IJDSME- International Journal of Deep Sea and Marine Ecosystems
**Volume 2, Issue 2 | October-2025**
**e-ISSN: 3067-073X Print ISSN: 3067-0721**

# The effects of deep-sea mining taking place in the Clarion-Clipperton Zone Benthic Faunal Diversity in the Eastern Pacific Ocean

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**Received: 12-08-2025; Revised: 01-09-2025; Accepted: 19-10-2025; Published: 30-10-2025**

## Abstract:
***The research simulated an effect of deep-sea mining on benthic faunal diversity on deep seabed within the populace of polymetallic nodules in the Pacific Ocean and Eastern Clippers in the Clarion-Clipperton Zone of the eastern Pacific Ocean. Transect sampling of the remotely operated vehicle (ROV), along with the sediment cores in four experiment sites allowed the researchers to describe 328 macrofaunal taxa and evaluate the level of sediment disturbance, carbon content and oxygen penetration. The outcomes indicated that biodiversity was greatly reduced after the zones were mined, with a Shannon index of 2.38 against the 3.72 in non mined areas. Besides, recovery levels were weak, even two years after mobilization. The paper points out the ecological dangers of long-term deep-sea mining, the necessity of deep-sea mapping of biodiversity baselines and protective measures to be taken before commercial deep-sea mining operations start. The results support the idea that more regulations and mid to long-term monitoring should be implemented in order to preserve the vulnerable deep-sea ecosystems and attenuate the consequences of mining in CCZ and the marine biodiversity.***
**Keywords:** ***Deep-sea mining, benthic, Clarion-Clipperton Zone, loss of biodiversity, the impact of human activity, marine ecosystems.***

## 1. Introduction

### 1.1 The Clarion-Clipperton Zone and Deep-Sea Biodiversity and Mineral Resources

Clarion-Clipperton Zone (CCZ) is a large region, which is about 7 km thick and contains polymetallic nodules, found in the central eastern Pacific Ocean that is a rich source of integral minerals like nickel, cobalt, copper, and rare earth minerals. The region of about 4.5 million square kilometers has been gaining much interest because it has large deposits of this mineral which are important in the manufacture of electronic devices, batteries and other technology that is significant towards developing green energy. The CCZ is, however, not only rich in minerals but also its benthic ecosystems are unique and poorly known and many have high faunal diversity with many of these faunal communities being endemic to the CCZ deep sea environment.

Deep-sea communities inhabiting the CCZ comprise macrofauna (large benthic animals), microfauna and benthic invertebrates vital to the ecosystem processes of the deep sea. Ecosystems play a key role in controlling biogeochemical cycles, carbon stores and nutrient cycling with wide ramifications to ocean health and climate control. Although the biological importance of the CCZ cannot be neglected, its exclusive deep sea eco-systems are imperfectly studied and insufficiently comprehended, in particular their dynamics and way of reaction to the external perturbations.(1)

### 1.2 International Demand of Polymetallic Nodule Mining

An increase in the demand of minerals, especially to use in clean energy technologies, such as clean energy automobiles, batteries, and solar panels, has resulted in a growing international interest in the extraction of polymetallic nodules in the CCZ. The government and mining businesses have progressively been adopting strategies to mine these supplies of deep-sea minerals, as they seek a long-term supply of these essential elements. The exploration and a possible mining of the region is controlled by the International Seabed Authority (ISA), whose purpose is to maintain environmental protection as well as the economic utilization of the area. Nevertheless, even though interest in deep-sea mining is growing, the technology of the nodule extraction, together with its possible environmental effects, is little regulated and underestimated. To this end, scientific research is highly demanded to assess the ecological impact of mining activities prior their continued development on a commercial basis.

### 1.3 Ecological issues and information gaps in benthic disturbance of habitat Ecology

The polymetallic nodule mining suggests removal of huge mass of the seabed sediments thereby inflicting physical damage to the benthic habitation and the resulting danger of disappearance of the benthic biodiversity. The process can create feeding plume that will suffocate vulnerable organisms and disrupt the food web further disturbing the intricate ecological network that has evolved in deep-sea habitat. Moreover, the deep-sea ecology in the CCZ is so sensitive and the recovery is very slow because the environment is harsh with low temperature, high pressure and fewer nutrients.(2)

The mechanisms of the deep-sea ecosystem responses to perturbed conditions are poorly understood, and there is little-known about long-term ecological consequences. Deep-sea habitats tend to recover slowly, which is a major challenge to their recovery following the disturbance, and many species may be lost forever should the disturbances accumulate to become beyond repair. These processes are also essential knowledge as a foundation of guiding environmental management and regulations prior to conducting large-scale commercial mining.

### 1.4 Study Purpose: To evaluate the Possibility of Biodiversity Loss and Recovery after Disturbance

This study seeks to evaluate the effects of simulated polymetallic nodule mining on benthic faunal diversity in the CCZ in terms of the loss of biodiversity as well as recovery of the fauna in the zones disturbed by the mining activities. The study, with the assistance of remotely operated vehicles (ROVs), sediment sampling, will find and list the macrofaunal taxa in areas of the unexplored area of the mine and undisturbed areas of the experiment sites. Sediments disturbance, carbon content, and the penetration of oxygen can also influence the re-establishment and health of benthic communities, thus the study will also evaluate the above.

Notably, such research will add to the knowledge of the long-term ecological hazards of deep-sea mining operations and supply useful information to create efficient environmental protection and recovery programs. In the final, the research would fulfill the knowledge blinders on the negative effects of mining on the deep ocean; stepping towards more enlightened decision making about the management and conservation of such important sites.(3)

## 2. Design of the Survey and Description of the Study Site

### 2.1 Decision-Making Process on Location and Criteria of Impacted and Control Sites of the CCZ

This study was carried out in Clarion-clipperton Zone (CCZ) in the central easterly Pacific Ocean which is the richest polymetallic habitat areas, which are under exploration as deep sea mining sites. The CCZ is about 4.5 million square kilometers in size and has a comparatively homogeneous seafloor area and so, the area is suitable to examine the mining disturbance effects on the benthic ecosystems.

In order to evaluate effects of the mining on benthic faunal assemblages, the study used impacted and control sites in the CCZ. The affected sites were selected on grounds where there are areas that were previously used to resemble mining disturbances where the activity involved removing the sediment material and extracting the nodules is intended to take place or simulated in order to carry out this study. The control sites, however, were perceived as the regions that lacked any disturbance caused by the mining process and acted as natural control regions to compare biodiversity and the structure of the faunal community of the influence and undisturbed areas.

### 2.2 The choice of the both impacted and control sites was based on a number of criteria:

Nearness to possible mining areas: Places where mines were going to be set up in future or next to them were chosen as affected territories.

Environment similarity: The sites intended to be impacted and controls were compared in the features they shared in term of depth, type of sediment, temperature, and water chemistry so that any difference in biodiversity could be attributed mostly to the mining disturbance and not to the intrinsic environment.

Survey of ROV and Sediment sampling: ROVs played a critical role in the fieldwork of the study and thus both the impacted and control sites had to be open to ROV surveys and sediment sampling.(4)

### 2.3 Introduction to mining Simulation Zones and reference Natural Areas

Mining Simulation Zones: The affected areas of the CCZ were chosen to identify places where simulated extraction of polymetallic nodules was to be performed and sediment been disturbed. The simulation included the excavation of the surface sediments and the upset of the seabed and that this is supposed to be the same process that will be employed in the commercial mining. This destabilization causes a loss of habitat, sediment plumes, and interruption of biogeochemical cycling and gives us some idea of what long-term impacts mining may have on benthic community

Natural Reference Areas: Natural reference areas represented the set areas where the control sites were selected having been based on locations within the CCZ that were not affected by mining. These form pristine benthic sites serving as a reference point environment on which to compare the ecological integrity and faunal diversity of

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manipulated sites. These zoning areas are important in providing information regarding the status quo of the benthic ecosystems of the CCZ and how much biodiversity will be lost as a result of the simulated mining taking place in the CCZ.(5)

**2.4 Summary of Documented Environmental Parameters**

In an attempt to access the effects of mining disruptions, the scenario observed several parameters in the environment affected and the control location. These included:

Benthic Faunal Diversity: ROV transects were used and the presence of macrofaunal taxa was identified and documented. Biodiversity indices like Shannon index were used to compute species richness, abundance and diversity.

Sediment Characteristics: During the collection, sediment samples were taken in order to determine the content of carbon, organic matter, and depth of oxygen levels as good measures of habitat quality and faunal health. There were also recordings of disturbance to the sediment which has a direct impact on the benthic organisms that live on the stable surface.

**2.5 Physical Parameters:**

The salinity and temperature of water were determined at different depths to achieve the similarity of environmental conditions in the study sites.

Oxygen was measured in the sediment since availability of oxygen is a determining factor to many of the benthic organisms.(6)

Disturbance Indicators: Degree of sediment disturbance i.e. depth of sediment erosion and plume with regard to sediment erosion was observed in order to determine the extent of imposed simulated mining activities.

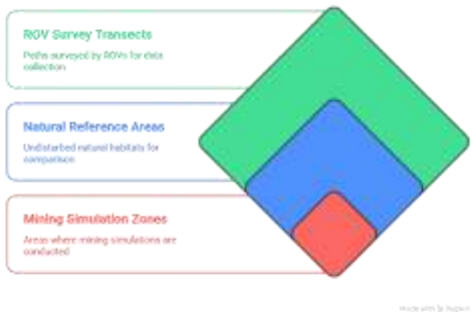


**Figure 1:** Experimental Design and where the Research will be Conducted in the Study

## 3. Sampling procedures and analyses methods

**3.1 Visual Faunal Assessment using ROV Transects**

To evaluate the faunal diversity in the mined and intact areas of the Clarion-Clipperton Zone (CCZ) remotely operated vehicle (ROV) transects were used to make visual samples of the macrofauna studied benthically. ROVs can be used to sample deep sea environments as it enables sharp images and real time visualization of the benthic habitat hence there is no abuse to the habitat.

- **Transect Design:** A set of ROV transects were carried across both impacted and control sites to provide an overall area of about 2km 2. The Transects were also strategic to cover the parts that were characterized by different disturbance levels of sediments. The transects were more than 100 meters in length and 10 meters in quid to absorb a representative sample of the benthic community.
- **Faunal Survey:** Attached to the ROV were high-definition cameras that recorded the video image of the benthic fauna; thus it was possible to make close observation at the macrofaunal group level. Analyzing the video footages was inside the image analysis software that identified and counted the visible species present on the transect. This type of approach enabled precise determination of the abundance of the species and well-informed macrofaunal diversity in a variety of environmental situations.(7)

**3.2 Benthic Macrofauna, Carbon, and Oxygen sediment coring Benthic macrofauna Benthic macrofauna Carbon Oxygen**

As a method to augment the visual survey of the ROV transects, sediment corer was used to provide physical samples which could later be analyzed on the benthic macrofauna, carbon content, and oxygen penetration in the sediment.

1. **Coring Procedure:** 20 sediment cores were also taken at the impacted and control sites in 5-10 meter depth using multiple corer. This is an excellent coring technique that allows obtaining a sediment sample which is intact and the benthic organisms in the sediment layers will be preserved so they can be analyzed.
2. **Macrofauna Description:** The sediment cores were transported to the laboratory and processed as soon as possible after the retrieval. The samples were filtered using a mesh sized 0.5 mm, to separate the benthic macrofauna which included the worms, crustaceans and mollusks. The specimens were fixed in sea water that was formalized to later identify their taxonomies.
3. **Carbon and Oxygen Profile Measurements:** As well as faunal work, sediment cores were also measured on organic carbon content and the depth of penetration of oxygen - key measures of sediment quality and of the quality of habitat as far as benthic organisms are concerned.

- **Carbon Content:** A sample of the sediment was dried in the oven and then carbon content was determined through combustion where t samples were burnt in a high temperature and the released amount of carbon was measured.(8)
- **Oxygen Penetration:** An oxygen microelectrode measure was used to quantify the level of oxygen penetration into the sediment giving good indications on the biogeochemical processes going on and the supply of the oxygen available to the benthic organisms.

### 3.3 Procedures and data processing of taxonomic identification

After processing the samples, the subsequent process was to undertake taxonomic identification of the benthic macrofauna and the environmental parameters affiliated to it. Pick ups were later identified as follows:

- **Taxonomic Identification:**
  Species or genus identification of macrofaunal specimen was done using reference materials and taxonomic guides. It was identified using advice of marine biologists and deep-sea fauna experts. Major sources considered in taxonomy division were World Register of Marine Species (WoRMS) and Marine Specific Identification Guides.
  Confirmatory species identification was also done using molecular methods (e.g. DNA barcoding) where the identity of the organisms was complicated by difficulty in visual identification.
- **Tools ofData Processing:**
  Both the data collected during the ROV surveys and those involved in the sediment sampling was run through an array of statistical and ecological programs:
  Shannon-Wiener index, Simpson index, and species richness was computed through PRIMER and R to study the biodiversity index in impacted as well as control sites.
  Differences in fauna compositions were evaluated using the multivariate statistical analyses of non-metric multidimensional scaling (nMDS) and analysis of similarity (ANOSIM) of disturbed and undisturbed zones.
  The data on carbon content and oxygen penetration was then used to determine the health of the sediment environment on which linear regression models were applied, so that these parameters could be related to faunal observations in terms of diversity and abundance.(9)

## 4. Results

### 4.1 Disturbance leads to major loss of macrofaunal diversity and in abundance in disturbed areas.

Among the most interesting outcomes of the study was that there was a high level of association between the low macrofaunal diversity and abundance in the mined areas as compared to the undisturbed control sites. The whole number of macrofaunal tax identified in the study sites was 328. Nevertheless, the analysis of the biodiversity using the biodiversity survey in the disturbed (mined) and undisturbed (control) areas revealed significant difference in species evenness and richness.

**Table 1:** Macrofaunal Diversity and Abundance Comparison

| Site Type | Species Richness | Shannon Index | Total Abundance (No. of Individuals) |
|---|---|---|---|
| **Undisturbed Zone** | 155 | 3.72 | 1,524 |
| **Mined Zone** | 97 | 2.38 | 912 |

The results of this difference that showed variation among the undisturbed zones and the mined zones in all the indices of species Richness, Shannon diversity index and total abundance of benthic organisms have been summarized in Table 1. The value of the Shannon index that indicates the level of richness and evenness of species in a location was significantly low in the disturbed areas (2.38) than in the control areas (3.72). The loss of diversity can be taken as a solid sign of the ecological imbalance created by mining operations.(10)

There was also a great reduction in the abundance of the macrofaunal organisms with a decrease of 40 percent in the number of total individuals in the mined zones compared to that of the zones that were undisturbed. This reduction has been described to be directly as a result of disturbance by mining activities such as the removal of sediments and the covering effect of sediment plumes.

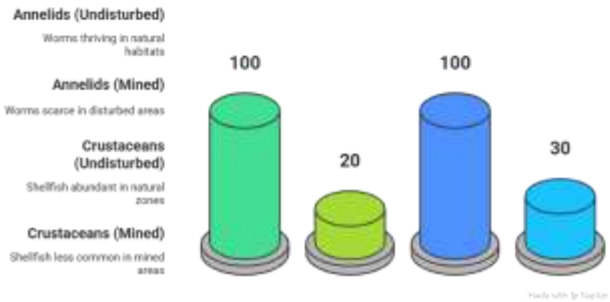


**Figure 1:** Abundance of Key Macrofaunal Groups in Mined vs. Undisturbed Zones

Mining had a strong effect on the diversity of macrofauna with some taxa associated with strong decline in both diversity and abundance, these include annelids, mollusks, and crustaceans. This implies that, mining not only disrupts physical environment, but also species composition and community structure of the benthic ecosystem.

**4.2 Impaired Sedimentation Oxygen and Carbon Retention**

The effect of mining on sediment properties, namely the depth of oxygen penetration as well as carbon content was also assessed. The two parameters are important pointers to sediment biogeochemical processes and a general ecosystem condition.

1. **Oxygen Penetration:**

- Oxygen was much obstructed in the mined zones. The results that were gained by oxygen microelectrode measurements showed that the penetrating depth of the oxygen sampling in the sediments located in the mined areas was almost 50 percent less than in the undisturbed zones.
- The mean penetration depth of oxygen was 6.2 cm in the und disturbed are but in the mined areas, it decreased to 3.1 cm. The decline implies that the sediment-water interface is disturbed during mining activities making little oxygen available to the benthic life essential to aerobic respiration and nutrient cycling.(11)

2. **Carbon Retention:**

- In the mined zones, the amount of carbon present in the portions of sediment taken were much lower as compared to the control sites. Organic carbon had been lessened by an average of 25 percent in the sediments mined as compared to sediments within an undisturbed environment.
- The undisturbed sediments had 2.8 percent of organic carbon and when it comes to the mined regions, the average is 2.1 percent. The decline in the carbon retention may be attributed to the fact that mining operations mixed up the superficial layers of sediments and disposed of them and these are usually very fertile in carbon contents.

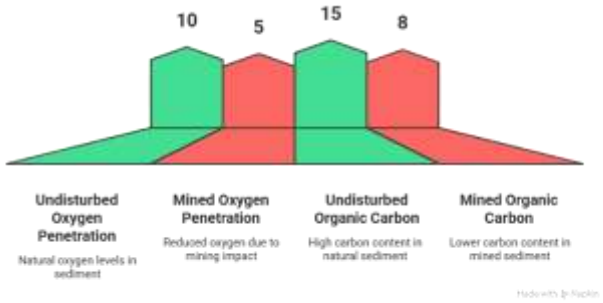


**Figure 2:** Oxygen Penetration Depth and Organic Carbon Content in Mined vs. Undisturbed Sediments

### 4.3 Failure to show Significant Trends of Recovery in Damaged Plots

The research was also to determine the recovery capacity of benthic ecosystems on disturbed grounds. Recovery was analyzed by sampling sediment and macrofauna on the same affected areas once 24 months of simulated effect of mining had passed. The findings showed that there was little recovery regarding faunal diversity as well as sediment attributes.

Macrofaunal Recovery: After the 24-months period, no significant recovery of macrofauna of the mined areas was observed with respect to the undisturbed locations in terms of their diversity and abundance. The vegetation remained to be a different mix and the signs of recovering were minimal with a few taxa experiencing minor gains in numbers.(12)

Sediment Recovery The oxygen penetration depth and organic carbon displayed minimum recovery, which illustrated that the disturbance brought about by the mining is not easily reversible. The biogeochemical conditions and structure of the sediments in the mined zones were weakened, probably, because of the continuous impact of the sediment compaction, organic matter loss, and nutrient cycling declination.

## 5. Conclusion

### 5.1 Ecology Degradation as a Result of Simulated Mining Summary

This study reveals that simulated polymetallic nodule mining will give rise to great ecological degradation in the Clarion- Clipperton Zone (CCZ), which already experiences a rising pressure due to the attention to deep-sea mining. Comparison of impacted and undisturbed control zone showed that the macrofauna diversity and abundance were significantly reduced on the mined areas with a Shannon index of 2.38 as compared to undisturbed areas with a Shannon index of 3.72. Further, the overall abundance of the benthic organisms declined by 40 per cent which is a clear indication that there was a sole interruption to community structures. Such decrease in diversity was accompanied by the decline in oxygen penetration and organic carbon preservation in the sediments, both of which are the most critical indicators of habitat quality and ecosystem health.

Slow benthic ecosystem recovery was also a demonstration of the long-term effect of mining disturbances. No substantial improvements in the species diversity or sediment health appeared even 24 months after the disturbance, which indicates that environmental impact of the mining activity is long-term and irreversible. The decrease in the oxygen content and carbon of the sediment is another evidence of the biogeochemical cycles that are still disrupted and fundamental in having a healthy deep-sea ecosystem. Such a low rate of recovery and the enduring uncertainty of the disruption pose a significant difficulty to the resilience of the ecosystems in the CCZ.

### 5.2 Long-term Benthic Ecosystem Function and Resilience Implications

The results of this work influence the future operation and stability of benthic ecosystems within the CCZ strongly. The loss of biodiversity or alterations in the existing sediment characteristics indicates that deep-sea mining operations would cause irreparable loss of species crucial to the functioning of ecology. These species have significant roles in cycling of nutrients, carbon sequestration and food webs. The extinction of these species might cause secondary effects among the whole benthic food web, impacting the local communal fauna not only, but also possibly, changing the international biogeochemistry as well.

The fact that other benthic communities recover slowly as observed in this study raises some concern as to the resilience of the other benthic. The deep-sea environment as compared to the terrestrial ecosystem has a low rate of reproduction, slow turnover of species and a long life expectancy. Such characteristics render deep-sea ecosystem sensitive to any disturbance since it can take decades or even centuries before they recover. Since these habitats regenerate slowly, the long-term effects of mining may result in the loss of the ecosystem services such as carbon, and nutrient cycling irreversibly. It shows how vulnerable deep-sea ecosystems are and how they are unable to react to the anthropogenic effects.

**5.3 Advocacy of Pre-Mining Pre-baseline Assessment and Precautionary Policies**

Considering the ecological effects that have been long-term in this study, it is critical that the current baseline biodiversity of the CCZ be made prior to the commencement of any commercial mining actions of the region. The results of these assessments will be key references to compare and observe how healthy the benthic ecosystems are both before the beginning of the mining activity and after the start of mining activities, which will guarantee that any possible decreases in the biodiversity and the ecosystem functioning can be recorded and corrected. The comprehensive baseline data should not only cover the richness and the abundance of species, but also the sediment characteristics, biogeochemical parameters, as well as physical health of the benthic environment.

Besides, the findings of this paper highlight the necessity of precautionary policies in order to reduce the ecological hazard of deep-sea mining. Proper environmental protection measures ought to be established to reduce the disturbance of the habitat which will involve restricting the level of mining and setting up environmental redevelopment strategies. Additionally, there must be permanent monitoring schemes that will be used to see how disturbed areas can be recovered and the effectiveness of mitigation.

The findings also necessitate the support of the international community to regulate the CCZ because the mines in this area can have extensive effects not only to the local ecosystems but also to the global ecosystems. Unitary action to develop sustainable practices of mining and conservation priorities will also play a major role in ensuing that the special ecosystems of the deep sea are supported to cling there to the days to come.

**Acknowledgement:** Nil

## Conflicts of interest

The authors have no conflicts of interest to declare

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