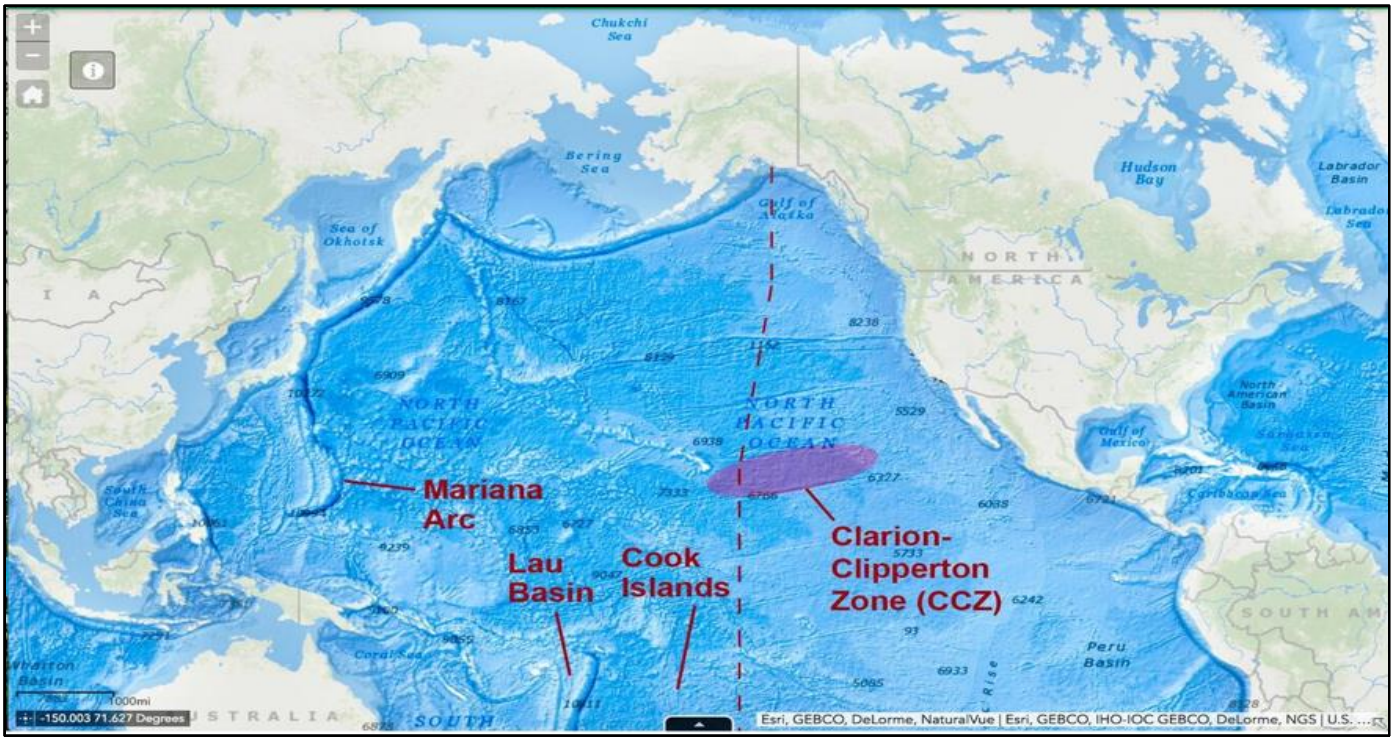

Fig 5 Map of the Clarion–Clipperton Zone (CCZ), the Pacific's Largest Nodule Mining Frontier.

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VI. RECOMMENDATIONS

The IUCN World Conservation Congress (2021) passed Resolution 122, urging a moratorium on DSM until:

Ecological risks are fully understood. Strong safeguards are enforced.

➢ *Governance is Transparent.*

- Alternatives such as recycling and circular economies are prioritized.
- Nations such as France, Palau, and Chile already support this pause—an encouraging step toward precaution.

VII. CONCLUSION

Deep-sea mining presents a defining environmental dilemma: it offers resources for renewable energy while threatening ecosystems that took millions of years to form.

The evidence is clear: risks are high, recovery is uncertain, and knowledge is limited. The responsible course is to pause, study more, and pursue alternatives before committing to an irreversible path.

The deep sea is not merely a storehouse of minerals. It is a living, climate-regulating system essential to planetary balance. Protecting it is not optional—it is a responsibility to future generations.

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